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NUTRITIONAL AND MEDICINAL PROPERTIES OF SEA BUCKTHORN AND COMPREHENSIVE REVIEW OF ITS PHYTOCHEMICAL CONSTITUENTS AND HEALTH BENEFITS

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Abstract
This review evaluates the medicinal and therapeutic potential of sea buckthorn, a thorny shrub, belongs to a family Elaeagnaceae in the prevention and management of multiple maladies, both acute and chronic. Owing to its nutritional and therapeutic qualities, the plant is utilized throughout the world, but most frequently in Europe and Asia. Preparations derived from sea buckthorn have been widely used in ancient cultures to treat ailments as ulcers, lagging digestion, gastroenteritis, cardiovascular issues, liver disease, tendon and ligament injuries, and skin disorders. Pharmacological and therapeutic properties of Sea buckthorn have been thoroughly studied in recent years utilizing several kinds of in vitro and in vivo models in addition to a small number of clinical trials. Numerous traditional uses of sea buckthorns have been validated by scientific analysis, pharmacological and phytochemical content investigation. It is well known that sea buckthorn exhibits immunomodulatory, anti- inflammatory, and antioxidant properties. Particularly, berries include vitamin C, which supports the immune system, both the seeds and pulp oil provide omegas 3, 6, 7 and 9 are beneficial to the skin, the cardiovascular system, and the metabolism. Given its vast therapeutic and pharmacological potential, sea buckthorn is undoubtedly an essential plant. However, this study's identification of a number of information gaps will spur further research and development, particularly in the area of sea buckthorn-based nutraceuticals and herbal medicine.

Keywords: Sea buckthorn, Phytochemicals, Omega, Hepatoprotective, Antioxidant

1. Introduction

1.1. Overview and Historical Background

For many years, herbal formulations have been used throughout the world as preventative and health-promoting measures in addition to therapeutic uses. The broadest berry-bearing shrub, the sea buckthorn, is a common term given to all species of Hippophae belonging to the family Elaeagnaceae (K. Wang, Xu, & Liao, 2022). It includes six species divided into three genera:

Elaeangnus L., Hippophae L., and Shepherdia Nutt (Shah, Idate, & Poorva, 2021). Sea buckthorn (Ahani & Attaran) is a thorny shrub found throughout Asia's Temperate Zone, Europe, and wherever subtropical zones exist, especially at high elevations in Europe and Asia and this shrub is most familiar for its nutritional and medicinal purpose (V. Singh, 2022). The very name of the genus Hippophae, which means 'shining horse', has a story that the Greeks feed their horses on this shrub due to its health benefits which gave their horses' coat a shiny appearance. It could be found in the seacoasts, on the mountains, and so on, thus the wide distribution of the plant in many continental areas including European and several Asian countries such as China, Mongolia, and Russia (Bartish & Thakur, 2022).

More specifically, in ancient times, sea buckthorn has been used in a number of historical cultures for its curative uses in traditional medicine in China, and Tibet (C.-H. Liu et al., 2020). This extensive availability also explains its tolerance to the various climatologic situations, adding value to it for horticulture and use especially in managing soil erosion and rehabilitation programs. The Hippophae rhamnoides plant has a rough, earthy-colored or dark bark and a dense, grayish green crown, as well as a very evolved and extensive root system. It can grow to be anywhere between 2 and 4 meters tall (Shah et al., 2021). Indeed, being berries, leaves and seeds, the plant's parts are packed with variety of vitamins, PUFAs, flavonoids, carotenoid, free amino acids, tocopherols, phenolic compounds and essential fatty acids which have got antioxidant, anti-inflammatory, immunomodulatory, anti-atherogenic, anti-stress, hepatoprotective, radioprotective, tissue repair, cardioprotective, gastrointestinal ulcer (Balta et al., 2021). The berries have high levels of vitamin C varies between 52.86 mg and 896 mg per 100 g compared with all other fruits and vegetables. The vitamin C content in 100 g of Sea buckthorn berries can reach as high as 275 mg,

far surpassing the same quantity of other fruits, such as mangoes (Balta et al., 2021), apricots (10 mg), bananas (8.7 mg), oranges (50 mg), and peaches (6.6 mg) (Ibrahim et al., 2020). Traditionally, various parts of sea buckthorn have being used in the treatment of diseases in various societies across the world. Berries are oval or daintily roundish like strawberries, ranging in color from bright yellow to dull orange and weighing between 270 and 480 mg, with elevated levels of vitamin E, vitamin C, flavonoids, carotenoids, and unsaturated fatty acids (Green, 2007). Berries are the source of nutrients required for better digestion and healthy skin. Whereas SBT leaves contain nutrients and bioactive substances which mainly include flavonoids, carotenoids, free and esterified sterols, triterpenols, and isoprenols. The leaves are an equally rich source of important antioxidants including β-carotene, vitamin E, catechins, elagic acid, ferulic acid, folic acid and significant values of calcium, magnesium and potassium use in the treatment of diverse diseases because of its antioxidant, cytoprotective and anti-bacterial effect (Sharma and Singh, 2017). Also, the oil obtained/pressed from the seeds and pulp of the berries are rich in fat-soluble vitamins and plant sterols and have various unsaturated fat structures that have been used in local treatment of injuries of the skin, formation of new tissue, respiratory and gastrointestinal ailments (Shah et al., 2021). Due to their excellent nourishing effects, various products made from sea buckthorn are available in many countries including the United States, China, India, Canada, Finland, Germany, and some other European countries (Ren et al., 2020). It has been seen that sea buckthorn has been adopted in different medical systems across different civilizations, and therefore the effectiveness and the therapeutic qualities of sea buckthorn have been verified across different kinds of medical systems (Ahani & Attaran, 2022).

1.2. Omega Fatty Acid: Overview and Background:

The organic substances that are most prevalent in the body are fatty acids. Eight main categories are used to classify them: fatty acyls, polyketides, isoprenols, sphingolipids, saccharolipids, glycerolipids, and sterols (Dudau et al., 2021). They function as signaling molecules and transmembrane protein modulators in addition to being involved in the synthesis of cell membranes, cellular transport, and energy storage (D. Zhang et al., 2022). Sufficient consumption of polyunsaturated fatty acids (PUFAs) is essential for proper bodily function. Two primary categories of polyunsaturated fatty acids (PUFAs) exist in the human body: omega-6 and omega-3 PUFAs. These groups are produced from two essential fatty acids, which are linoleic acid (LA, ω-6) and α-linolenic acid (ALA, ω-3), respectively (Shah et al., 2021). Desaturation, elongation, and β-oxidation produce all omega-3 polyunsaturated fatty acids from ALA (Shah et al., 2021). ince ALA cannot be produced in humans, it must be obtained through diet. Long-chain PUFAs, arachidonic acid (AA, ω-6), and docosahexaenoic acid (DHA, ω-3), make up over 90% of PUFAs. Humans can obtain long-chain PUFAs from their diet or by having the liver generate the corresponding shorter-chain PUFAs, LA for AA and ALA for DHA. Biological conversion is a somewhat inefficient and slow process, though. Thus, the primary human source of these fatty acids is diet (Lange, 2020). Consequently, consuming food is the only way to obtain the lacking nutrients. The oil obtained from the sea buckthorn pulp and seeds includes multiple important fatty acids, with linoleic and α-linolenic acid being the most prevalent.

Furthermore, a number of ω-7 fatty acids, which are uncommon in plants, are present in high concentrations (about 30%), including vaccenic acid, hexadecatrienoic acid, palmitoleic acid, and heptadecenoic acid (Jaśniewska & Diowksz, 2021). Because sea buckthorn adds relatively large doses of palmitoleic acid to the human diet amounts that cannot be achieved by consuming other foods it is therefore of particular importance as a dietary product (Ding et al., 2022). Due to new research and findings about the potential advantages and/or disadvantages of omega-9 FAs for biology, these compounds have attracted a lot of attention lately. A class of unsaturated FAs with a double bond at the ninth position from the methyl end are known as omega- 9 FAs (ω−9 FAs). They can be classified as mono- or polyunsaturated. These are regarded as purely "non-essential" FAs, in contrast to the 3s and 6s Omega-9 FAs (Farag & Gad, 2022).

1.3. Recent Research and Development

Some of the most recent research has been directed towards the cardiovascular properties of sea buckthorn, mainly its flavonoids and unsaturated fatty acid which have demonstrated the ability to decrease the risks of hypertension and raised cholesterol, hence lower chances of heart diseases (Kumari & Sharma, 2021). There is also some ongoing research related to its neuro protective properties of sea buckthorn because it has ability to boost overall neural health and guard against neurodegenerative diseases has been attributed to sea buckthorn’s antioxidant rich constituents and Omega-3 fatty acid constituents (Zhong, Zhao, Xie, & Wang, 2022).

The continual investigation on the mode of action of the sea buckthorn and components possesses is improving knowledge and utilization of this phytochemical wealthy plant for a wide array of health challenges. The aim of this article is to provide a comprehensive review of SB focusing on nutritional value, processing, food applications, health-promoting benefits and future challenges and trends.

2. Processing of Sea Buckthorn Barries

2.1. Harvesting

Due to the absence of an abscission layer, SB berries may endure on the branch throughout extended periods of time. It becomes harder to harvest as a result. Hand harvesting of SB berries with grabbing tools is prevalent. Removing berry-bearing branches from the trunk is the fundamental idea. Although picking undamaged SB berries is a labor-intensive task, skilled workers may harvest 1.0–1.5 kg of berries each hour. For manual harvesting, about 1500 hours are needed per acre (Janceva et al., 2022). In an attempt to increase harvest efficiency, SB has recently grown in properly spaced fields with the option to employ mechanical harvesters.

2.2. Sea Buckthorn Juice Processing

By weight, the SB berries are comprised of up of 24% seeds, 68% pulp, and 8% skin. Three layers form when raw SB berries are squeezed to extract juice: an opaque yellow or orange cream lies on top, followed by the layer of oil in the middle of the fruit, and the juice with sediment is at the

bottom (El-Sohaimy et al., 2022). The berries require to be frozen immediately after they have been collected. The frozen SB berries are mechanically shaken and trembled before being deposited into collectors and separated from the branches. After the seeds are taken out, the berries are often squashed to extract juice for additional processing (M. Li et al., 2022). There are essentially two distinct kinds of SB juice: cloudy juice and clear juice. The procedure for processing cloudy juice is simple and effortless to understand once the SB berries get squeezed and their seeds are separated through filtration, the pulp as entirety is homogenized.
The cloudy SB juice is used to make fruit oil or smoothies (Moskalets, Vovkohon, Ovezmyradova, & Pelekhatyi, 2021). There are two main phases in the production of clear SB juice. Firstly, the original mass of SB pulp is heated to 50–55°C and then squeezed to extract juice. The juice then undergoes ultrafiltration clarification in the second phase. Clear SB juice frequently mixes with other juices as an ingredient to make fruit beverages (Sharma and Singh, 2017). Analyzing the pasteurization processes used for SB juice. In the case of SB juice, pasteurization at 80°C for 10 minutes and then refrigeration for three months amounted to an 86% reduced amount of vitamin C (Aguiló-Aguayo and Plaza, 2017). In another assessment, after 45 seconds of heat exposure at 90°C and seven consecutive days of storage at 6°C, 11–12% of the vitamin C had been ruined (Mezey, Hegedűs, Mezeyová, Szarka, & Hegedűsová, 2022). Over 85% of the vitamin C in SB juice can be remained at under intensified UHT treatment conditions of 115–125°C for 1–10 seconds (Ao et al., 2022).

Table 1: Representation of Bioactive compounds with

Category	Particulars		Reference
Minerals	Phosphorus	Copper	(Wang et al., 2022a)
	Potassium	Zinc	
	Calcium	Manganese	
	Magnesium	Nickle	
	Ferric		
Vitamins	Vitamin B1	Vitamin C	(Ren et al., 2020)
	Vitamin B2	Vitamin E	
	Vitamin B6	Vitamin K	
	Vitamin B11		
Fatty Acids	Omega 3	omega 7	(Segliņa et al., 2021)
	Omega 6	Omega 9	
Carotenoids	Zeaxanthin		(H. Yan et al., 2021)
	β-carotene		
	β-criptoxanthin		
Organic acids	Malic acids		(Tkacz, Chmielewska, Turkiewicz, Nowicka, & Wojdyło, 2020)
	quinic acids		
	citric acids		
Phytosterol	sitosterol,		(Gâtlan & Gutt, 2021)
	campesterol,		
	Stigmastadienol		
	Stigmastanol		
	a-amyrin		
Carbohydrates	Monosaccharides	Glucose	(Nour et al., 2021)
		Fructose	
		Rhamnose	
		Xylose	
	disaccharides	Sucrose	
		Maltose	
Polyphenols	phenolic acid	p-coumaric acid	(Wang et al., 2022b)
		gallic acid	

		caffeic acid	
	Flavonoids	Kaempferol	
		Isorhamnetin	
		Catechin	
		Epicatechin	
Polysaccharides and sugar alcohols	Pectin,	Xylitol	(Shen et al., 2021)
	Sorbitol	Inositol	
	mannitol,	methyl inositol	
Enzyme	Superoxide dismutase		(K. Wang et al., 2022)

3. Nutritional Properties of Sea Buckthorn

Sea buckthorn's nutritional and biologically active substances fluctuate corresponding on the fruit's terms of size, species, maturation, atmosphere, the location, and ultimately how it is being identified (Nour, Panaite, Corbu, Ropota, & Turcu, 2021). The fresh weight moisture percentage of sea buckthorn fruit can vary between 70.6 to 76.9% (FW) in contrast to the percentage of solids and ash fraction extends from 18.5% to 33.8% (Topală, Mazilu, Vulpe, & Vîjan, 2020).

3.1. Major Nutrients

3.1.1. Carbohydrates

The carbohydrates class represents a few of the primary ingredients of the material that remains dry of sea buckthorn fruit. Total carbohydrate content is currently shown in most research to be between 400 and 600 g/kg dry weight (Solà Marsiñach & Cuenca, 2019). Sea buckthorn mainly comprises mono- and disaccharides. The range of total carbohydrate content (without dietary fiber) is 0.48%–2.87% FW (Gâtlan & Gutt, 2021). The predominant disaccharides are sucrose and maltose, whereas the primary monosaccharides are glucose, fructose, rhamnose, and xylose. About 0.42%–2.70% dry weight (DW) and 0.03%–1.30% DW, respectively, is composed of up of glucose and fructose. Sugars and organic acids collectively have been shown to severely impact the sea buckthorn berries' perceptions, which have implications for consumer acceptance of the product (Markkinen, Laaksonen, Nahku, Kuldjärv, & Yang, 2019).

A high carbohydrate/acid proportion provides an invaluable part regarding improving the texture and taste of sea buckthorn berries as they have a high titratable acidity and a low sugar content (Tkacz et al., 2020). This fluctuates according to variations in the geographic location's latitude and altitude (Markkinen et al., 2019).

3.1.2. Proteins and amino acids

The sea buckthorn plant possesses a high percentage of protein in its woody foliage, seeds, leaves, bark, and branches. Sea buckthorn leaves exhibit a substantial quantity of protein (average of 15%), which explains the reason why they are sometimes used as an unusual means of getting protein in diet for humans (W. Du et al., 2022). Surprisingly the protein concentration of sea buckthorn berries diverges greatly among different areas, the seeds are thought to be a unique source of amino acids (Wang et al., 2022b). Furthermore, sea buckthorn juice exhibits relatively high protein levels as a fruit juice, which can be seen by the liquid's cloudiness or opalescence. Most juices display opalescence caused by cellular waste, but this is mainly because of being composed of cell membranes, resulting in comprising significant amounts of proteins and giving the juice a steady turbidity. Sea buckthorn gives between 0.4% and 2.5% FW of protein along with between 0.77% and 2.19% FW of free amino acids. Juice from sea buckthorn is abundant in free amino acids. Sea buckthorn fruits include a total of 18 among the 22 recognized amino acids, half of which are required due to their vital roles in many bodily functions (Nour et al., 2021). Aspartic acid (0.43%–55.68% of total amino acids), serine (0.03%–11.12% of total amino acids), and glutamic acid (11.76%– 16.48% of total amino acids) are the three major amino acids that researchers found in sea buckthorn (approximately 19 distinct amino acids, 8 essential amino acids). The human body requires eight of these free amino acids: phenylalanine, valine, methionine, leucine, lysine, threonine, tryptophan, and isoleucine (Bośko et al., 2024). Sea buckthorn provides leucine and lysine, which are not present in the majority of plant feed ingredients. The limiting amino acids have been determined to be cysteine and methionine (Ciesarová et al., 2020).

3.1.3. Lipid and Fatty Acid

Sea buckthorn vary in lipid content from 1.2% to 7.8% FW. Fatty acids make up 8.8%–11.1% of total lipid, making them the predominant lipid . Particularly assessing the nutritional value, the fatty acid profile is vital, particularly when it comes to the amount of polyunsaturated fatty acids. There are currently reports of 19 fatty acids in sea buckthorn: 8 saturated and 11 unsaturated. The percentages of total fatty acids that are saturated, monounsaturated, and polyunsaturated are 13.70%–42.68%, 40.73%–60.37%, and 3.70%–24.62%, accordingly (Wang et al., 2022b).
Seafood supplies mandatory fatty acids, especially linoleic and a-linolenic acid (Ren et al., 2020). More importantly, it has been found subsequently that sea buckthorns contain an extensive amount of ω−7 fatty acids. ω−7 Hexadecatrienoic acid, heptadecenoic acid, palmitoleic acid, and vaccenic acid are the fatty acids found in sea buckthorns. Of them, sea buckthorn contains between 16% and 54% of total fatty acids in the form of palmitoleic acid, which is 2 -3 times higher than that of macadamia nuts and 3-5 times more than that of cod liver oil. Rich in oleic acid (ω−9 fatty acids) include seeds and soft portions of sea buckthorn (Attri & Goel, 2020).

3.1.4. Vitamins

Vitamins such as VB1, VB2, VB6, VB11, VC, VE, and VK are abundant in sea buckthorn as shown in **Table 1**. VB1 (0.16–0.35 mg/kg FW), VB2 (0.30–5.0 mg/kg FW), and VB11 (0–7.9 mg/kg FW) are the three primary B vitamins. Kiwi possesses the most significant VC of any fruit, as reported by the United States Department of Agriculture (USDA); fresh green kiwis contain 9270 mg/kg VC, while fresh yellow kiwis have 1610 mg/kg VC (Ren et al., 2020). The average VC content of fresh sea buckthorn is 7950 mg/kg, nearly five times more than that of yellow kiwi (Dong et al., 2023). Sea buckhorn contains the fat- soluble vitamins VE and VK. The word "VE" refers to a class of eight fat-soluble chemical substances that are both required for nutrition and exhibit antioxidant activity: tocopherols (a, b, c, and d isomers) and tocotrienols (a, b, c, and d isomers). A-tocopherol has the highest cellular activity among each of them. Sea buckthorn has an a-tocopherol concentration of 43–223 mg/kg FW (Lõugas, 2006).

3.1.5. Minerals

It is recommended to use sea buckthorn as an excellent source of vital minerals. Phosphorus and three important metal’s concentration fall in order of Potassium>Calcium>phosphorus> magnesium. The variety, location, and environment wherein sea buckthorn grows or harvested each have a significant impact on its mineral composition. There have been reports of 24 minerals, both macro and microelements, found in sea buckthorn. The primary macro elements are P (1.50–1.71 mg/kg DW), K (2.20–10.30 mg/kg DW), Ca (0.27–3.12 g/kg DW), and Mg (0.40–1.15 g/kg DW). The primary microelements are Ni (0.41–0.49 mg/kg DW), Zn (0.04–28.00 mg/kg DW), Mn (8.70–16.00 mg/kg DW), Fe (22–282 mg/kg DW), and Cu (0.14– 12.0 mg/kg DW).

The reported quantities of particular elements in sea buckthorn samples originating from many different countries, however, are very variable according to published data. Naturally, a range of factors, such as plant species, portion of the plant, cultivation region, soil composition, fertilizer treatment, degree of maturity, etc., affect an element's content in plant material. All of these characteristics are also present in sea buckthorn samples from various origins (Nour et al., 2021).

3.2. Lipophilic Components
3.2.1. Carotenoids
Large amounts of multiple carotenoids are among the main compounds identified in sea buckthorn fruit pulp, that have roles as antioxidants and contribute in the synthesis and epithelialization of collagen. It is widely acknowledged that the overall amount and prevalence of various forms of carotenoids vary considerably based on factors such as genetic heritage, growing conditions, climate, and harvesting period. It was discovered that a Romanian sea buckthorn variety's total carotenoid concentration is 860 mg/kg dry weight of berries, identifying zeaxanthin dipalmitate and other zeaxanthin esters, β-carotene, non-conjugated zeaxanthin, lycopene and β-cryptoxanthin palmitate as dominant carotenoid. When sea buckthorn fruits from ssp. Carpatica are analyzed, twelve carotenoid components are found: astaxanthin, zeaxanthin, zeaxanthin palmitate, γ-carotene, cis β-carotene, β-cryptoxanthin, lycopene, myristo-lutein palmitate lutein di-palmitate, β-carotene, α- carotene, and zeaxanthin di-palmitate (Roman et al., 2020).

Conversely, the Chinese sea buckthorn fruits possess a β-carotene quantity of 100 mg/kg fresh weight, which is twice the amount of carrots and more than that of pumpkin. Moreover, this concentration remains unchanged when the fruit is refrigerated. Furthermore, the carotenoids concentration of various sea buckthorn species from the Indian Himalayas was assessed. They revealed that, were compared to Hippophae tibetana and Hippophae salicifolia, berries species of Hippophae rhamnoides yielded the highest quantities of carotenoids (Tudor et al., 2019).

3.2.2 Tocochromanols
Tocopherols and tocotrienols (called tocochromanols), frequently recognized as vitamin E, are substantial bioactive components in sea buckthorn berries, which have a significant antioxidative effect. Berries' tocochromanol content is influenced by their origin, variety, maturity, and harvesting period. Sea buckthorn berries are a rich source of tocochromanols, especially α-tocopherol, when compared to other fruits and vegetables (Tkacz et al., 2022). Sea buckthorn has more vitamin E content than wheat, saffron, corn, and soybean germs (Shah et al., 2021). However, sunflower seeds, almonds, and hazelnuts are superior producers of α-tocopherol in comparison with sea buckthorn. However, in comparison to other vegetable oils like virgin olive oil (98–370 mg/kg), sunflower oil (432 and 92 mg/kg), corn oil (173 and 260 mg/kg), canola oil (120 and 122 mg/kg), and soybean oil (71 and 273 mg/kg), both the seed and pulp sea buckthorn oils are rich in α- and γ-tocopherols (444–1550 mg/kg and 461–1349 mg/kg of seed oil and 630–1940 mg/kg of α-tocopherols in pulp oil) (Barkhuu, Lodonjav, Ganzorig, & Tumurtogoo, 2021).

3.3. Hydlophilic components
3.3.1. Phenolic Compounds
Polyphenol content is the primary determinant of the antioxidant activity of plant-based diets. The majority of the plant's components with antioxidant properties are phenolic compounds. This chemical reaction is mostly caused by the redox characteristics, which are essential to the breakdown of peroxides or the adsorption and neutralization of free radicals. Numerous phenolic compounds, such as flavonoids, phenolic acids, and hydrolysable tannins, are present throughout the entire sea buckthorn plant, including the berries, roots, leaves, stems, and branches (Yue Li et al., 2021). In all, 15 phenolic compounds were discovered and categorized into 4 groups: flavones, phenolic acids, flavonol-monoglycosides, and flavonol-diglycosides. Using the RP-HPLC technique, only in the free fractions of every sea buckthorn subspecies, most common among these were flavonol diglycosides as 233 ± 46 mg/100 g dry weight, followed by flavonol monoglycosides, phenolic acids and flavones (147 ± 24 mg/100 g dry weight, 62.9 ± 23.4 mg/100 g dry weight and 30.9 ± 5.5 mg/100 g dry weight, respectively) (Guo et al., 2017).

The most prevalent polyphenols in food products are flavonoids, specifically their glycosides, together make up the most abundant class of antioxidants in nature (S. Liu et al., 2021). More than five times as many of them are found in sea buckthorn berries as in other high-flavonoid plants including hawthorn, cornelian cherry, wild-grown European blackberries, blackthorn or dog rose, mulberry, pomegranate, red rasberries, and blueberries (Criste et al., 2020). Flavonol glycosides represent the most concentrated family of phenolic chemicals in sea buckthorn (Yue Li et al., 2021). They occur primarily in the glycosylated aglycones of kaempferol, myricetin, quercetin, and isorhamnetin. Sea buckthorn is rich in flavonoid components, with isoramnetin glycosides and quercetin derivatives being the most prevalent. The latter is also the most significant in terms of amount. Research indicates that flavonol glycosides could be a significant factor in the management and prevention of chronic illnesses like diabetes, cancer, and heart disease (Xiao et al., 2021).

According to information provided, salicylic acid is the predominant phenolic acid in sea buckthorn berries when it comes to their phenolic acid composition. The amount of this acid varied according on the kind of berries, ranging from 21 to 47 mg/kg dry weight. It was followed by p-coumaric acid (1.4–9.8 mg/kg dry weight), caffeic acid (up to 6.7 mg/kg dry weight), gallic acid (1.0–4.6 mg/kg dry weight), and vanillic acid (0.5–1.8) mg/kg dry weight) (Schubertova, Krepsova, Janotkova, Potočňáková, & Kreps, 2021). Tanning agents are present in Hippophaë species together with flavonoids and phenolic acids. Water soluble polyphenol molecules with a relatively high molecular weight that are found in alkaloids, polysaccharides, and proteins are called tannins (Topală et al., 2020). Tannins in sea buckthorn are divided into two groups: hydrolysable and condensed tannins. Gallo and ellagitannins of monomeric type are the most abundant subgroups of hydrolysable tannins and include stachyurin, casuarinin, casuarictin, hippophaenin B, strictinin, and isostrictinin (Criste et al., 2020).

3.3.2. Ascorbic Acid

The most significant medicinal component of sea buckthorn fruit is ascorbic acid, or vitamin C, which functions as an antioxidant and preserves the integrity of the cell membrane. Nearly every portion of the sea buckthorn plant has been found to contain it: the juice from the berries (11.6–13.0 g/kg), the seeds (1.5 g/kg), and the leaves (up to 3.7 g/kg). There were significant differences in vitamin C levels between populations, subspecies, and various shrubs in H. rhamnoides. In fruit from the European rhamnoides subspecies, the concentration of vitamin C ranges from 0.3 to 3.1 g/kg; in Russian varieties from the mongolian subspecies, it varies from 0.4 to 3 g/kg; in the fluviatilis subspecies, it varies from 4.6 to 13.3 g/kg; and in the Chinese sinensis subspecies, it varies from 2 to 25 g/kg. Thus, it was discovered that sea buckthorn had 20 times more vitamin C than hawthorns, 3 times more than kiwi, 6 times more than citrus, 80 times more than tomatoes, and 200 times more than apples. It should be noted that ascorbate oxidase, the enzyme that breaks down ascorbic acid, is absent from sea buckthorn berries. As a result, dried fruits and sea buckthorn products both have high vitamin C content (Gâtlan and Gutt, 2021).

4. Sea Buckthorn Application

Sea buckthorn provides several financial benefits, notably in terms of protecting the environment and as a basic resource for nutraceutical and cosmetic products. It has been established that this crop is appropriate for retaining soil and water, as well as for forming wind barriers in marginal areas that are vulnerable to erosion, because of its high resistance to cold, drought, and salt, as well as its capacity to fix nitrogen in the soil (Y. Du et al., 2023). Numerous studies on Hippophaë species have been conducted recently by researchers in the domains of nutrition, food science, medicine, sports science, agriculture, and forestry, suggesting its usage as a food and medicine (Balta et al., 2021).

4.1. Therapeutic uses of sea buckthorn

The traditional knowledge of sea buckthorn fruits includes both their therapeutic and high nutritious qualities. Sea buckthorn fruits have been utilized for years in Europe and Asia, but they are now quite well-known globally, mostly because to their nutritional and medicinal qualities. Approximately two hundred industrial goods include them, including conventional and herbal medications used to treat heart disease, cancer, ulcers, liver problems, burns, and brain disorders, among other conditions as shown in table 2 (Ibrahim et al., 2020).

4.1.1. Antioxidant, immunomodulatory and anti-cancer activity

Countless experimental research has focused on the broad spectrum of impacts of oxidative damage to cells in biological systems, which has been linked to the pathogenesis of a wide range of clinical illnesses. Under H_2O_2- induced B16F10 cell model and D-galactose-induced animal model, hydroalcoholic extract from sea buckthorn seed residues (HYD-SBSR)s reduce cell apoptosis and attenuate oxidative stress damage. The preventive and repairing effects of HYD-SBSR on cells have been studied utilizing the H2O2-induced oxidative stress paradigm in B16F10 cells. The results showed that HYD-SBSR has cytoprotective benefits, as shown by moderate cell repair characteristics, increased resistance to oxidative stress, and decreased rates of apoptosis. Dextran sodium sulfate (DSS)-induced colitis is a model of inflammatory bowel conditions that can be significantly ameliorated by supplementing sea buckthorn polysaccharides to the diet. In mice, sea buckthorn improved intestinal barrier permeability, colon length, and disease activity index. The results of RT-qPCR also showed that following sea buckthorn intervention, there was a substantial decrease in the expression of various pro-inflammatory factors (IL-6, IL-1β, TNF-α, and IL-17F) and transcription factor RORγt secreted by Th17 cells, and an extensive increase in the expression levels of anti-inflammatory factors (IL-10 and TGF-β) and transcription factor Foxp3 secreted by Treg cells . The antioxidant and immunological features of Yellow River carp might decrease as a result of high-carbohydrate (HC) diets. Antioxidant and immunological functions are enhanced in HC by sea buckthorn flavonoids (SF). Yellow River carp (Cyprinus carpio L) went through a 10-week aquaculture experiment in which oxidative stress was raised. In vitro, SF progressively developed its ability to scavenge free radicals such as O2.-,·OH, and DPPH. Supplementing the diet of Yellow River carp with SF improved their immunological and antioxidant capabilities. This was due to modifications in the transcription and protein levels of these enzymes as well as the regulation of specific activiti. The cyclophosphamide-induced reduction in body weight, thymus/spleen index, and hematological parameters is reversed by SBT pulp oil. In contrast to immunosuppressive mice induced with cyclophosphamide, SBT pulp oil increases the production of secretory immunoglobulin A (sIgA), IFN-γ, IL-2, IL-4, IL-12, and TNF-α in the intestines, as well as NK cytotoxicity, macrophage phagocytosis, and T lymphocyte proliferation. It also regulates the proportion of T cell subsets in mesenteric lymph nodes (MLN) (J. Zhang et al., 2021). In rats, seabuckthorn leaves provided defense against oxidative stress caused by hexachlorocyclohexane (Lõugas, 2006).

4.1.2. Hepatoprotective activity

Changes in liver histology and liver enzymes by cyclophosphamide, decreased by administering sea buckthorn berry seed oil (SBO) in BALB/c mice . Three groups of ten male BALB/c mice each, in good health were divided. Group 1 served as control. Group 2 received ten days of intraperitoneal administration of cyclophosphamide (25 mg/Kg body weight). Sea buckthorn berry seed oil (40 mg/Kg body weight) was given orally to Group 3 for ten days along with cyclophosphamide (same dose). During the eleventh day, every animal was sacrificed. Salivary enzyme levels were measured as indicators of liver damage. To find proof of hepatic injury and healing, liver histology was performed. Significant increases were observed in Group-2 in serum levels of alanine aminotransferase, aspartate aminotransferase (AST), and alkaline phosphatase (ALP). Hepatic damage serum marker increases were noticeably slower in Group 3. In lead acetate intoxicated Wistar rats, the effects of dosing with sea buckthorn(Hippophae rhamnoides) leaf extract (SLE) were studied. In order to examine the liver function enzymes, blood samples were taken on day zero as well as on days 45 and 60. Aspartate aminotransferase (AST), alanine aminotransferase, acid phosphatase (ACP), and alkaline phosphatase (ALP) activity increased in lead acetate intoxicated groups, along with liver weight and hepatic oxidative stress. When administered simultaneously with SLE, a protective effect against lead poisoning. SLE supplementation also decreased hepatic oxidative stress and the level of AST, ALT, and ALP (Zargar et al., 2022).

4.1.3. Modulation of hypoxia-induced transvascular leakage

Unacclimatized individuals may experience cerebral and pulmonary syndromes shortly thereafter climbing to high altitudes, leading to high altitude illnesses such as high-altitude cerebral edema and high altitude pulmonary edema. These illnesses may arise from the extravasation of fluid from intravascular to extravascular space in the brain, lungs, and peripheral tissues. The hypoxia caused rise in vascular permeability may be due to a higher production of reactive oxygen and nitrogen species, which in consequently may increase oxidative damage of lipids, proteins and DNA as being exposed to hypoxia has been demonstrated to decrease the activity and effectiveness of antioxidant enzyme system.

Vascular Endothelial Growth factor (VEGF) expression was decreased in the lungs and brain of rats when the SBT leaf alcoholic extract and seed oil were administered, significantly preventing transvascular fluid leakage caused by hypobaric hypoxia (L. Du et al., 2020).

4.1.4. Cardiovascular health maintaining

The term "CVD" describes ischemic or hemorrhagic diseases of the heart, brain, and systemic tissue that are brought on by hyperlipidemia, blood viscosity, atherosclerosis, and high blood pressure. One useful strategy to keep cardiovascular health is to prevent platelet aggregation. In women with high cholesterol, two months of supplementing with 100% sea buckthorn juice (SBJ) might alter blood lipids, LDL subfractions, and other cardiovascular risk factors. For two months, a group of twenty-eight adult women, with a mean age of fifty.58 ± 5.76 years and hypercholesterolemia, who were not on medication, drank 50 mL of 100% SBJ every day. Body weight (BW), body mass index (BM, body fat mass (BFM), and visceral fat area (VFA) will all significantly decrease; skeletal muscle mass (SMM) and fat-free mass (FFM) will, however, significantly increase. When 100% SBJ was supplemented, the levels of atherogenic LDL subfractions (LDL), low-density lipoprotein (LDL), and high-density lipoprotein (HDL) were all significantly increased while the LDL/HDL ratio was improved. By triggering the protein kinase B (Akt)- endothelial nitric oxide synthase (ENOS) signaling pathway, sea buckthorn oil protects rats' hearts from myocardial ischemia-reperfusion damage.

Myocardial GSH levels and cardiac function are stabilized by pretreatment with 20 mg/kg pulp oil, which also considerably reduces lipid peroxidation. In addition, sea buckthorn oil lowers tumor necrosis factor levels, enhances hemodynamics and systolic function, and prevents the activity of lactate dehydrogenase, a sign of injury to cardiac cells. It was studied how SBBO affected hemodynamic, antioxidant, histological, and ultrastructural parameters in isoproterenol-induced cardiotoxicity. When administered to rats at a dose of 20 mL/kg daily, SBBO dramatically modifies hemodynamic and oxidative derangements.

Through histological and ultrastructural analyses, the protective effect of sea buckthorn oil against ISO-induced cardiotoxicity was demonstrated further. The SBBO's antioxidant and free radical scavenging properties help to reduce myocardial damage in rats with ISO-induced heart injury (Tomar et al., 2019). Researchers are under increasing pressure to look at angiotensin-converting enzyme (ACE) inhibitory peptides synthesized from dietary protein as safer therapeutic alternatives, since the side effects associated with manufactured antihypertensive medicines. Protein isolated by alkaline extraction and acid precipitation from sea buckthorn seed possesses non-competitive inhibitory mechanism and good inhibition stability on angiotensin-converting enzyme (ACE) (Gâtlan and Gutt, 2021).

Table 2: A summary of studies on SB major health-promoting benefits.

Health-promoting benefit	In vivo or in Vitro	Research Outcomes	References
Antioxidant	In Vivo	Rats' induced oxidative stress from hexachlorocyclohexane is protected by sea buckthorn leaves.	(Gâtlan and Gutt, 2021).
Anti-cancer activity	In Vivo	In H2O2-induced B16F10 cell model and a D-galactose-induced mouse model, hydroalcoholic extract from sea buckthorn seed residue stops cell death and reduces oxidative stress damage.	(Raghavan et al., 2008).
Inflammatory	In Vivo	An inflammatory bowel disease model, dextran sodium sulfate (DSS) induced colitis is significantly improved by dietary supplements with sea buckthorn polysaccharides.	(Siddalingaswamy and Khanum, 2010)
Antioxidant/ Inflammatory	In Vivo	In Yellow River carp (Cyprinus carpio L), sea buckthorn flavonoids (SF) enhance antioxidant and immunological performance in high-carbohydrates induced oxidative stress during 10-week aquaculture experiment.	(Cavak et al., 2022)
Immunomodulatory effects	In Vivo	SBT pulp oil reverse the declining trend of body weight, thymus/spleen index and hematological markers generated by cyclophosphamide.	(J. Zhang et al., 2021)
Hepatoprotective activity	In Vivo	Attenuated cyclophosphamide-induced alterations in liver enzymes and liver histology in BALB/c mice treated with sea buckthorn berry seed oil (SBO)	(Dupak et al., 2022)
Hepatoprotective activity	In Vivo	Supplemented simultaneously, seabuckthorn leaf extract SLE had a preventive effect against lead intoxication.	(Zargar et al., 2022)
Transvascular fluid leakage Protection	In Vivo	SBT leaf alcoholic extract and seed oil significantly protected rats' lungs and brains against hypobaric hypoxia-induced transvascular fluid leakage.	(L. Du, Liu, Wan, Chen, & Fan, 2020).
Cardiovascular health maintaining	In Vivo	In women with high cholesterol, two months of supplementing with 100% sea buckthorn juice (SBJ) might alter blood lipids, LDL subfractions, and other cardiovascular risk factors.	(Dupak et al., 2022)
Cardioprotective	In Vivo	Because of its antioxidant and free radical scavenging properties, the SBBO reduces myocardium damage in rats that have isoproterenol-induced cardiotoxicity.	(Tomar, Kaushik, Arya, & Bhatia, 2019)
Myocardial ischemia	In Vivo	In rats, sea buckthorn oil prevents cardiac ischemia-reperfusion injury via triggering the signaling pathway between endothelial nitric oxide synthase (ENOS) and protein kinase B (Akt).	(Dupak et al., 2022)
Anti-bacterial	In vitro	Using the agar disc diffusion method, the antibacterial effectiveness of sea buckthorn was examined against several microbial cultures that cause infections or illnesses.	(Sandulachi et al., 2022).
Healing effect on wounds	In Vivo	Compared to the control group, the seabuckthorn leaf aqueous lyophilized extract (SBTL-ALE) extract significantly lessens the burn caused by a circular metallic probe heated to 85°C and left on the depilated skin of the rat for 20 seconds.	(Dupak et al., 2022)

4.1.5. Anti-bacterial

Hiporamin is a new phytochemical medication that has been discovered by a methodical chemical analysis of active fractions from SBT leaves. Hiporamin has a broad range of antiviral and antimicrobial activity (V. Singh, 2022). Purified polyphenol fraction hiporamin contains monomeric hydrolysable gallotannins, ellagitannins (NMR spectra ideally show strictinin, isostrictinin,casuarinin, casuarictin pedun- culagin, and stachyurin).(Y. H. Lee et al., 2021). Using the agar disc diffusion method, the antibacterial effectiveness of sea buckthorn was examined against various microbiological cultures that cause infections and illnesses, including Staphylococcus aureus, Bacillus subtilis, Salmonella Typhimurium, Escherichia coli, and Candida albicans. The inhibition zones for Salmonella Typhimurium ATCC 14028 (13–18 mm), Bacillus subtilis ATCC 6633 (19–29 mm), Escherichia coli ATCC 25922 (12–18 mm), and Staphylococcus aureus ATCC 25923 (21–30 mm) varied from 12 to 30 mm (Sandulachi et al., 2022). Hippochae rhamnoides L., or sea buckthorn, is a type of edible and therapeutic plant. However, buyers do not readily accept it because of its acidic taste. You might use fermentation to change its flavor profile in order to get over this. After 20 hours of fermentation at 37°C, the biological enzyme activity and total flavonoid content (TFC) of sea buckthorn juice (SBJ) increased. The TFC reached 2.38 mg/mL, and the superoxide dismutase (SOD) activity reached 725.44 U/mL. Staphylococcus aureus, Botrytis cinerea, and Escherichia coli were all susceptible to the potent antibacterial action of FSB (X. Liu et al., 2023). Based on the diameter of the inhibition zone, sea buckthorn's antimicrobial activity against Bacillus pumilus was found to be 3.70–15.91 mm/g−1 for whole sea buckthorn fruits and 13.33–26.67 mm/g−1 for sea buckthorn purees (Criste et al., 2020).

4.1.6. Healing effect on acute and chronic wounds

Preparations based on SBT have been widely utilized to treat duodenal and stomach ulcers, burns of various etiologies, and skin radiation lesions. Using various animal models and clinical trials, the preventive and therapeutic benefits of SBT against wounds, burns, scalds, ulcers, and mucosal injuries have been thoroughly studied

Chitosan scaffolds based on sea buckthorn oil loaded nanoemulsion (SOL-NE) are created by incorporating SOL-NE as a nanofiller into fibers that can promote wound healing in diabetic Wistar rats (Type 2 diabetes) by significantly downregulating the level of matrix metalloproteinases MMP-9 and encouraging collagen deposition and reepithelization (Kaur et al., 2024). The Bates-Jensen Wound Assessment Tool (BWAT), a 15-item questionnaire intended to assess wounds, demonstrated in a randomized clinical trial that 40% sea buckthorn cream healed wounds more quickly (6.7±2.1 days) than 1 silver sulfadiazine dressings (SSD cream on second-degree burns. The application of both Seabuckthorn leaf aqueous lyophilized extract (SBTL-ALE) and superpulsed 904 nm laser Photobiomodulation therapy (PBMT) significantly improves the third-degree burn caused by a circular metallic probe (1.5 cm diameter) heated to 85°C (in hot water) and left on the depilated skin of the rat for 20 seconds, as compared to the control group. By speeding cellular proliferation, neovascularization, collagen deposition, lowering oxidative stress, attenuating inflammatory responses, and activating bioenergetics, combined therapy methods synergistically accelerate burn repair. Furthermore, there is a great chance that this combination of treatments can be applied topically to full thickness third degree burns as a successful therapeutic approach in the management of burn patients (Jastrząb and Skrzydlewska, 2019).

Athletes and soldiers are also provided with SB-based food products because of their superior nutritional value. For instance, SB juice was created and approved as one of the official beverages for Chinese athletes competing in the 1988 Olympics. Genghis Khan fueled his army with sea buckthorn (Melissa Petitto, 2020). SB is frequently found in cosmetic goods in addition to food. For instance, a lot of anti-aging and anti-wrinkle treatments contain SB fruit oil (A. Singh, Ansari, Haider, Akhtar, & Ahsan, 2020).

4.1. Sea buckthorn in cosmetic industry

Global production of cosmetics including and derived from sea buckthorn extracts occurs. These include hair lotions, facial masks, moisturizers, and bath soaks made from H. rhamnoides L.; they also include hygiene goods including shampoo, skin cream, and bath soaks, as well as mouthwash made from sea buckthorn (Mihalcea et al., 2021).

4.3 sea buckthorn in food industry

For millennia, people have used SB berries for food, medicine, and therapy. In addition to wine and soft candies. A small number of commercial SB based food products have been produced without the use of sugar or other flavor-masking agents because of its inherent astringency. Sugar/acid ratio is the primary indicator to boost consumer acceptance of SB. SB food products can be categorized into four groups:

- Beverage items created with SB juice: This category comprises wine, nectar, and SB juice.
- Food items manufactured from the SB berry include tea, dried berries, candies, and powdered SB berry.
- Products based on SB pulp, seed oil, or their mixtures are very health benefits, SB seed oil and fruit oil are both frequently taken orally. Other food oil formulations also contain either fruit oil or SB seed oil of sea buckthorn.
- Products made from SB berry extract: Examples include yellow/orange pigment made from SB and SB flavonoid, which is frequently taken as a health supplement.
- Products made from SB berry extract are frequently utilized as additions or components in prepared foods and dietary supplements.

5. Mega Fatty Acids Profile of Sea Buckthorn:

5.1 therapeutic benefits of sea buckthorn’s fatty acids

A number of beneficial effects that the fatty acids in sea buckthorn oil offer are supported by both traditional use and contemporary research (Gâtlan & Gutt, 2021). Three different types of fatty acids have been identified in sea buckthorn oil, highly saturated fatty acids (palmitic acid and stearic acid), monounsaturated fatty acids (palmitoleic acid also called omega-7 and oleic acid also called omega-9), and polyunsaturated fatty acids (linoleic acid also called omega-3 and linolenic acid also called omega 6)(Table 3) (Solà Marsiñach & Cuenca, 2019).

5.1.1. Monounsaturated fatty acids

5.1.1.1. Palmitoleic acid (PA)

In the kingdom of plants, PA is a very rare omega-7 monounsaturated fatty acid. As such, introducing it into the human diet through veggie food sources is exceedingly challenging. This fatty acid is found in very few plants, including sea buckthorn. In particular, only the berry's soft section contains PA (Ding et al., 2022). Multiple research investigations highlight the advantages of PA for managing the symptoms of vaginal inflammatory atrophy. Multiple various therapies are available for this illness, although they are often ineffective. Therapeutic options involve retinoid cream, anti-inflammatory ointment, systemic and localized corticoids, local testosterone, estrogen and systemic estrogens, and surgery. That's why studies have been conducted on replacement solutions, including the sea buckthorn treatment. For instance, a recent study reported on Agro Food Industry Hi- Tech examines for giving five patients three omega-7 sea buckthorn capsules orally two times daily for a duration of twelve weeks.

According to the study's findings, Significant progress has been made in three women with chronic vaginal inflammatory atrophy. The reduction in symptoms was not as obvious in the two fewest extreme situations. Given that the omega-7 treatments failed to increase the percentage of estrogen in bloodstreams. However, only a small number of individuals were enrolled, indicating the need for additional clinical trials. Furthermore, melanogenesis is believed to be inhibited by PA. Melanocyts, the cells that make melanin pigment, synthesize melanogenesis. Yoon and colleagues' study used murine B16 melanoma cells to test the PA's inhibitory effectiveness against three important melanogenic enzymes. Microphtalmina associated transcription factors (MITF), tyrosinase, tyrosinase related protein-1 (TRP-1) and tyrosinase related protein-2 (TRP-2) were the enzymes in consideration. The findings indicated that tyrosinase, TRP-2, and MITF were inhibited; as a result, one possible anti-melanogenic therapy that may help with hyperpigmentation issues is PA (Dudau et al., 2021). Human sebum belongs to another effect of PA on skin and mucous membranes. Triglycerides, wax esters, and squalene make up the majority of human sebum, which is specific to sebaceous cells. PA is accountable for the majority of the epidermal layer's self-disinfecting action, and sebum does contribute to this activity. Using lipids that were obtained from the skin's surface, Wille & Kydonieus conducted an in-vitro investigation to investigate the antibacterial activity.

The findings showed that PA was efficient in inhibiting pathological mold cells from attaching to the separated mammalian corneal layer sheets at concentrations over 1.0 mg/ml, whereas it had minimal effect on C. albicans growth at doses below 0.5 mg/ml. It is also utilized as a therapeutic prophylactic medication for incision ailments and catheter films, PA has the capacity to inhibit the attachment of Candida albicans to the skin. However, against gram-negative bacteria, this fatty acid is ineffective (Xin et al., 2022). It appears that PA plays a significant part in decreasing cholesterol. A study compares how food affects rats with hypercholesterolemia. Six groups of rats were assigned to different diets that varied in their content of oleate, palmitate, stearate, palmitoleate, linoleate, or α-linoleate. The overall amount of cholesterol in the blood has been shown to be reduced by palmitoleate just as effectively as by linoleate. Although exact mechanism underlying its action is still unknown, rats given palmitoleate have been shown to exhibit significant levels of lecitin cholesterol acil transferase (LCAT) (Tereshchuk et al., 2020). Insulin resistance combined with liver disease. As a further consequence of PA, a potential link among PA along with insulin sensitivity in the liver was investigated by Souza and associates. The study's concept involves feeding two groups of mice, one a conventional diet and the other a high-fat diet for a duration of 12 weeks. For the previous two weeks, mice that were fed a high-fat diet were treated daily with either oleic acid or palmitic acid. The following 12 weeks, the mice received a subcutaneous injection of either insulin or a vehicle, and a number of parameters were evaluated. According to the study's findings, PPAR-dependent PA supplementation increased glucose absorption and decreased liver lipogenesis in mice given a high-fat diet by activating AMPk and FGF-21. To prevent abnormal lipid accumulation in the liver and to manage insulin resistance, all of these effects are necessary. Additionally, the study indicated that PA is a significant non-pharmacological treatment for liver disease and diabetes. It also revealed a decrease in lipogenesis and an increase in lipolysis in adipocytes. Furthermore, PA was observed to have an impact on the immune system, as evidenced by a decrease in proinflammatory cytokine expression and NF-kB p65 phosphorylation in macrophages (Solà Marsiñach & Cuenca, 2019).

5.1.1.2. Oleic acid (OA)

OA is an omega-9 monounsaturated fatty acid having 18 carbons and a double bond at carbon 9. Oleic acid is abundant in seeds and tender tissues. 13–19% of seed oil and 12– 33% of pulp oil in both regions contain OA (Rashid et al., 2020). The antiatherogenic effects of OA may be explained by the fact that multiple studies demonstrate. It seems that the endothelium's gene expression for cell adhesion molecules has been reduced by OA (Hao et al., 2019). Research conducted on *in-vitro* investigation to examine the impact of OA upon cells of endothelial tissue in the human umbilical vein (Bass, Soukup, Ghio, & Madden, 2020). As the OA's have suppressive effect on endothelial activation, the risk of atherosclerosis is decreased. The way that OA alters macrophage adhering may help to explain these antiatherogenic properties, which is explained by decreased expression of NF-kB after endothelial cell stimulation (Dienaitė et al., 2020).

5.1.2. Polyunsaturated fatty acids

5.1.2.1. α-Linolenic acid (ala)

Three cis double bonds and eighteen carbons make up the unsaturated omega-3 fatty acid ALA. It is an isomer of GLA and an important fatty acid that is exclusively found in diet. Even though it can also be found in the berries' soft parts. It is primarily found in seed oil, of which there are 20–35% (Attri & Goel, 2020). The amount of ALA varies depending on the sub-species, much like in the other fatty acid situations described above. Compared to subsp. Sinnensis, ALA exhibits variance, with subsp. rhamnoides having a higher average ratio (Sharma, Arora, Sahoo, & Deswal, 2020). Numerous studies have examined ALA's strong cardioprotective properties. The European Food Safety Authority (EFSA) has approved that upholds ALA's role in regulating normal blood cholesterol levels. A dose-related and inverse link among nutritional ALA (range, 0.17 to 3.48 g/d) and the prevalence of calcified atherosclerotic plaque in the coronary arteries (CAC) was found in a cohort study conducted by numerous researchers. The susceptibility of atherosclerotic plaques and their overall burden are directly correlated with the presence of CAC. As a result, lowering the amount of CAC lowers the chance of developing atherosclerosis, and vice versa (Bruno, Dovera, Ciccarone, & Colombo, 2022). Additionally, crossover research was carried out on participants with moderate hypercholesterolemia to demonstrate the impact of food on the inflammatory process associated with cardiovascular disease.

The American diet (as the control diet, a polyunsaturated fatty acid-rich diet), LA diet and ALA diet were the three diets created for this study. The participants were divided into three groups and given a set of each of these test diets. The findings demonstrated that an ALA diet reduced C-reactive protein, the emergence of atherosclerosis is linked to that protein. Additionally, an ALA-based diet differs from a control diet in reducing E selectin and vascular cell adhesion molecule-1 (VCAM-1). The two high-PUFA diets reduced TAG, LDL cholesterol, and total cholesterol in the blood. Furthermore, the ALA diet raised serum EPA levels while decreasing apolipoprotein AI and HDL cholesterol beyond the American diet. The study found that a diet high in ALA can help lower several risk factors for cardiovascular disease, including pro-inflammatory cytokines, VCAM-1 alterations, cholesterol levels, and serum EPA levels (Solà Marsiñach & Cuenca, 2019). In participants with high-normal blood pressure and moderate hypertension, ALA's antihypertensive effect was assessed in a study published in the *Journal of Olea Science*. The participants were split into two groups: one that was given 14 grams of regular blended oil, and the other that was given ALA-enriched oil. Systolic and diastolic blood pressure in the ALA-enriched group were significantly lower than in the control group, according to the data. According to the study's findings, ALA had no adverse impacts on blood pressure during the investigation and had an antihypertensive impact (K. Chen et al., 2022). An assessment is being conducted on the possible impact of ALA on bone preservation. N- telopeptides, a biomarker of bone mineral density, were evaluated in response to various diets. The outcomes demonstrated a statistically significant reduction in N-telopeptides conclusion that ALA and LA might be crucial for maintaining bone growth and turnover (Park et al., 2022). Researchers additionally investigated the impact of nutrition on bone health in 1865 female participants. X-rays were used to quantify the hip, lumbar, femoral trochanter, bone mineral density, and Ward's triangle. A food questionnaire was used to measure the food consumption of arachidonic acid, calcium, vitamin D, ALA, EPA, and DHA. The scientists discovered that ALA, EPA, and DHA were positively correlated in relation to bone mineral density (Pariyani et al., 2020).

5.1.2.2. Linoleic acid (LA)

LA is an omega-6 polyunsaturated fatty acid that has two double bonds at carbon nine and twelve. LA and α-linolenic acid (ALA) together make up the necessary fatty acids that the body is unable to produce on its own. The European Food Safety Authority (EFSA) has approved a health claim claiming children's appropriate growth and development depend on LA and ALA (Z. Sun et al., 2024). It is hypothesized that the antiarrhythmic mechanism of LA is connected to the cardiac myocytes' sodium and calcium channel regulation (ul Baseer et al., 2020). LA is an essential polyunsaturated fatty acid that is prevalent in human skin. (Dudau et al., 2021). As a result, numerous research has concentrated on LA's advantageous benefits on skin and mucous membranes.

To stop the water loss from the epidermis, the lipids produced by the skin's lamellar granules preserve the skin's protective layer. Researchers confirm that as people age, their skin becomes weaker and drier due to a slowdown in lamellar granule reproduction. Omega-6 may be able to synthesis lipid in the lamellar granules, fortifying the epidermis barrier by lipid, shielding the skin from water loss by epidermal, restoring normal skin metabolism (Moore, Wagner, & Komarnytsky, 2020). Furthermore, a decrease in LA in sebum is seen in individuals with acne skin, which can clog pores and cause dermatitis and comedones. Furthermore, it's believed that LA may increase sebaceous gland activity, clearing clogged pores and reducing the frequency of comedones (Shah et al., 2021). The relationship between LA and cholesterol levels is another advantageous impact that has been studied recently. In one investigation, two groups of white rabbits suffering from atherosclerosis were created based on the diets the rabbits were fed. The first group received 1 ml sea buckthorn seed oil, the second will received a high-cholesterol diet, third group received a high-cholesterol diet plus 1 ml sea buckthorn oil for 30 days, the fourth group served as control group. The study’s findings showed that group 3 LDL-cholestero to LA, although other authors thought that intakes of ALA, PA, and sea buckthorn oil sterols had also been linked to the reduction of blood cholesterol, LDL-cholesterol, triglycerides, and other cardiovascular disease risk factors (Solà Marsiñach & Cuenca, 2019). Omega-3 and omega-6 PUFAs compete for incorporation into cell membranes. A balanced intake of these different types of PUFAs is important. In addition, different PUFAs have opposing physiological functions. Specifically, omega-6 and omega-3 PUFAs promote systemic proinflammatory and anti- inflammatory states, respectively. Although omega-6 PUFAs are converted to AA and subsequently to prostaglandins and leukotrienes, which have proinflammatory effects, omega-3 fatty acids DHA and eicosapentaenoic acid (EPA, ω-3) act as competitive inhibitors of omega-6 PUFAs, thereby resulting in the reduced synthesis of proinflammatory mediators (Pariyani et al., 2020).

5.1.2.3. γ-Linolenic acid (GLA)

GLA is the result of a Δ-6-desaturasa transforming LA. GLA fatty acid also called omega-6, and its multiple impacts on the organism make it fascinating. Numerous research has examined the advantages of omega-6 oils, especially GLA. It has been suggested that oils high in GLA can help with rheumatoid arthritis, premenstrual syndrome, dermatitis and eczema, and heart disease prevention (Pundir et al., 2021). Additionally, it enhances blood circulation, which is critical for the skin's oxygenation and nutrition as well as the elimination of excess pollutants. As a constituent of the skin's intracellular cement, GLA is also important for binding epidermal cells. Furthermore, it belongs to the class of phospholipids, which make up the majority of cell membranes. Additional noteworthy characteristics of GLA include its ability to ward off infections, combat allergies, ease inflammation, and decelerate the aging process (Pariyani et al., 2020).

Table 3: Implications of selecting omega-3, omega-6, omega-7 and omega-9 fatty acids

Fatty Acid	Dietary Source	Function/Mechanism	Implication	References
Omega-3 Fatty Acids				
α-linolenic acid, ALA	Plant oils linseed oil, kiwifruit oil, chia seed oil, flaxseed oil, canola (rapeseed) oil, soybean, purslane, walnuts	cardioprotective properties, calcified atherosclerotic plaque, maintaining bone growth, hypocholesterolemic	↓ platelet aggregation, ↓ oxidative stress, ↓ inflammation,	**(Chao et al., 2019)**
Omega-6 Fatty Acids				

Linoleic acid, LA	Corn, peanut, soybean, Cottonseed,	sodium and calcium channel regulation, lamellar granule reproduction	↓ Arrythmia, ↑ skin's protection	**(ul Baseer et al., 2020). (Solà Marsiñach & Cuenca, 2019)**
Omega-9 Fatty Acids				
Oleic acid, OA	Olive oil, macadamia oil	↓ atherogenicity, hypolipidemic hypotensive	↓ LDL cholesterol ↓ LDL cholesterol oxidation ↑ vasoprotective improved lipid profile	**(Hao et al., 2019).**
Omega-7 Fatty Acids				
Palmitoleic acid (PA)	**Cold water fish, metabolic synthesis from EPA**	**Hypolipidemic, vaginal inflammatory atrophy, PPAR-α-dependent PA supplementation increased glucose absorption**	**↑ anti-inflammatory, ↑Hypoglycemic**	**(Solà Marsiñach & Cuenca, 2019).**

6. Future challenges and trends

SB contains numerous bioactive compounds. Some of them are valuable from nutritional point of view in which further in depth investigation is required. For example, 5-hydroxytryptamine (5-HT) plays an important role in the synthesis of serotonin relating to sleep, appetite, temperature, sexual behavior, and pain sensation. SB berry and stem contain 5-HT that is rarely found in the plants. The health effect of 5-HT from SB requires further investigation under its mechanism. L-quebrachitol is another bioactive compound identified in SB. L-quebrachitol in SB might lead to improvement of pancreas and reversal of insulin resistance that is highly associated with type-2 diabetes (Mu, Tao, Yuan, & Lv, 2022). Thus, SB effect on type-2 diabetes needs to be further explored.

The future of product development on SB is to further explore its health-promoting benefits on other potentials which the current research has shown some positive indications, such as Alzheimer's disease, diabetes (Mulati et al., 2020). Another trend is to discover if there is any synergetic effect when SB is formulated with other ingredients. SB is a plant that possesses both high ecological and economic values. However, the economic value does not always keep abreast of that in ecology. One study has indicated that growth rate of SB ecological value was slower than that of economy between 2003 and 2017 in a Northwest region in China based on an equilibrium analysis using 12 indicators of ecological function and economic value (Sanwal, Mishra, Sahu, & Naik, 2022). Thus, the maximization of both SB ecological and economic values is meaningful for sustainable development of SB.

7. Conclusion

Hippophae rhamnoides L. Sea buckthorn has attracted a lot of attention owing to its diversified nutritional and therapeutic values. Traditional people of different regions of Europe and Asia have been using this deciduous shrub because its fruits are very rich in vitamins, minerals, and other biologically active compounds known as phytochemicals that are beneficial to human health. For instance, sea buckthorn enjoys a rich reputation as a product with a high antioxidant value attributed mainly to its vitamin C and E, carotenoids, and flavonoids concentrations. Modern pharmacological research has also considered the uses of sea buckthorns to support treatment of chronic illnesses and to be a health remedy supplement.

The fruit, leaves, and oil of sea buckthorn contain bio-active compounds which are cardioprotective, hepatoprotective, anticancerous, and anti- inflammatory in nature. Of these, the berries are most widely known for their richness in the unsaturated fatty acid, such as ω-3, ω-6 and ω-7 fatty acids which are essential for optimal cardiovascular and skin health. An analysis of some phytochemicals shows that the seeds contain a rich combination of nutrients that are responsible for these curative effects. For example: the berry oil contains palmitoleic acid; the fat, which is rather scarce in the plant species, has the curative and regenerating effect on the skin. On the other hand, the leaves are known to contain relatively high concentrations of phenol that afford antioxidant qualities that augment the healing power of this plant. In view of these promising features of sea buckthorn, there is a serious lack of literature that can be explored to achieve its full potential.

Though a number of research articles are available on the subject, most are in vitro or involve animals. In human clinical trials, they are relatively few, and the data obtained from these trials are usually insufficient to support the therapeutic benefits of sea buckthorn as envisaged. In addition, there is no cool named extract and irregular dose regimens, which hamper the assessment of its clinical effectiveness. Further research should aim at conductifying well controlled clinical trials which will attest to the health enhancing effects seen in current preliminary works.

The original concentrations of the constituents obtained by the extraction must be determined accurately and without fail thus formal procedures for achieving such objectives must be developed. Furthermore, understanding the bio-pharmacological effects of the sea buckthorn might also help in understanding different therapeutic uses of the sea buckthorn (Cavak et al., 2022).

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