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The Golden Superfruit: Unveiling the Nutritional Riches and Multifaceted Health Benefits of Seabuckthorn

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ABSTRACT

Seabuckthorn, binomially named *Hippophae rhamnoides L.,* is widely recognised as a nutritional powerhouse due to its exceptional nutrient profile. This hardy shrub produces small, tart berries packed with an array of vitamins, minerals, and bioactive compounds. Seabuckthorn berries are particularly rich in vitamin C and also contain significant amounts of vitamins A and E, as well as B-complex. The berries are an excellent source of essential fatty acids, including the rare omega-7 fatty acid, which is believed to support skin health and mucous membrane integrity. It has also garnered significant attention owing to its potential anticancer properties. The plant contains a rich array of bioactive compounds, including flavonoids like quercetin, carotenoids, and tocopherols, which have been associated with the induction of apoptosis in cancer cells and suppression of angiogenesis, which demonstrates promising antiproliferative and antitumor effects in assorted studies. However, its use as an anti-cancer agent requires further research elucidation for understanding its advantages over conventional cancer therapies. This review article unveils the unique nutritional composition of Seabuckthorn and its significance as a functional food, covering its potential applications in promoting overall health and addressing specific nutritional deficiencies.

Keywords: Anti-cancer activity; Functional foods; Health benefits; Phytochemicals; Nutritional properties; Sea buckthorn

1. INTRODUCTION

Hippophae rhamnoides L. is a flowering plant belonging to the family *Elaeagnaceae*. A deciduous plant with hardy woody morphology, synonymously recognised as Siberian apple, sand thorn, and sea berry, is indigenous to both Asia and Europe. Seabuckthorn (*Hippophae rhamnoides* L), recognised for its multifaceted therapeuticProperties have attracted significant interest from researchers, scientists, and nutritionists due to their exceptionally high concentration of bioactive compounds, including vitamins like A, C, E, K, and vitamin B complex, reducing oxidative stress, thus being explored as an antioxidant agent. Seabuckthorn's fruit, seed, and juice have been documented to include more than 190 bioactive nutrients[1]. The plant is also an excellent source of fatty acids like omega-3, 6, 9, and rare omega-7 fatty acid, which is believed to support skin health. In-vitro studies have demonstrated that palmitoleic acid in the tart berries of Seabuckthorn inhibits the growth of leukaemia cells in the body and regulates inflammation. The plant is also home to various mineral elements potassium, calcium, selenium, magnesium, phosphorus, iron, zinc, copper, etc, flavonoids like flavonols, flavanols, anthocyanins, quercetin, rutin, and isoquercetrin, carotenoids listing beta-carotene, lycopene, lutein, zeaxanthin that is instrumental in providing various health benefits like reducing the risk of chronic diseases such as cancers and age-related muscular degeneration[2]. Seabuckthorn leaves and berries are also a rich source of terpenes, tannins, organic acids, amino acids, and carbohydrates, causing the plant to have various antioxidant, anti-inflammatory, anti-cancerous, and great medicinal potential. The Seabuckthorn oil consists of various organic acids like citric acid, malic acid, and various amines like serine, cysteine, certain ceramides, squalene, and niacin[3]. The listed properties make the Seabuckthorn plant a promising dietary supplement. The plant phytochemicals dominate the function of the circulatory system by regulating the blood pressure levels, modulating the level of cholesterol in the body, and preventing atherosclerosis[3-4]. The plant also addresses a wide array of ailments related to the gastrointestinal segment of the body by reducing the inflammation of digestive tracts, healing ulcers, and regulating bowel movements. Because of its unique properties and promising results in various fields, Seabuckthorn has been sobriquet as a superfood with a myriad profile of beneficial compounds[5]. This evaluation comprehensively reviews the nutritional component, the bioactive compounds, and their applications in various pharmaceutical, dietary,

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paediatric, and other benefits of the Seabuckthorn plant by surveying and understanding the various literary sources available.

2. NUTRITIONAL COMPOSITION OF SEABUCKTHORN

2.1 Macronutrients

2.1.1 Carbohydrates

Carbohydrates are an essential component of Seabuckthorn berries, and their dry weight ranges from 400 to 600 grams per kilogram. The fresh berries are an excellent source of glucose, fructose, xylose, and a small concentration of sucrose, with glucose, fructose, and xylose being the dominating sugars. For human metabolism, the main source of energy is monosaccharides, while the building blocks of the body and the primary storage units are the polysaccharides[3]. An abundant amount of dietary fibre supplements is present in the berries, whose fraction is constituted by various polysaccharides like hemicellulose, cellulose, pectin, and hydrocolloids, which are instrumental in maintaining healthy human digestive health[6]. The dietary fibres hold crucial vitality as they aid in regulating glucose levels in the blood and foster a healthy gut microbiota. Yang also explored the sugar content in variegated subspecies of *Hippophae rhamnoides* L, including *mongolica, sinensis, and rhamnoides* that are being cultivated in China, Finland, and Russia. The study was carried out for four consecutive years. In the juices extracted from the Finnish fruits (subspecies: *rhamnoides)* and wild Chinese berries (subspecies: *sinensis*), the amalgamation of glucose and fructose amounts to 0.6g/100 ml.

2.1.2 Proteins

The protein content and amino acid profile are important criteria in classifying a food as a superfood. The Seabuckthorn pulp protein primarily consists of two proteins- albumin and globulin, and has a high concentration of nitrogenous compounds whose origin is non-proteinaceous[7]. Seabuckthorn fruit is known to contain eighteen out of the twenty amino acids known and their derivatives. These derivatives isolated from amino acids enhance the bone differentiation and promote the differentiation of mesenchymal stem cells into osteoblasts[8]. Essential amino acids

The amino acids present in the fruits include threonine, leucine, methionine, isoleucine, valine, tryptophan, and phenylalanine. Fig. 1 demonstrates the structure of essential amino acids. These amino acids are critical for various physiological processes in humans, such as protein synthesis, muscle growth, fat metabolism, neurotransmitter regulation, and cognitive functions. These amino acids contribute to crucial human processes like building muscle, energy production, and the loss of fat concentration, as well as provide vital control of our emotions and cognitive functions. Research portrays that the Seabuckthorn juice contains primarily nine organic acids, namely, quinic acid, L-malic acid, D-malic acid, succinic acid, pyruvic acid, tartaric acid, acetic acid, formic acid, and citric acid[9]. Experimentally, it is observed that distinct parts of the plant have different percentage compositions of amino acids. Seabuckthorn's berries, leaves and branches have the highest content of the aspartic acid and glutamic acid with concentrations of 1.11 and 1.24 % in fruits, 2.42 and 1.60 % in leaves and 3.71 and 0.97 % of these acids are present in the branches of the plant whereas tyrosine and glutamic acids have their highest proportions present in the seeds of the plant[10].

2.1.3 Lipids

Seabuckthorn berries have distinguishingly higher fatty acids and phytosterols content as compared to other macronutrients. These compounds play a significant role in maintaining human health by regulating skin metabolism, are instrumental in maintaining the mucus membrane, and Managing dry eye syndrome. Fatty acids are also important as they reduce the chance of cardiovascular diseases[11-12]. The plant boasts a fascinating lipid concentration with stearic acid and palmitic acid, both saturated. Among the monounsaturated fats are the palmitoleic and oleic acids. Interestingly, Seabuckthorn also houses the rare omega-7 fatty acid, which is believed to improve overall skin health

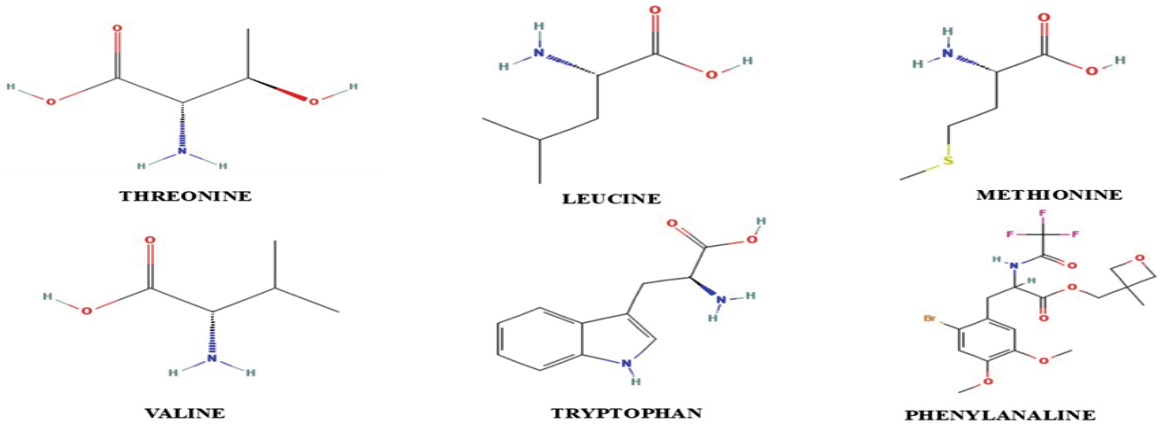

Figure 1. Molecular structures of essential amino acids found abundantly in Seabuckthorn *(Hippophae rhamnoides L.)* berries, including threonine, leucine, methionine, isoleucine, valine, tryptophan, and phenylalanine.

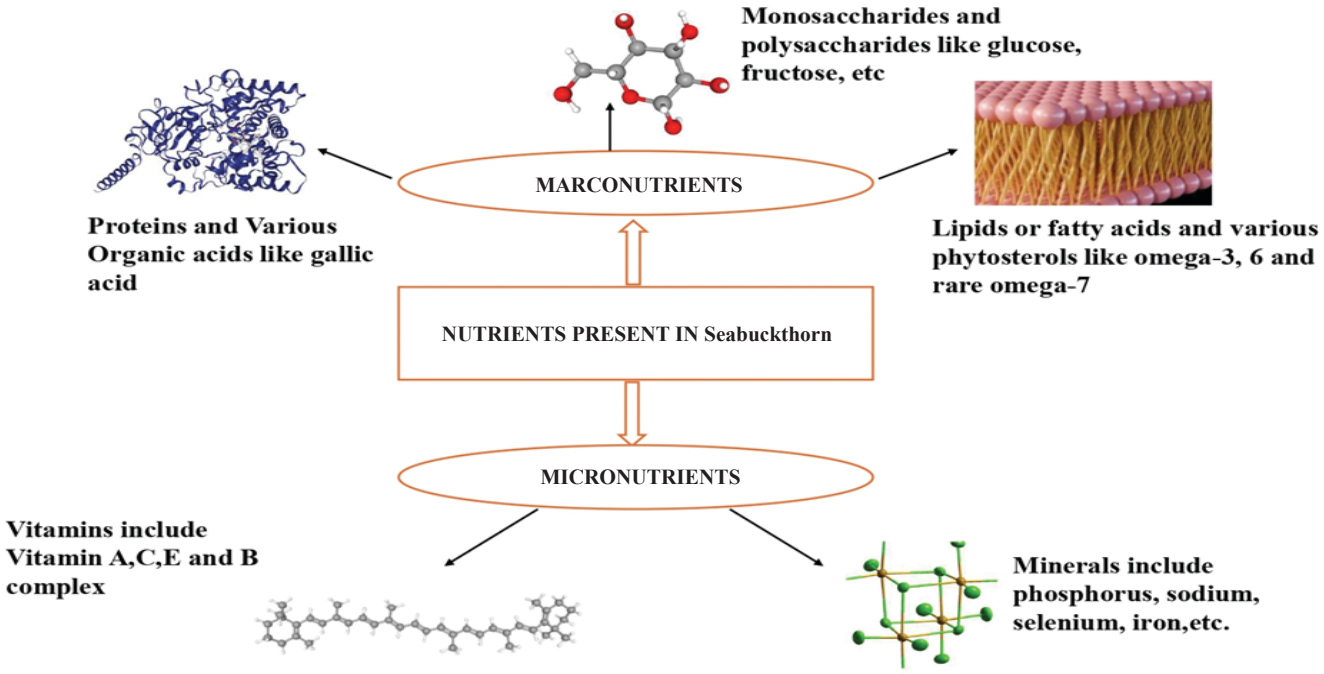

Figure 2. A comprehensive schematic representation of the macronutrients (carbohydrates, proteins, lipids) and micronutrients (vitamins, minerals) found in Seabuckthorn berries, seeds, leaves, and oil.

and is important for skin renewal and regeneration. Furthermore, the plant also has omega-6 and 3 fatty acids known as linoleic and alpha-linolenic acid[13]. It is evident that these organic acids increase the overall flexibility and plasticity of the blood vessels and have the potential to prevent the thickening and hardening of the blood vessels, which is also known as coronary atherosclerosis, and lower the blood pressure of the body[14-15] The Seabuckthorn oil also expresses an intricate ratio of 1:1 of omega-3 to omega-6 fatty acids, a well-balanced composition which is considered healthy for overall human health[6,16]. Phytosterols are natural compounds that are structurally similar to cholesterol, encompassing plant sterols and stanols. Seabuckthorn is a vast sea of phytosterols that may prevent cardiovascular diseases. The phytosterols are identified using bio-analytical techniques like Gas Chromatography in combination with Mass Spectroscopy by cold pressing the Seabuckthorn seed oil[17]. Sitosterol and Δ^5-avenasterol were quantitatively the most important phytosterols identified. The consumption of plant sterols or phytosterols is evident in reducing plasma cholesterol in the body, which is essential for the prevention, treatment, and healing of coronary heart disease and reducing overall cardiac inflammation. Fig. 2 summarises the nutrient groups of Seabuckthorn. It highlights key components such as essential fatty acids (omega-3, 6, 7, and 9), phytosterols, polyphenols, flavonoids, carotenoids, tocopherols, and tocotrienols. The balance and diversity of these nutrients contribute to Seabuckthorn's therapeutic properties, including cardiovascular support, skin regeneration, anti-inflammatory effects, and immune modulation.

2.2 Micronutrients

2.2.1 Vitamins

Popularly recognised as the "natural treasure trove of vitamins," Seabuckthorn is indisputably an excellent source of these micronutrients, including both fat-soluble vitamins (A, D, E, and K) and water-soluble vitamins (vitamin B complex and Vitamin C)[18]. The tart berries, leaves, and stems of these plants house vitamin C in much higher quantities than equivalent in mango, orange, apricot, banana, and peach. 100 g of Seabuckthorn berries contains 275mg of vitamin C (ascorbic acid), which is 27.7 mg that of mango, 10 mg of banana, 50 mg of orange, and 6.6 mg of peach[19]. The extraordinary concentration of vitamin C in the Seabuckthorn berries places them as an excellent source of antioxidants supporting immune functions, facilitating a boost of collagen in the skin, maintaining skin elasticity, and enhancing iron absorption in the body[20]. In addition to vitamin C, Seabuckthorn berries are also blessed with an abundant amount of Vitamin A in the form of carotenoids like beta-carotene and vitamin E in the form of tocopherols and tocotrienols. Vitamin K, which is instrumental in blood clotting and bone density regulation, is also found in Seabuckthorn berries. It is also crucial for post-translational modifications of proteins that are functional in blood coagulation/clotting[21]. Seabuckthorn also has significant amounts of vitamin B complex enlisting vitamin B1(thiamine) required for nerve function, B2 (riboflavin) important for optic health and skin elasticity, B3 (niacin) is required for the conversion of carbohydrates, alcohol and fats into

energy maintaining the overall digestive health, B6 (pyridoxine), B9 (folate) and vitamin B12 (cobalamin) which is required for energy metabolism[22-23]. Traces of vitamin D have been reported, though its functional significance in Seabuckthorn remains unclear. It is believed that vitamin D, along with vitamin K is maintains the normal bone function of the body. This vast range of vitamins present in the Seabuckthorn plant highlights the broader spectrum of health benefits, as these vitamins are involved in regulating normal body functions and overcoming numerous deficiencies[24].

2.2.2 Minerals

Seabuckthorn is a superfood, a nutritional powerhouse because of the wide array of mineral and trace elements that are present in the various parts of the plant, which are salient in the regulation of metabolic functions. Seabuckthorn is power-packed with various mineral elements like magnesium, phosphorus, zinc, sodium, potassium, copper, sodium, etc, which contribute to the overall nutritional benefits of the plant[25]. Among the list, the most abundant mineral element is potassium, which is present in the pulp of the berries at a concentration of 10.12-14.84 ppm and in the seeds at a range of 9.33-13.42 ppm[26]. The mineral content has significant differences at various stages of maturity in the Seabuckthorn fruit. The composition of these mineral elements is influenced by a varied range of parameters, including types of subspecies, plant parts, composition of the soil, area in which the plant is propagated, application of fertilisers over a stipulated time, seasons, and so on. The tracer elements, like selenium, are found to improve the circulation in small blood vessels (myocardial microcirculation). This activity of the heart is achieved by lowering the oxygen needs of the heart muscle and increasing its potential to withstand low low-oxygen environment[27-28].

3. PHYTOCHEMICALS IN SEABUCKTHORN

3.1 Flavonoids

Seabuckthorn has a long history in ancient Chinese and South-East Asian medicines because of the presence of various bioactive compounds that have made its use possible as a folk remedy. These substances are called flavonoids, which are a group of phytochemicals or plant-based chemicals popular for their antioxidant, anti-cancerous, anti-viral, and anti-inflammatory properties.[27] Seabuckthorn is a commendable natural source of more than ninety-five flavonoids, which exist in roots, stems, flowers, leaves, and berries of the plant. The ninety-five flavonoids are comprised of seventy-five flavanols, six catechins, one leucocyanidin, nine anthocyanidins, one proanthocyanidin, two dihydroflavones, and one chalcone[28]. The most abundant flavonoids found in the Seabuckthorn plant are isorhamnetin, kaempferol, white anthocyanin, epicatechin, myricetin, and quercetin. Flavonoids, including isorhamnetin, quercetin, and kaempferol, are known for their potent antioxidant, anti-inflammatory, and cardioprotective properties. Carotenoids such as beta-carotene, zeaxanthin, and lycopene are responsible for the vibrant orange hue of the berries and offer significant health benefits by acting as antioxidants, promoting skin and eye health, and reducing the risk of chronic diseases. Seabuckthorn flavanols are in the range of 463.1mg to 893.92 mg per 100-gram DM, constituting about 99 % of the total phenolic content of the plant, where their concentrations and levels are strongly influenced by the geographical factors[29]. Flavonoids, along with phenolic acids, are also collectively known as polyphenols. These polyphenols are responsible for the antioxidant properties of the Seabuckthorn plant. Seventeen phenolic acids occur in the berries of this plant, with salicylic acid (55-73.4 %) being of vital importance[30]. Salicylic acid helps in controlling the sebum production in the skin by clearing Skin pores and hence is the most important active

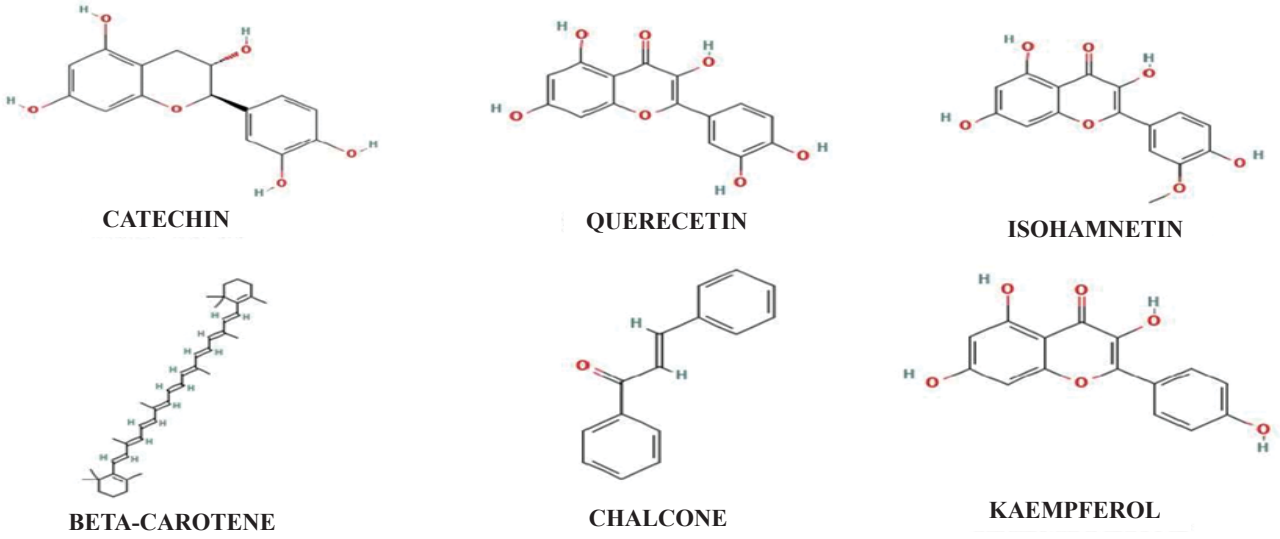

Figure 3. The chemical structures of prominent flavonoids and carotenoids isolated from Seabuckthorn.

ingredient for oily-acne prone skin. The concentration of phenolic acids is dominated by gallic acid composition. These polyphenols are an active ingredient in herbal medicines for the treatment of cardiovascular diseases; their work is to reduce the permeability of the capillaries and enhance their flexibility, and they are also employed in the prevention and improvement of angina pectoris, overall improving the cardiac functions[31]. The flavonoids, especially, reduce the cholesterol and triglyceride levels in the blood and are also believed to purify the blood of toxic substances and old and dead cells.

3.2 Carotenoids

Carotenoids are richly coloured substances naturally synthesised by plants, algae, bacteria that can perform photosynthesis, archaea, and fungi, providing vibrant pigments of red, orange, and yellow colour to pumpkins, carrots, corn, tomatoes, and many other arthropods like lobsters and shrimps etc. These compounds are a family of six hundred fat-soluble components, and the typical orange colour of the Seabuckthorn berries is the artistic fill of these carotenoids. Carotenoids can be discreetly categorised into main groups: the carotenes, having alpha, beta, and gamma as the three prominent isomers, and the xanthophylls. The carotenes are pure hydrocarbons, whereas the oxygen-containing functional groups are attached to the hydrocarbon chain in the xanthophylls. The beta-carotene is the precursor of vitamin A (retinol) in the human body, and this conversion of beta-carotene to vitamin A is essential as it aids in improving vision and provides protection against muscular degeneration[32]. The carotenoids usually act as strong antioxidant agents and may reduce the risk of several diseases, like cancer and cardiovascular disorders. They are also responsible for collagen synthesis, boosting the immune system response, and epithelialization in the body[33]. The governing carotenoid in the Seabuckthorn nutritional profile is beta-carotene. The beta-carotene concentration is 15-55 % in the berries, and the rest is present in the pulp, juice, and seed oil[34]. These carotenoids capture the free radicals that cause damage to the cells and hence lower the overall oxidative stress in the body. They also provide electrons to these free radicals for stabilising them and preventing them from further damaging the cell membrane. The alcoholic extract isolated from the dried Seabuckthorn berries is a more powerful antioxidant agent as compared to 2,6-di-tert-butyl-phydroxytoluene (BHT) and tert-butyl-hydroxyanisole (BHA), which are the standard antioxidants[35]. But it is important to understand that the antioxidant activity of the Seabuckthorn is not solely dependent on the carotenoids, but is also a contribution from other polyphenolic compounds, which also enhance the overall activity. Other carotenoids include zeaxanthin, a xanthophyll which is present in the oil of the berries[36], the Seabuckthorn leaves and berries contain lycopene, which reduces the risk of cancers, and lutein, known as "the eye vitamin", prevents or improves age-related muscular and optic problems[37]. Fig. 3 portrays the structures of the dominating flavanols and carotenoids.

3.3 Tocopherols and Tocotrienols

Vitamin E is a fat-soluble vitamin and can be stored in the body so that it does not have to be consumed daily. These vitamin E compounds are collectively called chromon-6-ols or tocochromanols, which are made up of tocopherols and tocotrienols[38]. Sources which are abundantly blessed with tocopherols and tocotrienols include soyabean, cheese, nuts and nut oils, oat meals, avocado, green leafy vegetables, olives, sunflower, corn, barley, and rice bran where tocopherols are dominant in olives, sunflower and soyabean oil and tocotrienols are present in palm oil and rice bran[39-40]. The difference lies in the structure of these antioxidant compounds; tocopherols come with a saturated phytyl chain, whereas tocotrienols have an unsaturated isoprenoid side chain with three double bonds. A study was formulated by Staffan C. Andersson[34] and team, which investigated the composition of tocopherols and tocotrienols in the four cultivars of Seabuckthorn over three years. The results of this study successfully concluded that Seabuckthorn berries have an abundant number of tocopherols and tocotrienols. These compounds are made an essential part of the diet for patients suffering from Alzheimer's[41]. Studies have also shown that tocotrienols have a higher capability of lowering the cholesterol levels and suppressing the growth of tumours[42]. The Seabuckthorn oil is a rich source of tocopherols and tocotrienols[38] and is responsible for inhibiting the enzyme action involved in the process of inflammation, reducing the conditions in case of Alzheimer's disease or other critical ailments.

4. POTENTIAL HEALTH BENEFITS

Seabuckthorn with its wide array of macronutrients like carbohydrates, proteins and lipids, a broad spectrum of micronutrients like vitamins and minerals and a numerous bioactive compounds like carotenoids, polyphenols, phytosterols, tocopherols and tocotrienols making it one of the most promising natural resources which may be employed for the treatment of various health conditions like cardiovascular disorders, exerting antioxidant and anti-inflammatory properties, provision of immune system support, anti-cancerous and anti-diabetic support as well as hepatoprotective and neuroprotective abilities.

4.1 Antioxidant and Anti-Inflammatory Properties

Seabuckthorn has been extensively exploited for its antioxidant properties. The phenolic composition of this hardy woody shrub has portrayed commendable antioxidant activity by scavenging or inhibiting hydrogen peroxide (H_2O_2) or H_2O_2/Fe, which causes the breakdown of the fat molecules (lipid peroxidation) and causes modifications in the structures of proteins, which is called protein

carbonylation. The protein modifications or carbonylation are important indicators of oxidative stress in the body. The phenolic content of the Seabuckthorn plant has notably caused the reduction of this protein carbonylation into plasma proteins, with an appreciable 60 % inhibition rate of plasma lipid peroxidation demonstrated at a concentration of 50µg/ml for 1 hour[3]. At 500mg/L, an alcoholic extract isolated from the Seabuckthorn leaves prevents the formation of chromium-based radicals, cell death, or apoptosis, and helps return the antioxidant levels in the body to normal[43]. Ursolic acid and oleanolic acid present in the peel extract of the Seabuckthorn are confirmed in stabilising cell membranes by inhibiting the degranulation of mast cells. Anti-inflammatory action of Seabuckthorn may also be attributed to hindering the mechanism of action of interleukins or pro-inflammatory cytokines[44], but an overall in vivo assessment and clinical studies are required for the further success of the process.

4.2 Cardiovascular Health

Every year, 23 million people nearly face death due to cardiovascular conditions.[43] Cardiovascular conditions are cardiac and blood vessel defects that include two risk factors: hyperlipidaemia and hypercholesterolaemia, along with other conditions like coronary artery disease, coronary heart disease, stroke, myocardial infarction, atherosclerosis, peripheral artery disease, and arrhythmia. Flavonoids like quercetin, isoquercetin, catechin, and isorhamnetin are polyphenols[12] present in Seabuckthorn fruits and leaves that aid in the treatment of cardiovascular ailments and lower the risk of diseases, and show anti-hyperlipidaemic effects. The mechanism of the hypocholesterolaemic effect of phytosterols is conducted by blocking the reabsorption of cholesterol in the body and thereby increasing its elimination as neutral steroidal compounds. An experimental setup showed that the Seabuckthorn fruit oil extract caused dysfunction in hamsters with hyperlipidaemia, overall improving the blood-fat levels in the hamsters, relieving the oxidative stress, and resulting in better hepatoprotective function of the rodent commonly through the AMP-Activated Protein Kinase (AMPK) and Akt pathways[45]. The flavonoids present in the Seabuckthorn seeds have an overall hypolipidemic and hypoglycaemic effect, reducing the cholesterol levels in the blood serum and liver.

4.3 Dermatological Benefits

Skin is the largest organ of our body, and many times mastering a perfect skin care routine and using the right ingredients becomes a hassle for all of us. Seabuckthorn is a vast natural reservoir of many active compounds like vitamins, minerals, polyphenols, etc, that contribute to its extensive use in skin science. The vitamin B complex present in the berries of the Seabuckthorn plant is believed to enhance skin elasticity. The Seabuckthorn oil is rich in several organic acids like citric acid, malic acid, and various amines like serine, cysteine, certain ceramides, squalene, and niacin that help in maintaining skin elasticity and overall skin health by controlling hyperpigmentation and reducing the inflammation and puffiness of the underlying skin cells. Traditionally, Seabuckthorn has been exploited for its use in skin healing and skin regeneration. Seabuckthorn oil and fruits contain a huge amount of unsaturated fatty acids like omega-3 and 6, polyphenols, and several vitamins that make it a promising ingredient in skin cell membrane regeneration. Palmitoleic acid is one such component that is instrumental in burn treatment and wound healing. A random triple-blind clinical trials were conducted Fig. 4. This figure depicts the protective mechanism of Seabuckthorn oil and extracts when administered orally or topically, reducing the damage caused by ultraviolet

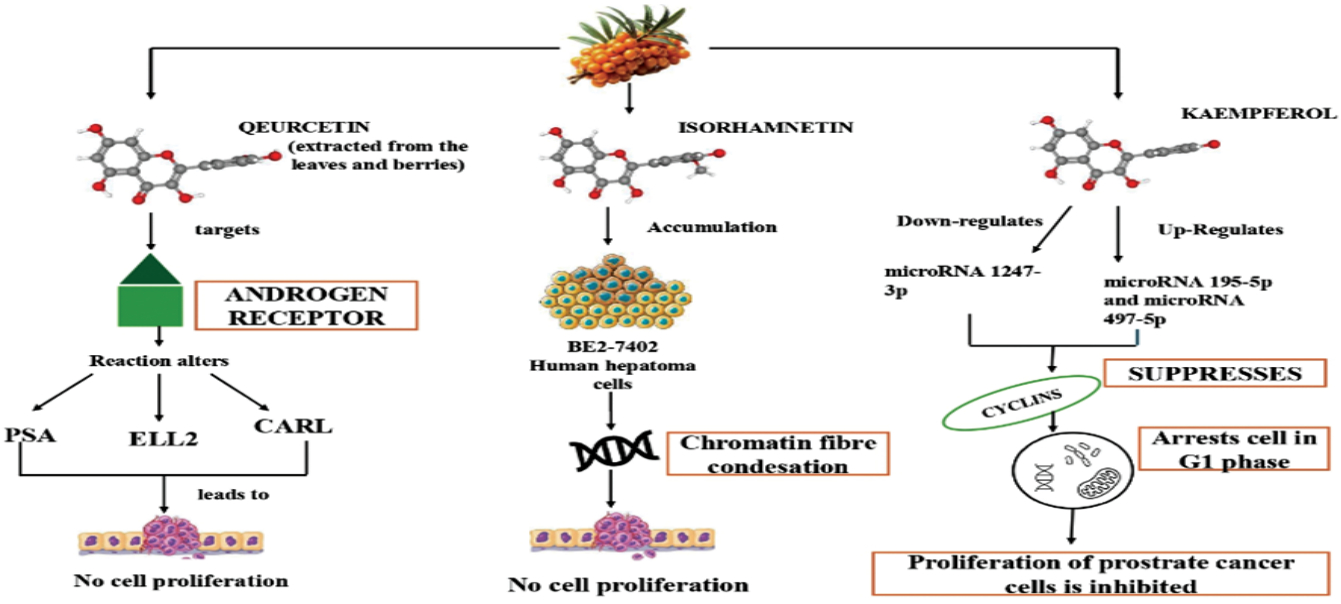

Figure 4. Action mechanism of flavonoids of Seabuckthorn.

(UV) radiation on keratinocytes. Seabuckthorn's bioactive compounds, including palmitoleic acid, carotenoids, and tocopherols, enhance the skin's redox balance, prevent lipid peroxidation, and promote cell membrane stability. These actions contribute to the prevention of photoaging, reduction of skin inflammation, and support of keratinocyte health, showcasing Seabuckthorn's potential as a natural photoprotective and skin-regenerative agentWith second-degree burn patients. Results from the trials showed that patients who were treated with 40 % Seabuckthorn cream were healed five days earlier compared to those patients who were treated with sulfadiazine bandages[46]. The wound healing ability of the Seabuckthorn oil is a gift of compounds like carotenoids, tocopherols, omega-3, and omega-6 fatty acids[47] Ultraviolet radiations from the sun cause impairment in the redox system of the cell and harms the keratin-forming mechanism. The oral administration of Seabuckthorn in the form of tablets or even oil reduces this lipid metabolism impairment and protects the keratin-forming cells, thus it may be attenuated as a promising photo-protection ingredient.

4.4 Anti-Cancer Activity of Seabuckthorn

Researchers and medical professionals are producing ways and techniques to cure cancer with minimal physiological damage to the patient, and one such technique is the employment of the bioactive compounds from the natural reservoir, Seabuckthorn. The polyphenols of the Seabuckthorn plant, especially kaempferol, have the potential to fight the colon cancer both in living organisms (in vivo system) and in laboratory settings (in vitro system). This anti-cancer activity is achieved by upregulating and downregulating the expression of certain microRNAs, miR195-5p and miR497-5p, and miR1247-3p, respectively. The polyphenols suppress the cyclins expression, hence arresting the cell cycle in the G1 phase or the Growth Phase-1, thereby controlling the proliferation of the colon cancer.[46,48] In-vitro (lab studies) have shown that the extract from the Seabuckthorn leaves is capable of effectively targeting the androgen receptor, altering the activity of the androgen receptor genes and other similar compounds like the Prostate Specific Antigen (PSA), Eleven-nineteen Lysine rich Leukaemia 2 (ELL2), and calreticulin (CARL)[49-50]. These facts back the argument that the Seabuckthorn leaf extract has the potential to slow down the regulation, growth, and proliferation of prostate cancer Fig. 2. An experiment was performed on the MDA-MB-231 breast cancer cells. Wang[51], *et al* showed that the seeds of the Seabuckthorn plant have a commendable concentration of procyanidins, which inhibited the activity of fatty acid synthetase enzyme; a biocatalyst required for the synthesis of the long chain of fatty acids, which are found in cancer cells. The seed extract at a concentration of 0.087µg/ml inhibited 50 % of FAS activity. The authors suggested that the procyanidins extracted from the seeds of the Seabuckthorn can cause cell apoptosis or cell death, which is related to the amount of dose given for the treatment, which is achieved by the inhibition of the intracellular activity of FAS[52]. Various animal models have been employed to study the Seabuckthorn's activity and potential on cancer cells in living systems (in vivo trials). Another study highlighted the possibility that the Seabuckthorn fruits have anti-cancer properties. The study revealed that they hindered the development of skin papilloma (tumours), which is caused by dimethylobenzeno anthracene in mice[53]. A clinical trial also showed that the ethanol extracted from the Seabuckthorn berries, when tested against acute myeloid leukaemia cells at a concentration of 25, 50, and 100µg/ml, showed anti-proliferative activity. However, only a few numbers of clinical trials and literature are available on the anti-cancer potential of the phenolic compounds of the Seabuckthorn, and almost no sources on the activities of the carotenoids are cited. Therefore, this field is a developing research area concerning the prospects.

4.5 Diabetic Control of Seabuckthorn

Diabetes is a chronic condition, about certain dysfunctional aspects of the endocrine system, which prevents the proper synthesis and utilisation of insulin in the body, leading to higher concentrations of glucose in the blood. Much scientific research has been performed to explore the potential of Seabuckthorn as a treatment for diabetes. Seabuckthorn pulp oil has anti-diabetic activity on the islets of Langerhans of the human body. The palmitoleic acid present in the pulp oil of Seabuckthorn activates the G-protein receptor in the beta-cells of the pancreas, which enhances the efficacy of the insulin produced by glucose stimulation. Xylitol is a compound extracted from Seabuckthorn berries and is an excellent dietary supplement for people with diabetes. Positive impacts of Seabuckthorn may also be enhanced in combination with other berries. Case studies have shown that when children who were suffering from type 1 diabetes were fed blueberries and Seabuckthorn concentrate formulations together, there was an improvement in overall blood sugar and lipid levels of these children. Seabuckthorn also demonstrates a potential of lowering hypoglycemia, hypertriglyceridemia, and thus may prevent diabetic complications associated with hyperlipidaemia and oxidative stress[54].

4.6 Neuroprotective Action of *Hippophae rhamnoides* L

Neuroprotective ability is a combination of two words: neuro and protection, which simply translates into the ability to protect the brain and the nervous system from any disorder or damage. Seabuckthorn, with its various bioactive compounds and phytochemicals, can improve brain functions in diverse ways and hence can be used as a remedy for neurodysfunction. This is done by scavenging the free radicals that increase the oxidative stress and cause damage to the brain cells. Seabuckthorn can also hinder the activity of acetylcholinesterase (AChE) enzyme

and monoamine oxidase enzyme, which can degrade neurotransmitters like acetylcholine and serotonin, thereby disrupting normal body function.[55] These neurotransmitters regulate the art of memory, learning, cognition, and mood. Another brain disorder includes Alzheimer's. Alzheimer's is the most prevalent form of dementia that reduces cognitive abilities, interfering with the person's day-to-day activities[56]. It is a neurodegenerative disorder that occurs due to critical histopathological changes, including which extracellular amyloid. Seabuckthorn powder is most prevalent at 1.5g/ml concentration, and removes these deposits because of the antioxidants present in the powder. These antioxidants prevent apoptosis by exerting a neuroprotective activity[46]. The plant is also capable of improving epileptiform activity (seizure-like activity) in the brain's cerebral cortex and hippocampus, which is a sea-horse shaped structure in the brain in rats when they are suffering from iron-induced epilepsy and showed signs of reduced anxiety behaviour, improved memory impairment, and histological damage in these tiny creatures[57]. All these mechanisms are a result of flavonoids and other compounds present in the plant, but do not guarantee the same results in humans and require significant clinical trials for their applications.

5. SEABUCKTHORN AS FUNCTIONAL FOODS

The bioactive compounds present in *Hippophae rhamnoides L* make it a perfect candidate to be exploited as functional foods. This plant is being employed in food products in the current scenario as an antioxidant, antimicrobial, and as a food additive. Consequently, a variety of Seabuckthorn foods have been created at the global level, which have better taste and texture, have increased shelf life, and guarantee a year-round supply of the products even when they are out of season. The currently explored areas of Seabuckthorn food include its application as a food additive, as alcoholic beverages, fermented Seabuckthorn foods, and Seabuckthorn tea, which is prepared by making a decoction of the Seabuckthorn leaves and Seabuckthorn oil.

5.1 Food Additives

The Seabuckthorn plant has been gifted with the ability to provide natural pigment and preservation to the food. The fruit has abundant yellow pigment because of the carotenoids, specifically beta-carotene and flavonoids, so present. These have been added to the vegetable cream, ice creams, candies, and other confectionery items. The meat processing industry is currently looking for ways to incorporate natural preservatives and tenderising agents. Kozhakhiyeva M demonstrated that on adding 5 % of Seabuckthorn powder to Jaya, a cooked and smoked horse meat, its bioactive content and functionality were enhanced. The sample showed that the lysis of the lipid molecules in the meat was reduced by 38 %, and the lipid hydroperoxides were reduced by 24 % after storing after 21 days. By the addition of the leaf powder of the Seabuckthorn, the reducing ability of white wine has been increased from 33.1 to 62.1 %[58]. This powder was also capable of skyrocketing the phenolic content from 11 to 23.7 % and increased the colour intensity of the wine from 39.9 to 57 %, which has increased the overall antioxidant property of the wine without the addition of sulphates[59]. Studies have been evident in showing that Seabuckthorn juice may also be added to the chewing gum for enhancing flavours, it is also used to purify the enzyme chitinase by utilising its action on the antifreeze protein HrCHI4 resulting in the preservation of integrity and freshness of the green pea membrane by retaining the volatile compounds therefore broadening our understanding of the edible food preservatives[60].

5.2 Seabuckthorn as an Alcoholic Beverage

People's awareness has changed the idea and perception of drinking and is not only restricted to alcoholic beverages but now has a broader horizon with the addition of healthy and flavourful components. Alcoholic beverages prepared from Seabuckthorn have a low alcohol content and are prepared by crushing, squeezing, filtering, fermenting, and soaking the Seabuckthorn fruits or berries. The beverage so prepared is highly enriched with organic acids, has a high number of esters with low alcohol content, and extraordinarily rich and diverse flavours, and is also regarded as "royal wine"[61]. The only drawback is the advent of the geographical conditions, which allow only a few countries to enjoy this magic, like western

Table 1. Types of fermented Seabuckthorn foods, their ingredients, methods of preparation, and place of origin

Types of fermented foods	Ingredients and methods of preparation	Place of origin	Cited grom
Seabuckthorn wine	Water, *Saccharomyces cerevisiae,* alcohol, and Seabuckthorn	Shanxi, China	Li[62]
Sparkling wine formulated with Seabuckthorn	Juice from Seabuckthorn, yeast, honey, $NaHSO_3$, water	Sichuan, China	Zhang[63], *et al*
Wolberry, red dates, and Sea Buckthorn fruit wine	Seabuckthorn, red dates, wolfberry, sulphite, gelatine, yeast sugar extract, bentonite, and water	Xinjiang, China	Mu[64], *et al*
Seabuckthorn beer	Formaldehyde, barley, lactic acid, H_3PO_4, and Seabuckthorn extract	Inner Mongolia, China	Ji & Chui[65]
Grape mixed with Sea Buckthorn wine	Grape juice, Seabuckthorn juice, and water	Gansu, China	Mi[66], *et al*

and northern China, Mongolia, and Russia. With the advancement in the brewery and wine industry, the traditional Seabuckthorn single fruit wine has witnessed an evolution and now is a multi-fruit blended wine with better taste and flavours, resulting in the exploration of a wide horizon of the blended fruits[62]. Table 1 highlights the common Seabuckthorn beverages.

5.3 Fermented Seabuckthorn Foods

Processing any berry plant leads to unavoidable waste generation, and so is the case with the Seabuckthorn berries. Processing of the berries of this plant generates a significant amount of waste, whose improper disposal leads to environmental pollution. The fermentation process uses this waste as a substrate and, under optimal conditions, generates 3 % ethanolic fermented beverages of the Seabuckthorn plant. This beverage holds elevated levels of phenolic compounds, namely gallic acid and vanillic acid, which have high antioxidant activity, and low levels of ethanol, making this drink a highly functional and healthy one[67]. Other fermented foods derived from Seabuckthorn include yogurt, vinegar, fermented soya bean milk, and fermented probiotics. The probiotics present in the Seabuckthorn also catalyse the activity of the intestinal juices, thereby enhancing the digestion of the food present in the intestines.[61] Seabuckthorn yogurt is becoming increasingly popular in the dairy industry because of its highly nutritious benefits. Seabuckthorn yogurt is developed from Seabuckthorn berries and is fabulously rich in proteins, fats, carbohydrates, and other antioxidants, including vitamin C and E, various phenolic acids, providing people with their exact nutrient needs. This yogurt has a shelf life of 12 days when stored at 4 ℃, and by increasing the temperature to 15 ℃, it can be stored for three days without any reduction in its microbial activity. Seabuckthorn vinegar is an acidic relish fermented with fruits and dry fruits as the main ingredients. The secretion of organic acid from this fruity vinegar promotes the secretion of digestive juices and helps in the quick absorption of food and nutrient material by the human body[68].

6. CONCLUSION

Sophisticatedly composite plant, Seabuckthorn plant is a highly assorted natural resource that contains innumerable benefits. Native to China and the Himalayan regions of Nepal and India, this plant has been exploited for its vast reservoir of compounds since time immemorial. The leaves, fruits, berries and seeds of this hardy, woody deciduous tree are employed in various fields like medicine, food industry, cosmetology, etc, by penetrating its roots into various other industries. With two hundred bioactive compounds and clinical trials for over 5 years, Seabuckthorn has stood out as one of the most useful plants to humans. This wide spectrum of compounds provides treatment or prevention for various conditions like cardiovascular disease, neural disabilities, diabetes, several types of cancers, and dermatological benefits. With an excellent amino acid profile, the only plant source to have rare omega-7 fatty acid, it helps to lower the levels of cholesterol in the body, maintaining a healthy heart condition, and keeping inflammation in check. The antioxidant, antitumour, skin healing properties, cardiovascular regulations, and immunomodulatory effects make Seabuckthorn a highly valuable plant, which has painted a picture of high economic importance and is crucial for ecological impacts. These nutrients from fruits, seeds, and leaves can be commercialised and marketed strategically to extract maximum results. There is tremendous literature, surveys, and studies that are showing the importance of the plant in various sectors, thus proving an undoubtedly bright future for the plant.

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