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Bioactive and Nutritional Properties of Sea Buckthorn Oil (*Hippophae rhamnoides* L.): A Potential Role in Cardiometabolic Disease Prevention

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This study evaluated the nutritional and bioactive potential of sea buckthorn oil (*Hippophae rhamnoides* L.), with emphasis on its possible use in the prevention of chronic diseases. The antioxidant activity (AA; DPPH method), total polyphenol content (TPC; Folin–Ciocalteu method), fatty acid profile (GC-FID), and health-related lipid indices were determined. Commercially available cold-pressed sea buckthorn oils were analyzed. The samples originated from a Slovak producer (sample 1) and from a German producer (sample 2). Antioxidant activity was 54.33 ±1.88% in sample no. 1 and 61.48 ±1.66% in sample no. 2 ($p < 0.001$). Statistically significant differences ($p < 0.001$) were also found between the evaluated samples in TPC. The sample from the Slovak producer reached 44.67 ±3.18 mg GAE·L^{-1}, while the sample from the foreign producer reached 99.58 ±3.15 mg GAE·L^{-1}. Fatty acid profile analysis revealed a high content of polyunsaturated fatty acids in both samples. The most abundant fatty acids were linoleic acid, α-linolenic acid, and oleic acid. The n-6/n-3 ratio was 1.391 and 2.189, respectively. The low atherogenic and thrombogenic indices in the tested matrices also indicated a favorable lipid profile with potential benefits for cardiometabolic health. Based on the results obtained, it can be concluded that sea buckthorn oil is a promising natural raw material with high biological value. Its favorable composition, antioxidant content, and suitable fatty acid profile support its potential application in functional nutrition and in the prevention of chronic diseases.

Keywords: *Hippophae rhamnoides*, oil, antioxidant activity, TPC, fatty acids, nutritional indices, health

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Introduction

The relationship between nutrition and the prevention of non-communicable diseases has become an important topic of scientific and public interest. Unhealthy dietary patterns, particularly a high intake of energy-dense and nutritionally unbalanced foods, together with physical inactivity and excessive stress, are major lifestyle-related factors associated with cardiovascular diseases, type 2 diabetes mellitus, obesity, and metabolic syndrome (Lordan and Grant, 2023; WHO, 2025). In this context, plant-based foods have attracted considerable attention as natural sources of phytonutrients with antioxidant, anti-inflammatory, and lipid-modulating properties. These bioactive compounds may contribute to health protection and are increasingly investigated for their use in functional foods and plant-derived oils (Watzl, 2008; Sharifi-Rad et al., 2020; Siddiqui et al., 2023; Knazicka et al., 2025).

One of the promising medicinal and functional plants is sea buckthorn (*Hippophae rhamnoides* L.). The genus *Hippophae* L. belongs to the family Elaeagnaceae and includes deciduous shrubs or small trees, usually reaching 2–5 m in height, although under favorable conditions they may grow taller. Sea buckthorn is a wind-pollinated and dioecious plant, with male and female flowers occurring on separate individuals. Its yellow to orange, and occasionally reddish, fruits contain a single seed and are valued for their nutritional and biological properties. *Hippophae rhamnoides* is widely distributed across China, the Himalayas, Central Asia, Russia, and many parts of Europe (Jia and Bartish, 2018).

Hippophae rhamnoides is characterized by a rich composition of bioactive compounds, including vitamin C, carotenoids, phenolic compounds, tocopherols, phytosterols, and favorable fatty acid profile (Christaki, 2012; Krejcarová et al., 2015; Wang et al., 2022). Dienaitė et al. (2020) identified 28 compounds in sea buckthorn pomace, mainly flavonols such as glycosides of isorhamnetin, quercetin, and kaempferol, as well as catechin. In recent years, increasing attention has been paid to the biological properties of sea buckthorn berries, seeds, leaves, and derived products. Several studies have reported that *Hippophae rhamnoides* possessed a broad spectrum of biological activities, including anti-inflammatory, immunomodulatory, and hepatoprotective effects (Geetha et al., 2005; Olas, 2016; Olas et al., 2018; Ji et al., 2020; Wang et al., 2022). Sea buckthorn has also been reported to contribute to the therapeutic management of cardiovascular diseases, particularly by alleviating processes associated with atherosclerosis and hypertension. Its cardioprotective potential is believed to be related mainly to the suppression of inflammatory responses, which play an important role in the initiation and progression of cardiovascular disorders (Chen et al., 2024). Clinical and experimental studies suggest that sea buckthorn-derived products may modulate markers of liver injury, such as alanine aminotransferase and aspartate aminotransferase, and may attenuate oxidative stress and inflammation in liver tissues. Moreover, selected sea buckthorn-derived bioactive compounds have shown neuroprotective potential, partly through the inhibition of acetylcholinesterase and monoamine oxidase A, enzymes involved in neurotransmitter degradation (Gao et al., 2003; Wang et al., 2022; Dubey et al., 2024).

Sea buckthorn oil is particularly valuable due to its content of unsaturated fatty acids, tocopherols, carotenoids, phytosterols, and other important antioxidants (Kallio et al., 2002; Burčová et al., 2017). These constituents may contribute to the modulation of oxidative stress, inflammatory processes, and lipid metabolism (Olas, 2016; Olas et al., 2018; Wang et al., 2022; Chen et al., 2024). Sea buckthorn seed oil is especially rich in unsaturated fatty acids, including linoleic, α-linolenic, and oleic acids (Otgonbayar et al., 2011). In addition, it contains several lipophilic bioactive compounds with antioxidant and potentially cardioprotective effects. The presence of n - 3 fatty acids may improve endothelial function and promote vascular relaxation, while the unique fatty acid composition of sea buckthorn seed oil likely contributes to its hypolipidemic effect. Supplementation with this oil may reduce risk factors for ischemic heart disease, including elevated triacylglyceride and LDL cholesterol levels. Moreover, antioxidants present in sea buckthorn oil may play a protective role, particularly against oxidative stress, which is among the major factors involved in aging and the development of various diseases (Olas et al., 2018).

The objective of this research was to evaluate the nutritional and bioactive potential of sea buckthorn oil (from different producers), specifically by determining its antioxidant activity (AA), total polyphenol content (TPC), and fatty acid profile, as well as by calculating selected health-related lipid indices to assess its potential impact on human health.

Material and Methodology

Characterization of the material

The plant material used for the analyses consisted of commercially available BIO cold-pressed oil of sea buckthorn (*Hippophae rhamnoides* L.). The samples were obtained from a Slovak producer (sample 1) and from a German producer (sample 2). The oils were packaged in amber bottles with cardboard covers to prevent exposure to light and temperature changes. They reflected the actual state of bulk oils in commercial trade, providing an accurate basis for evaluation. The oils were kept at 10 °C in a low-temperature environment and protected from light.

Evaluation of antioxidant activity

Antioxidant activity was determined spectrophotometrically using the DPPH (2,2-diphenyl-1-picrylhydrazyl) method according to Brand-Williams et al. (1995), modified for analysis in a 96-well microplate (Kováčiková et al., 2025). The reaction mixture consisted of 20.0 µL of the analyzed sample, blank, or standard (in triplicate), followed by the addition of 180 µL of the DPPH• solution. The microplate was incubated with continuous shaking in the dark at room temperature (23 °C) for 10 minutes. Absorbance was measured at 515 nm using a Glomax Multi+ UV-Vis microplate photometer (Promega Corp., Madison, WI, USA). The AA was expressed as % of DPPH inhibition. The AA of the samples was quantified using a calibration curve prepared with Trolox equivalents (0–100 mg·L^{-1}; $R^2 = 0.9991$). The power of AA was categorized as weak (0–29%), medium-strong (30–59%), or strong (≥60%).

Evaluation of total polyphenol content

Total polyphenol content was determined using the Folin-Ciocalteu reagent, adapted for 96-well microplates according to Kováčiková et al. (2025). The procedure involved pipetting 50.0 µL of distilled water, 25.0 µL of the sample or standard (in triplicate), and 25.0 µL of the Folin-Ciocalteu reagent into the wells. After a 6-minute incubation, 100 µL of a 7.50% sodium carbonate solution was added. The microplate was then incubated in the dark at room temperature (23 °C) for 90 minutes, and absorbance was measured at 765 nm using a Glomax Multi+ UV-Vis microplate photometer (Promega Corp., Madison, WI, USA). Measurements were calibrated using a standard curve prepared with gallic acid (0–500 mg·L^{-1}; $R^2 = 0.9992$). Results were expressed as gallic acid equivalents (GAE) in mg·L^{-1}.

Evaluation of fatty acid profile and health-nutritional indices

The procedure for the determination of fatty acid composition was described by Knazicka et al. (2025). The fatty acid methyl esters (FAME) were extracted with petroleum ether and analyzed using gas chromatography (GC) with a flame ionization detector (FID) on an Agilent 6890A (Agilent Technologies, Santa Clara, CA, USA) equipped with a multimode and with a DB-23 column. A 37-component standard mixture (Supelco 47885-U; Sigma-Aldrich, Laramie, WY, USA) was used for column calibration. The fatty acids were calculated as the % of the sum of fatty acids using Agilent OpenLab ChemStation software (OpenLab CDS ChemStation Edition B.04.01). Each sample was analyzed in duplicate.

Health-nutritional indices, including the atherogenic index (*AI*) and thrombogenic index (*TI*), were calculated based on the fatty acid profile according to Ulbricht and Southgate (1991):

a)

$$AI = \frac{\mathrm{C12{:}0} + (4 \cdot \mathrm{C14{:}0}) + \mathrm{C16{:}0}}{\sum \mathrm{UFA}}$$

b)

$$TI = \frac{(\mathrm{C14{:}0} + \mathrm{C16{:}0}) + \mathrm{C18{:}0}}{\left[\begin{array}{c}(0.5 \cdot \sum \mathrm{MUFA}) + (0.5 \cdot \sum \mathrm{n\text{-}6 \cdot PUFA}) + \\ + (3 \cdot \sum \mathrm{n\text{-}3 \cdot PUFA}) + (n-3/n-6)\end{array}\right]}$$

Statistical analysis

All obtained data were statistically evaluated using GraphPad Prism 10.4.1 (GraphPad Software Incorporated, San Diego, CA, USA). The significance of differences between groups was determined using a parametric t-test, with the statistical significance set at $p < 0.001$.

Results and Discussion

Currently, in accordance with the principles of rational nutrition, significant changes in dietary habits are being observed, mainly manifested as a reduction in saturated fatty acid (SFA) intake and an increase in the consumption of monounsaturated (MUFA) and polyunsaturated (PUFA) fatty acids. As stated by Kamińska et al. (2025; 2024), this trend is reflected in the growing consumer interest in cold-pressed vegetable oils, which are perceived as valuable sources of bioactive substances. Similarly, Knazicka et al. (2025) confirmed that the increased interest in unconventional vegetable oils is related to their favorable nutritional indices and biological activity.

Evaluation of antioxidant activity

In our study, the commercial BIO sea buckthorn oil from a foreign producer showed significantly ($p < 0.001$) higher AA (61.48 ±1.66%) than sample 1, which represented sea buckthorn oil from a Slovak producer (54.33 ±1.88%; Figure 1). The observed differences in AA between the samples may be due to various factors, including the geographical origin of the raw material, agroecological conditions during cultivation, degree of fruit maturity, and processing technology. Sea buckthorn is a key source of natural antioxidants. The presence of bioactive compounds may also play an important role, particularly carotenoids, tocopherols, polyphenols, flavonoids, and phytosterols, which significantly contribute to the antioxidant potential of sea buckthorn oil. Wang et al. (2022) reported that these substances reduce oxidative stress and damage to cellular structures. Zheng et al. (2017) demonstrated that sea buckthorn oils obtained by different technologies differ in phytochemical content and antioxidant properties. Wirkowska-Wojdyła et al. (2024) emphasized the importance of oxidative stability in commercial oils, while Lyu et al. (2022) pointed out the synergistic action of several bioactive substances. Kim et al. (2024) reported that sea buckthorn extracts showed significant AA (58.16% DPPH inhibition), and Wu et al. (2024) confirmed a strong correlation between polyphenol content and AA.

Regarding human health, Chan et al. (2024) found in a randomized trial that supplementation with sea buckthorn oil increased catalase activity. The beneficial effects of sea buckthorn products on health are also supported by the results of an intervention study by Kopčeková et al. (2023), which investigated the effect of regular consumption of 100% sea buckthorn juice in women of reproductive age with hypercholesterolemia. During the 8-week intervention, daily consumption of 50 mL of sea buckthorn juice led to statistically significant reductions in body weight, body mass index, body fat, and visceral fat, as well as improvements in the lipid profile, particularly a decrease in LDL-cholesterol and an increase in HDL-cholesterol. Favorable changes in inflammatory markers were also observed, suggesting the anti-inflammatory potential of sea buckthorn. These findings confirm that the bioactive compounds of this crop, particularly flavonoids and vitamin C, may synergistically reduce atherogenic risk and prevent cardiovascular diseases. Our results for the AA of both sea buckthorn oils (54.33–61.48%) confirm that they are significant sources of antioxidants with potential in the prevention of oxidative stress, which is associated with the development of several chronic diseases, including cardiovascular diseases, type 2 diabetes mellitus, and other non-communicable lifestyle-related diseases.

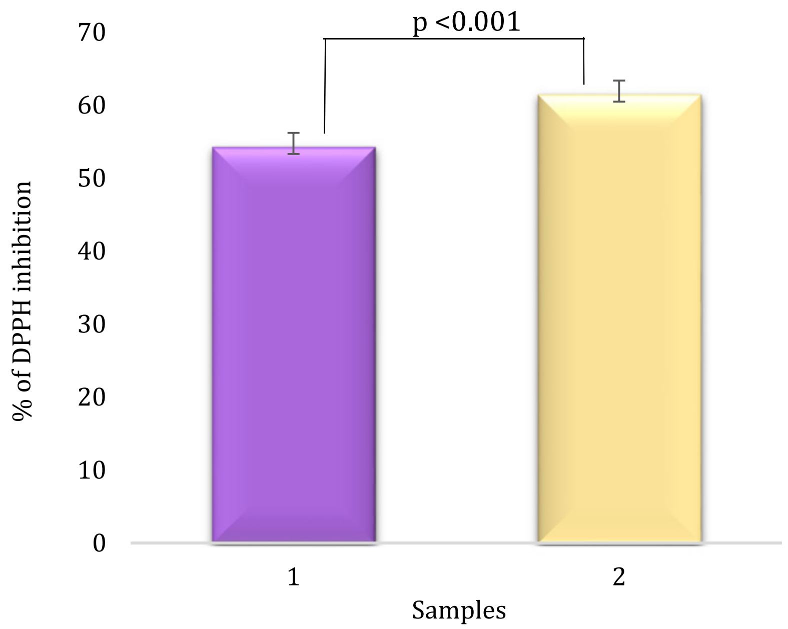

Figure 1 Antioxidant activity of the evaluated sea buckthorn oil samples: 1 – BIO cold-pressed sea buckthorn oil from a Slovak producer; 2 – BIO cold-pressed sea buckthorn oil from a foreign producer (Germany). The power of AA was classified as weak (0 – 29%) < moderately strong (30 – 59%) < strong (≥60%)

Evaluation of total polyphenol content

Polyphenols are the dominant group of substances responsible for the protective effects of sea buckthorn. The most important polyphenolic compounds in sea buckthorn include flavonoids and phenolic acids, with quercetin, isorhamnetin, kaempferol, catechins, and their derivatives. These compounds can neutralize free radicals and modulate oxidative stress-related processes (Mihal et al., 2023). In our study, marked differences in TPC were observed between the evaluated sea buckthorn oils (Figure 2). Sample 1 had a TPC value of 44.67 ±3.18 mg GAE·L^{-1}, whereas sample 2 showed an approximately twofold higher value (99.58 ±3.15 mg GAE·L^{-1}), indicating that its elevated phenolic content may contribute to its higher antioxidant potential. Sytařová et al. (2020) reported that TPC exhibits high variability depending on the variety and environmental conditions. Dolkar et al. (2017) confirmed these differences among various sea buckthorn cultivars, and Raal et al. (2023) emphasized the influence of the extraction procedure used on the resulting values. De Filette et al. (2024) reported in their analysis of berry seed oils (including sea buckthorn oil) that phenolic compounds are key to oil stability, although most polyphenols often remain in the pomace.

Evaluation of fatty acid profile and health-nutritional indices

Both analyzed oils showed a high proportion of PUFA (65.97 vs. 64.97%). In sample 2, we recorded a significantly ($p < 0.001$) higher content of linoleic acid (44.60%) compared with sample 1 (38.38%). Dal Bosco et al. (2024) reported that this acid has a favorable effect on reducing cardiovascular risk, and Wang et al. (2023) highlighted its importance in regulating metabolism. According to Solà Marsiñach and Cuenca (2019), sea buckthorn oil contains approximately 39.0–41.0% linoleic acid and 26.0–30.0% α-linolenic acid, which corresponds with the results of our study (Table 1). Sala-Vila et al. (2022) stated that a higher intake of α-linolenic acid is associated with a reduced risk of coronary heart disease. The $n - 6/n - 3$ ratio in our samples (1.39 and 2.19, respectively) is very favorable. Fatima et al. (2012) and Kuhkheil et al. (2018) confirmed that sea buckthorn oil is rich in unsaturated fatty acids, as Shafi et al. (2008) determined for samples from different geographical locations. In the analysis of MUFA, we found that oleic acid was significantly ($p < 0.001$) higher in sample 2 (21.74%) compared with sample 1 (18.44%). Oleic acid is associated with a reduced risk of cardiovascular disease, and its beneficial effects are mainly attributable to its positive

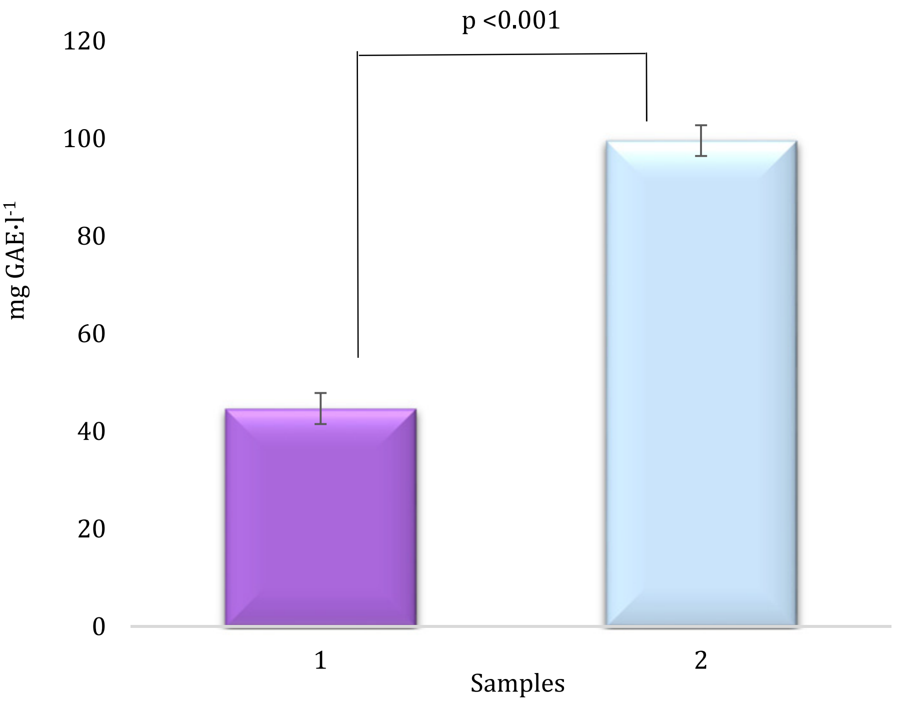

Figure 2 Total polyphenol content (TPC) of the evaluated sea buckthorn oil samples:1 – BIO cold-pressed sea buckthorn oil from a Slovak producer; 2 – BIO cold-pressed sea buckthorn oil from a foreign producer (Germany)

effects on the vascular endothelium, reduced adhesion molecule expression, and prevention of atherosclerotic changes (Solà Marsiñach and Cuenca, 2019).

The favorable fatty acid composition was also reflected in the lipid indices. Our results for AI (0.078–0.095) and *TI* (0.102–0.105) indicated low atherogenic and thrombogenic risk potential. Ulbricht and Southgate (1991), as well as Simopoulos and Cleland (2003), stated that these indices reflect the nutritional quality of lipids and their potential influence on cholesterol metabolism. Chen and Liu (2020) summarized that foods with low *AI* and *TI* values are characterized by high nutritional quality. Therefore, the analyzed sea buckthorn oils can be considered nutritionally favorable cold-pressed vegetable oils and an important source of essential fatty acids, as also declared by the producers. However, their high PUFA content may increase susceptibility to oxidation; therefore, appropriate storage conditions are important.

Conclusions

The results confirmed that sea buckthorn oil represents a nutritionally valuable plant oil with potential for the prevention of chronic non-communicable diseases. In our study, the commercial BIO cold-pressed sea buckthorn oil from a Slovak producer exhibited moderately strong AA (54.33 ±1.88%), while the oil from a foreign producer showed significantly higher antioxidant potential (61.48 ±1.66%; $p < 0.001$). The higher TPC value in sample 2 corresponded with its higher AA, confirming the importance of phenolic compounds as key contributors to the biological activity of sea buckthorn oil. The results indicate the ability of sea buckthorn oil to neutralize free radicals and suggest its potential role in protecting against oxidative stress, which is involved in the development of cardiometabolic diseases. The fatty acid profile confirmed a high proportion of PUFA in both analyzed oils. The most abundant fatty acids were linoleic, α-linolenic, and

Table 1 Fatty acid profile (%) and health-nutritional indices of the evaluated sea buckthorn oils

Fatty acid	**Evaluated sea buckthorn oil samples**		
	Sample 1 (x ±SD)	**Sample 2 (x ±SD)**	**p-value**
Myristic acid (C14:0)	0.10 ±0.000	ND	–
Pentadecanoic acid (C15:0)	ND	0.11 ±0.000	–
Palmitic acid (C16:0)	7.75 ±0.002	6.91 ±0.009	p <0.001
Palmitoleic acid (C16:1)	1.39 ±0.000	0.55 ±0.001	p <0.001
Stearic acid (C18:0)	3.65 ±0.001	3.12 ±0.002	p <0.001
Oleic acid (C18:1cis n-9)	18.44 ±0.002	21.74 ±0.010	p <0.001
Linoleic acid (C18:2cis n-6)	38.38 ±0.002	44.60 ±0.003	p <0.001
α-linolenic acid (C18:3 n-3)	27.59 ±0.007	20.37 ±0.001	p <0.001
Arachidic acid (C20:0)	0.23 ±0.000	0.37 ±0.000	p <0.001
cis-11-eicosenoic acid (C20:1 n-9)	0.13 ±0.000	0.26 ±0.000	p <0.001
Behenic acid (C22:0)	0.28 ±0.001	0.27 ±0.001	–
Lignoceric acid (C24:0)	0.08 ±0.000	ND	–
∑ PUFA	65.97	64.97	
∑ MUFA	19.97	22.55	
∑ SFA	12.08	10.78	
∑ *n* - 3/*n* - 6	0.72	0.46	
∑ *n* - 6/*n* - 3	1.39	2.19	
Health-nutritional indices			
AI	0.095	0.078	
TI	0.102	0.105	

Notes: 1 – BIO cold-pressed sea buckthorn oil from a Slovak producer; 2 – BIO cold-pressed sea buckthorn oil from a foreign producer (Germany); PUFA – polyunsaturated fatty acid; MUFA – monounsaturated fatty acid; SFA – saturated fatty acid; *AI* – atherogenic index; *TI* – thrombogenic index; *x* – arithmetic mean; SD – standard deviation; ND – not detected. The significance of differences between groups was determined at the statistical level of $p < 0.001$

oleic acid. The favorable n - 6/n - 3 ratio, together with the AI and TI values, indicates a low atherogenic and thrombogenic potential of the analyzed oils. Based on the obtained results, sea buckthorn oil can be considered a promising natural raw material with high biological value. At the same time, the results highlight the need for quality control and standardization of production processes, as the origin of the raw material and the technological processing can significantly affect the final nutritional and biological properties.

Conflict of interest

The authors have no competing interests to declare.

Ethical statement

This article doesn't contain any studies that would require an ethical statement.

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