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Seabuckthorn *Hippophae rhamnoides*: A Miracle Shrub to Combat Environmental Shift

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ABSTRACT

A native of northwest Europe and central Asia, including the northern Himalayas and portions of China, Seabuckthorn (*Hippophae rhamnoides*) is a member of the Elaeagnaceae family. Seabuckthorn is a plant that grows well in arid, cold areas; its components, fruit, and leaves are utilised in traditional Asian medicine. Seabuckthorn, which is well-known for its nutrient-dense, tasty berries, has a wide range of bioactive substances, such as polyphenols like flavonoids, phenolic acids, tannins, fatty acids, vitamins, and phytosterols, which support its culinary, cosmetic, and therapeutic applications. The plant is highly valued in traditional medicine, offering a wide range of health benefits having rich antioxidant properties and stress-relief. Seabuckthorn is highly included in daily diets for preventing diet-related diseases. It is especially advantageous for land reclamation and reforestation in vulnerable mountain regions because of its capacity to stop soil erosion, encourage nitrogen fixation, and enhance soil fertility. Seabuckthorn is perfect for agroforestry in climate-vulnerable areas since it grows well in harsh environments.It aids in carbon capture and boosts resilience to climate change. Despite global expansion, improved varieties with higher yields, disease resistance, and enhanced medicinal and culinary traits are still needed for broader, more effective cultivation. The current review describes nutritional, medicinal, and ecological significance of Seabuckthorn (*Hippophae rhamnoides*) as a factor in health, soil fertility, and climate stability. It also expounded and stressed why better varieties were necessary to promote sustainable cultivation.

Keywords: Himalayan ecosystem; Seabuckthorn; Phytochemical; Soil conservation; Ecosystem; Soil fertility

1. INTRODUCTION

The hardy deciduous shrub known as Seabuckthorn (*Hippophae rhamnoides L.*) is valued for its vivid yellow to orange berries. For millennia, people in Europe and Asia have prized it for its nutritional and therapeutic qualities.[1] Seabuckthorn leaves were fed to horses in ancient Greece to increase their weight and give them glossy coats, thus the plant's Latin name, *Hippophae*, which means "shiny horse". Seabuckthorn, which is native to temperate regions between latitudes 27 °N and 69 °N and longitudes 70 °W and 122 °E, is found throughout many nations, including China, Mongolia, Russia, and many European countries, including the UK, France, Germany, and Scandinavia.[2] It thrives in a range of harsh climates and soils, enduring temperatures from -43 °C to 40 °C, and altitudes up to 3,900 meters-though it typically fruits best between 1,200 to 2,000 meters[1,3]. Despite being drought-resistant, Seabuckthorn naturally grows in areas with 400–600 mm of annual rainfall. Seabuckthorn was first introduced to Canada from Russia in 1938, initially for ornamental purposes[4]. However, it later gained attention for conservation efforts in Saskatchewan and Manitoba. Over the years, it has been planted widely to protect wildlife habitats, prevent soil erosion, and reclaim degraded land. Canada alone has distributed over a million seedlings, with more than 250,000 mature fruit-bearing plants currently growing on the prairies[3,5].

Economically, Seabuckthorn holds great promise. Wild varieties yield between 750–1,500 kg of berries per hectare, while cultivated orchards can produce up to 10 tons per hectare. The berries are very nutrient-dense, high in carotenoids, flavonoids, essential oils, and vitamins C and E (up to 600 mg and 160 mg per 100 g, respectively)[6]. These substances have several health advantages, such as immune-stimulating, antioxidant, and maybe anti-cancer effects. Because of its quick growth and nitrogen-fixing root nodules, Seabuckthorn is a significant ecological factor in soil conservation and reforestation in China. The fruit, often referred to as a "third-generation fruit," is processed into juice,

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marmalade, and oil, and used in both the food and cosmetic industries[7]. The plant has a long-standing role in traditional medicine. Ancient Greeks, Tibetans, and Mongolians used it to treat ailments ranging from respiratory to digestive disorders. Today, over 20 countries actively cultivate and study Seabuckthorn. It was even recognised by the World Health Organisation as one of the top ten most valuable health product raw materials. There are over 150 identified species, subspecies, and varieties of Seabuckthorn across Eurasia, with *Hippophae rhamnoides* being the most widespread in Europe[8]. It depends on the wind for pollination and is dioecious, meaning that its male and female plants are distinct. It is extremely versatile due to its ability to withstand harsh temperatures and poor soils, but it may also become invasive in some low-humidity settings[9].

Depending on growing conditions, each plant can yield between 2-12 kg of fruit annually, with regions like Novosibirsk and northern China achieving the highest outputs[10]. However, in arid regions of China, many introduced varieties struggle due to environmental stress. Seabuckthorns' worldwide distribution, their climatic adaptability, and significance to ecology have also been explained through Fig. 1. Beyond the fruit, bioactive substances such as flavonoids, triterpenes, steroids, and polysaccharides are present in every part of the plant, including the leaves, bark, roots, and even processing leftovers[11]. Numerous health which have advantages, like protection on the liver, antiviral, anti-inflammatory, anti-diabetic, antioxidant, and even anti-radiation. have been related to these, properties substances. Notably, Russian scientists have found Seabuckthorn effective in shielding the human body from cosmic radiation[12]. With a growing range of food, cosmetic, and nutraceutical products being developed, Seabuckthorn has emerged as both a valuable ecological asset and a thriving industry, promising benefits for both health and the environment[13].

2. HISTORICAL BACKGROUND

Seabuckthorn (*Hippophae rhamnoides). L.*), a plant of an evolutionary line. covering some 200 million years, takes a high rank in both ancient natural history and folklore medicine[14]. Fossil records and botanical records. suggest that this tough shrub is endowed with. outlived radical environment. Through millennia, there was adaptation to some of the. toughest weather of the world. Eurasian continent. The first example of the use of Seabuckthorn appears in ancient Greece[4,15]. The genus name Hippophae, meaning shining horse, is based on the historic use of the plant to feed horses. The ancient Greek horse breeders observed that the inclusion of Seabuckthorn leaves in horse feed resulted in increased weight and a lustrous coat in horses. This ancient discovery of the plant's health-enhancing 16 properties highlights its adaptogenic and nutritious content. Seabuckthorn was employed in ancient Tibetan medicine as an extremely effective treatment material since the 8th century AD. It was known as a "holy fruit" in the ancient literature and employed to cure respiratory ailments, gastrointestinal disease, dermatological conditions, and general debility. It was given sacred status in the medicinal cultures of Tibet because of its general spectrum of effectiveness. It was also in Mongolia that the plant was subsequently considered a 12th-century sacred botanical resource. It was extensively used in medical practices and was eaten for health reasons. Referred to as "the emperor's fruit," it symbolised vitality and longevity[17].

In China, the traditional pharmacopoeia recognised Seabuckthorn for its ability to harmonize vital bodily functions. Practitioners prescribed its berries and leaves to alleviate coughs, improve digestion, enhance peripheral circulation, and treat various dermal conditions[18.] Its continued cultivation in the Himalayas-particularly in regions of Nepal and northern India-speaks to its

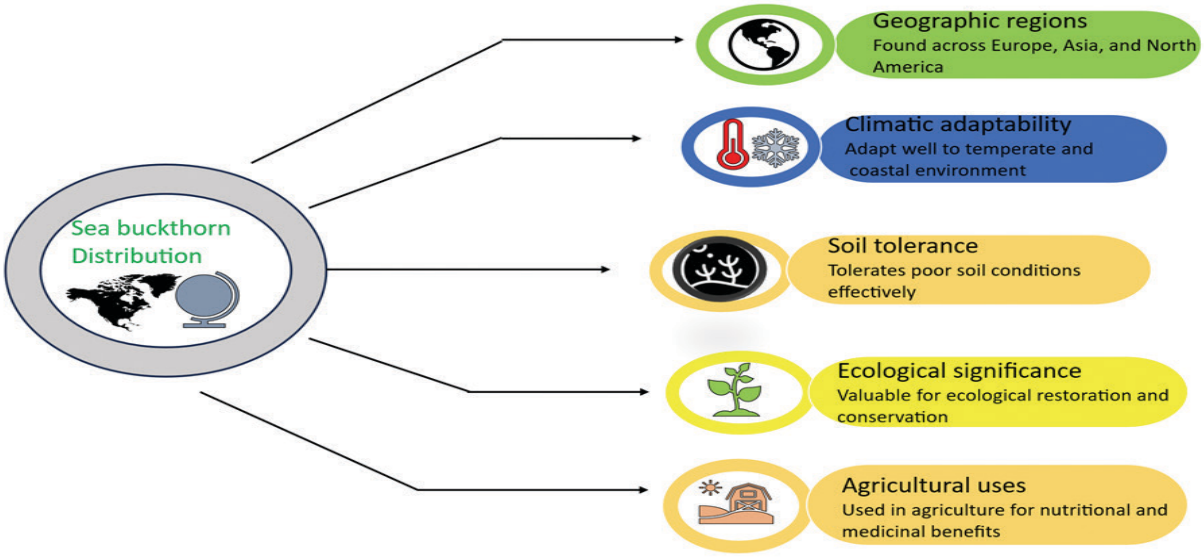

Figure 1. The Figure illustrates the global impact of Seabuckthorn, which highlights its agricultural uses, ecological significance, soil tolerance, geographical regions where it is mostly found, and climatic adaptability worldwide.

enduring therapeutic relevance. Even today, communities across the Tibetan Plateau and adjacent high-altitude ecosystems rely on Seabuckthorn for its restorative, anti-inflammatory, and immunomodulatory properties[19]. Collectively, these historical accounts not only highlight the plant's longstanding ethnomedicinal value but also form the foundation for the modern scientific exploration of Seabuckthorn's pharmacological potential[20-21].

3. BOTANICAL DESCRIPTION AND TAXONOMY

The Seabuckthorn (*Hippophae rhamnoides* L.), a resistant deciduous shrub or small tree that belongs to the genus *Hippophae* and family Elaeagnaceae, is well-known for its ecological flexibility and endurance. Though some wild or farmed specimens have been known to grow up to 18 meters in ideal circumstances, it usually reaches a height of 1 to 8 meters[22]. Seabuckthorn has recognisable and distinctive leaves. Its narrowly lanceolate or linear leaves are usually less than 7 millimetres wide and range in length from 3 to 8 cm. The upper surface of the leaves presents a dark grayish-green hue, while the underside is coated with a characteristic silvery-white sheen, giving the plant a shimmering appearance when viewed in sunlight. The plant bears small, vibrant fruits that are generally spherical to slightly oblate in shape, with diameters averaging between 5 to 8 millimetres[23]. These berries often bunch close together in the limbs, producing thick fruiting aggregates. The fruit colour is a bright orange yellow to a reddish-brown of a deep colour, and the surface. texture is mildly wrinkled. The fruit pulp is so soft and oily, and tastes tart. flavour demonstrating its abundant vitamin and nutrient content.

Then inside the fruit are sharp, shiny. seeds. Each seed is approximately 42 millimetres wide and long 1 mm. and is obliquely ovate in form. The Seed coat brown, smooth, and has a. large longitudinal groove along the. midline. The seed kernel is a creamy one indoors. colour of white and is covered with durable. outer shell. This unique morphological structure, and together with its rich. leads to, phytochemical composition. The pre-eminence of Seabuckthorn in both. conservation of the environment and nutraceutical. applications[24]. It is a highly adaptable and hard species that also makes it an ideal species. growing in varied soils and climates. types, especially in cold and arid, and nutrient-poor regions. The pruning spread of Seabuckthorn is a good way to yield plants which inherit the good features of the parent. The flowchart of fig. 2 pertains to the pruning growth of Seabuckthorn.

4. PHYTOCHEMICAL COMPOSITION

4.1 Lipids and Fatty Acids

Seabuckthorn berries contain lipids in high concentration, which are found in seeds as well as in fruit pulp. Both the essential omega-6 fatty acid linoleic acid and omega-3 fatty acid alpha-linolenic acid are rich beyond measure in the oil of the seed[25]. These fatty acids play a pivotal role in cell structural function, metabolic process, as well as regulation of inflammation. In addition to the more familiar omega-3 and omega-6 fatty acids, Seabuckthorn pulp oil also has the less common omega-7 fatty acid palmitoleic acid. Palmitoleic acid is associated with a variety of positive health impacts, especially in dermatology, wound recovery, and anti-inflammatory potential. The precise composition of Seabuckthorn oil will be a function of various variables, including which

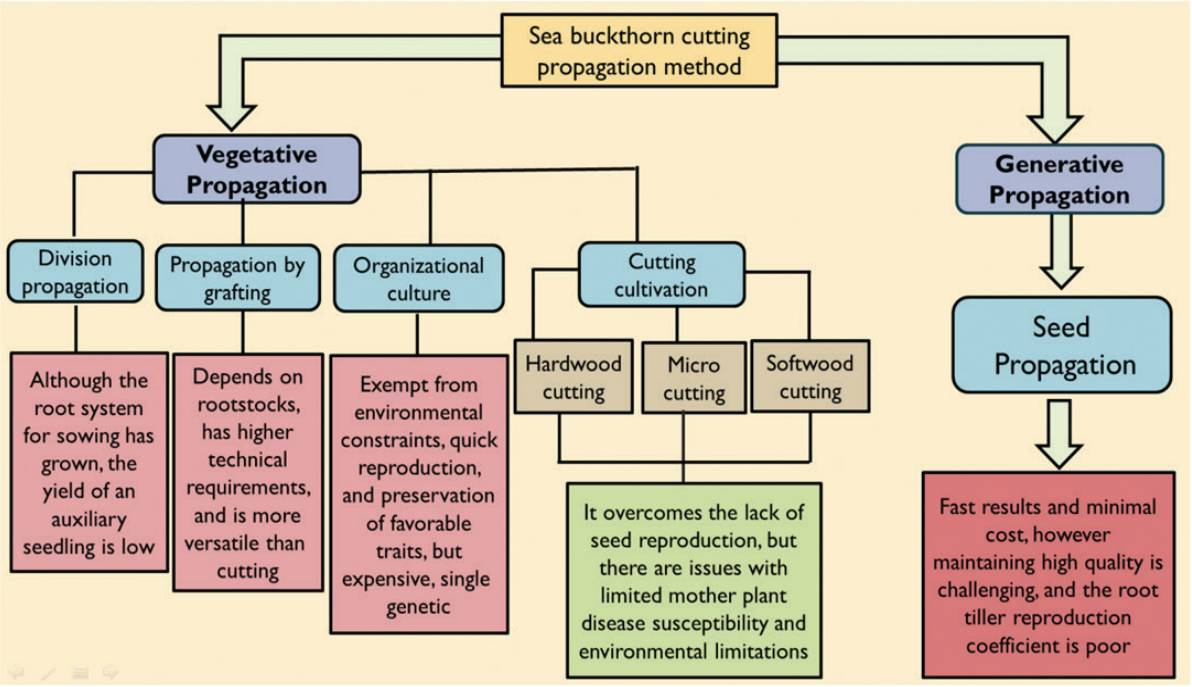

Figure 2. Demonstrating a cutting propagation mode of the Seabuckthorn in which cuttings of the healthy shoots are made 15-20 cm long, rooting hormones used and placed under moist and well-drained medium to generate genetically identical plants.

subspecies of plant is used, where the plant was grown, and how the oil is produced. The fatty acid content of the seed oil is about 17 % oleic acid. Yes, it does have omega-6 and omega-3 fatty acids in a regular ratio[26-27]. Pulp oil has greater levels of saturated fatty acids, such as palmitic acid and greater palmitoleic acid. Cerides, hydrocarbons, and phytosterols such as β-sitosterol are present in seed and pulp oils and are responsible for their good antioxidant activity.

4.2 Carbohydrates and Dietary Fiber

Seabuckthorn berries also have a notable composition of carbohydrates, whose source is mainly simple sugars such as glucose and fructose. Two variables that might influence the carbohydrate content are the subspecies and the harvesting time. The majority of the total sugar composition of the berries is these simple sugars[25,29]. In addition, Seabuckthorn berries are a rich source of dietary fiber, which includes pectin, cellulose, and hemicellulose. These fibers support gastrointestinal health, ensure normal bowel function, and enhance overall gastrointestinal function. The skin and pulp of the Seabuckthorn berry provide a more fibre-rich source, while seeds contain a richer starch source that contributes to the overall carbohydrate content. Seabuckthorn dietary fibres balance blood sugar levels, and berries are found to be the most suitable food option for those who desire to control glycaemic response[30].

4.3 Proteins and Amino Acids

While fruits are not generally considered to be major protein sources, Seabuckthorn is an exception. The leaves and seeds, as well as other plant parts, contain very high protein. On the contrary, the seeds alone contain a considerable percentage of the entire protein content of the fruit[31-32]. Comparing with protein content in some other fruit juices, in Seabuckthorn juice, it can be seen that Seabuckthorn contains higher protein content, responsible for the turbidity of the juice. Protein content in Seabuckthorn varies from 46 to 129 grams per kilogram dry weight based on subspecies. Seabuckthorn is an uncommon plant source of protein for human nutrition[33].

4.4 Carotenoids

One of the most striking characteristics is the exceptionally high carotenoid content in the fruit of Seabuckthorn. Orange-yellow color of the fruit is caused by organic pigments called carotenoids. They are active antioxidants, and several carotenoids-most notably β-carotene-are precursors of vitamin A, which is needed for normal vision and immunity. Furthermore, lutein and zeaxanthin, both of great benefit to eye health, are included in Seabuckthorn berries[34]. Such substances reinforce the macular pigment in the eye and also protect the retina from oxidative stress-induced damage. Beta carotene is most widespread, and Seabuckthorn berries will have an average of 11 milligrams of total carotenoids per 100 grams. Carotenoid content can vary with the subspecies and climatic conditions under which crops are grown[35].

4.5 Phenolic Compounds

Phenolic chemicals which are flavonoids and phenolic acids are another significant bioactive constituent of Seabuckthorn. These compounds are famous due to their strong antioxidant properties, which help in the scavenging of free radicals and reduction of oxidative stress to prevent cell damage[36]. Seabuckthorn has a variety of phenolic chemicals in its berries, leaves, stems, and roots. Salicylic acid is the most typical phenolic acid in the fruit. Other interesting phenolic acids which can be found in Seabuckthorn include gallic acid, caffeic acid, and p-coumaric acid. Seabuckthorn too is a good source of flavonoids, such as kaempferol, isorhamnetin and quercetin[37-38]. Seabuckthorn is a great food source that people choose to improve their antioxidant levels and prevent the occurrence of oxidative stresses due to the high level of phenolic compounds[39].

4.6 Phytosterols

Just like cholesterol, they are structured in a similar way, phytosterols are a group of sterols produced by plants and they come with multiple health benefits, particularly in the relationship of the heart. There are several phytosterols present in the berries: 80-sitosterol, campesterol and stigmasterol.40 These sterols are mainly located in the pulp lipids of the berries and they are adding to the lipid profile of the fruit. Phytosterols have been shown to reduce cholesterol, improve lipid metabolism and health of the heart in general. Besides its cardiovascular benefit, phytosterols in Seabuckthorn are recognised to be anti-inflammatory, which again contributes to the overall health benefits of this terrific fruit, and hence the plant reduces the risk of chronic diseases.

5. CHEMICAL COMPOSITION AND NUTRITIONAL VALUES

Seabuckthorn (*Hippophae rhamnoides*) is a fruit in the forest that is one of the richest in vitamins, antioxidants, and bioactive compounds. Comparisons of the yields of fresh fruit and juice of various regions of the *Hippophae* species were done and the best yields of fresh fruit (1313.6kg/ha) and juice (1505.5kg/ha) are the products of *H. rhamnoides* of Kiahe Gansu. Other species, including *H. rhamnoides* ssp. stellatopilosa(found in china), have minimal values. Generally, the increased juice content in Tibet and Gansu provenances demonstrates that the geography affects production. Moreover, carotenoid and β-carotene content in *Hippophae rhamnoides* ssp. sinensis oils from different provenances were also compared. Pulp oils show significantly higher carotenoid levels, with Wutai Shanxi pulp peaking at 1375.00 mg/100g and β-carotene at 5.44 mg/100g. Seed oils generally exhibit

lower carotenoid content, with the highest being from Jianping Liaoning (104.17 mg/100g). This highlights pulp as a richer carotenoid source[42].

Pulp oils contain by far greater amounts of carotenoid and 2-carotene, compared with oils obtained elsewhere of Hippophae rhamnoides ssp. sinensis. The withhest amounts of carotenoids (1375.00 mg/100g) and 5-carotene (5.44mg/100g) was observed in Wutai Shanxi pulp. Jianping Liaoning seeds have the highest carotenoid content (104.17 mg/100g), but seed oils typically have lower levels. These findings show that pulp oil is a richer source of carotenoids. Unsaponifiable matter and phytosterol in oils of different *Hippophae* species were also demonstrated. *H. rhamnoides* ssp. sinensis seed oil had the highest phytosterol content (1430.1 mg/100g), while its pulp oil showed lower unsaponifiable matter (1.75 %). H. neurocarpa and *H. tibetana* seed oils had phytosterol contents of 804.2 and 967.7 mg/100g respectively, with *H. tibetana* pulp oil having the highest unsaponifiable matter (3.07 %)[42]. Among all, *H. rhamnoides* ssp. *Turkestanica* seed oil showed high phytosterol content (1237.6 mg/100g). In general, pulp oils contained more unsaponifiable matter than seed oils, suggesting differences in nutritional and bioactive profiles among species.

5.1 Rich Source of Vitamin C and Antioxidants

The extraordinarily high vitamin C content of Seabuckthorn berries is one of their most notable characteristics. The subspecies can have a substantial impact on this concentration. The Chinese species *(S. sinensis)* has up to 2500 mg of vitamin C per 100 grams of fresh berries, but the European variation *(S. rhamnoides)* has only 360 mg. Depending on the processing and place of origin, the vitamin C level in juice can vary greatly, ranging from as low as 3.8 mg/100 g to as high as 1505.5 mg/100 g[43]. Another excellent source of carotenoids is Seabuckthorn, especially β-carotene, which is a precursor to vitamin A. About 30-40 mg of carotene per 100 grams may be found in berry pulp. In oil, the concentration of carotenoid increases significantly[44]. Levels in *H. rhamnoides* ssp. *sinensis* pulp oil, for example, vary from 365.8 mg/100 g to 1375.0 mg/100 g, but levels in seed oil range from 24.22 mg/100 g to 133.30 mg/100 g. Significant carotenoid concentrations, which vary by geographic origin, are also seen in the oil of other subspecies, including *H. neurocarpa* and *H. mongolica*[45].

5.2 Vitamin E and Flavonoids

Vitamin E (tocopherol), a vital antioxidant that aids in shielding cells from oxidative stress, is also abundant in Seabuckthorn. The vitamin E content of the berries may go up to 160 mg/100 g. The *H. rhamnoides* ssp. sinensis seed oil in China has a range of 1.1676 mg/100 g to 2.1188 mg/100 g which is higher than Russian varieties but lower than Canadian ones. The levels of vitamin E in dried pulp are 0.5468 mg/100 g to 1.4525 mg/100 g. Flavonoids, or vitamin P, present in Seabuckthorn also provide further antioxidant effects, and can help promote immunological and cardiovascular health along with vitamin C and E[46-47].

5.3 Proteins, Amino Acids, and Sugars

Organic acids and soluble carbohydrates are good sources found in Seabuckthorn berries. They consist of sugars up to 13 %, primarily xylose, fructose and glucose. Organic acids such as succinic and malic acid that contain about 3.9 % of the berry bulk provide it with its sour taste and digestive benefits. The berries too have a spectacular number of amino acids- 18 in total, some of which are essential that the body cannot synthesize itself. This renders Seabuckthorn an important source of plant-based proteins[48]. In addition, it contains many minerals, including nitrogen, phosphorus, iron, manganese, boron, calcium, aluminium, and silicon-as many as 24 chemical elements have been found in its juice.

5.4 Fatty Acid Composition and Oil Content

There are two primary categories of Seabuckthorn oil namely pulp oil and seed oil. Each has a unique nutritional profile and content. Essential fatty acids such as linoleic acid (omega-6) and linolenic acid (omega-3) are abundant in seed oil and are both vital for cellular and cardiovascular function[49]. In contrast, pulp oil has high levels of palmitic and palmitoleic acids (C16:0 and C16:1), which are good for skin health and repair[50]. Depending on the subspecies and place of origin, the oil content might vary significantly. While pulp oil concentration varies from 2.02 % to 34.26 %, seed oil content ranges from 5.62 % to 19.51 %[51]. This variation emphasizes how crucial area and species are when assessing the nutritional value of Seabuckthorn Seabuckthorn also has antioxidant properties, which is illustrated through Fig. 3.

6. SEABUCKTHORN IN THE FOOD INDUSTRY: A VERSATILE SUPERFRUIT

While all parts of the Seabuckthorn plant have nutritional or medicinal importance, the food industry remains its most significant area of application. Among its components, the fruit is the most prized for its versatility and nutritional density, though the leaves are also commonly used, such as in the preparation of Seabuckthorn tea[52]. The pulp is mainly processed into juice, while the seeds are used to extract highly valued oil-both are key ingredients in a wide range of functional foods and dietary supplements. As of 2018, over 200 different products have been developed from various species of *Hippophaë*, highlighting the fruit's incredible adaptability across multiple food categories.

6.1 Food Supplements and Additives

Seabuckthorn oil holds a prominent place in the health supplement market, often included in formulations that support the health of mucous membranes and improve

antioxidant defence. Its appeal lies in being a natural source of vitamins, fatty acids, and bioactive compounds[53]. In Finland, Seabuckthorn is even used in baby food as a functional ingredient due to its safety and nutrient density[54]. Additionally, the leftover material from juice production-known as Seabuckthorn residue-has been successfully used to enrich meat products. Particularly in hand-deboned goods, it improves the meat's antioxidant content and lessens the breakdown of fatty acids without changing the meat's flavour, texture, or aroma. A notable innovation includes "Seabuckthorn yellow," a pigment extracted from the fruit peel, which serves as a natural food colouring agent[55]. The dried peel, rich in antioxidants, is also processed into powder form and used as a nutritional booster, particularly beneficial for people with weak immune systems or oxidative stress issues. Another commercial product includes a Seabuckthorn-infused edible salt, free of additives and known for its unique taste and potent antioxidant properties.

6.2 Refreshing Beverages

Juices and energizing drinks are some of the most traditional and popular Seabuckthorn products[56]. Rich in vitamin C and carotenoids, these drinks are well-liked in Scandinavia and other nations, including China, Germany, and Finland[57]. During the 1992 Seoul Olympics, Chinese competitors famously drank Seabuckthorn beverages. and were included in the diet of Indian soldiers operating in extreme cold environments due to their immunity-boosting effects.

6.3 Jams and Jellies

Despite the tart and slightly exotic flavour, Seabuckthorn berries are excellent for making jams and jellies. Their sharp taste can be balanced by blending them with milder fruits such as apples, currants, strawberries, and raspberries[58]. Jams prepared from Seabuckthorn and raspberries or strawberries were the most appreciated ones by the taste panel because they had a good balance of flavour and colour[59]. Because of the bioactive composition of Seabuckthorn, such jams are not just tasty but also packed with health goodness, with a unique alternative to traditional fruit preserves.

6.4 Dairy Innovations

Seabuckthorn has also found a niche in dairy products. Yogurt, kefir, and cheese have been fortified with Seabuckthorn puree to provide nutritional value and taste[60]. Studies suggest that incorporation of the fruit enhances antioxidant activity and subtly increases the acidity of fermented drinks, which can aid in digestive health. Seabuckthorn has been a novel ingredient in cheese-making. In feta cheese production, it has been utilised in the production of a biodegradable growth matrix for probiotic beneficial probiotic bacteria (Lactobacillus casei). In addition to aiding probiotic growth, it also prevents the formation of harmful microorganisms and provides the final product with a better taste and texture.

6.5 Alcoholic Beverages

Seabuckthorn has even found its way to the alcoholic drink industry. Tinctures of the berries have been used in herbal medicine for centuries to boost digestive

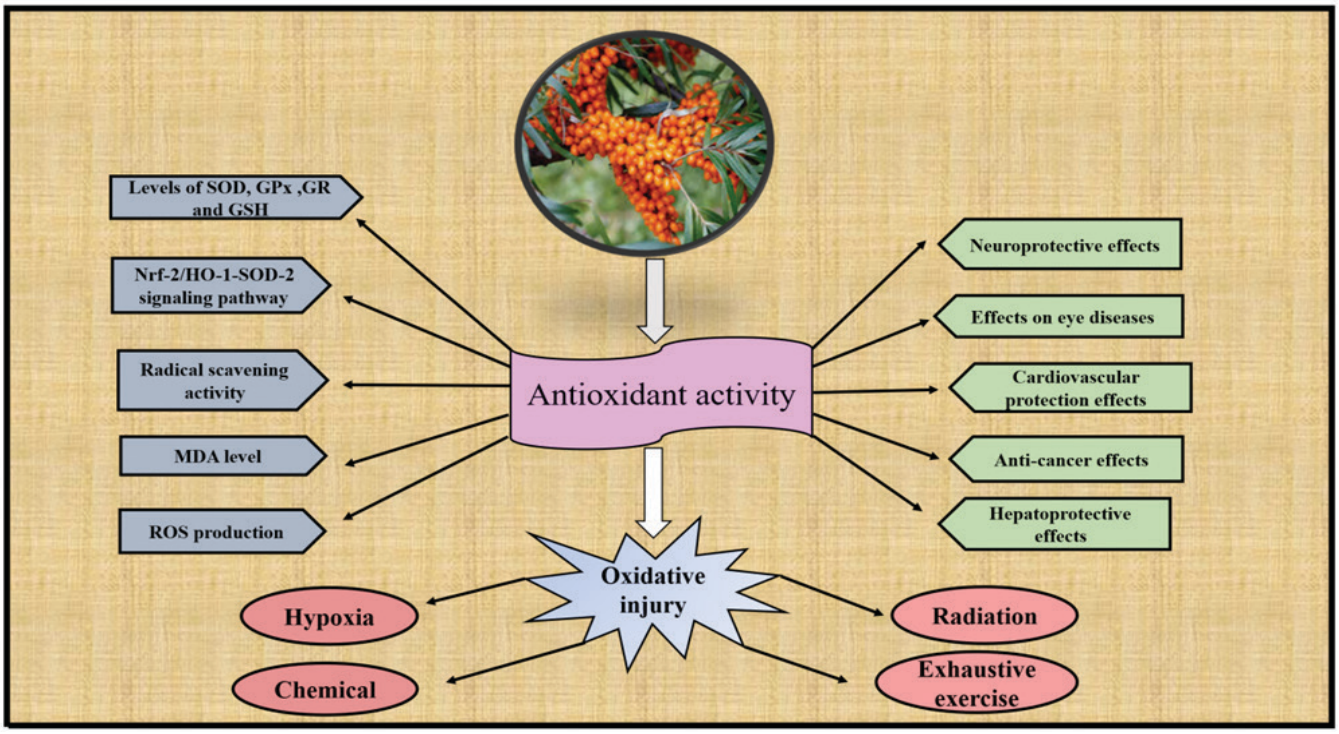

Figure 3. Demonstrating the powerful antioxidant effect of Seabuckthorn, emphasizing its effect in free radical neutralisation, protection of cellular structures, inhibiting oxidative stress, and enhancement of human well-being and disease prevention.

health as well as treat conditions such as slow digestion. Seabuckthorn wine also became popular in the Czech Republic, where it has a premium price because of its golden color and nice smell[61]. It is also applied to brewing specialty beers and fermented beverages. Among the ways is applying by-products for the production of juice-e.g., Seabuckthorn marc (pressed pulp)-as a raw material for fermentative processing to produce low-alcohol, health-beneficial beverages. These green initiatives use most of the fruit parts and open new market possibilities[62].

7. ROLE IN ECO-ENVIRONMENTAL IMPROVEMENT

Hippophae rhamnoides is a robust plant species that is globally renowned for its vast ecological importance, especially in soil improvement, water conservation, biodiversity improvement, and land degradation prevention. The capability of the plant to tolerate poor water and soil conditions renders it a suitable species in ecological rehabilitation, particularly in areas where it is arid and mountainous[63].

7.1 Water Retention and Soil Enhancement

One of the most significant features of *H. rhamnoides* is a sturdy root system, enabling the plant to draw water from deep in the soil. At maturity, the plant enhances the physical quality of the soil and its water-retaining capacity. Studies have shown that in the dry season, soil moisture content in *H. rhamnoides* plantations is as high as 7.6 %, while in surrounding barren grasslands, it is only 6.8 %[64]. The soil's bulk density in these woodlands (1.28 g/cm^3) is also slightly lower than in barren lands (1.29 g/cm^3), contributing to improved permeability. Additionally, infiltration rates are significantly higher in *H. rhamnoides* areas-with initial infiltration rates of 2.84 mm/min and stable rates of 1.54 mm/min-far surpassing those of untreated mountain soils.

7.2 Soil Fertility and Productivity

Beyond water management, *H. rhamnoides* improves soil fertility through nitrogen-fixing root nodules. The decomposition of its leaf litter and organic materials enriches the soil with essential nutrients[65]. Research in Wuqi County, Shaanxi Province, revealed that plantations aged 2–13 years showed significantly enhanced soil productivity. Net primary productivity reached 3,820 kg/ha, compared to just 665.79 kg/ha in barren grasslands. Nitrogen levels in the soil nearly doubled (92.25 kg/ha vs. 49.04 kg/ha), while phosphorus accumulation also increased notably (8.25 kg/ha vs. 6.38 kg/ha)[66].

7.3 Biodiversity Restoration and Ecosystem Development

Over time, *H. rhamnoides* plantations facilitate the development of rich, diverse ecosystems. After 7–8 years, vegetation coverage can reach up to 80 %, supporting a mix of naturally occurring and introduced plant species. In Jianping County, China, over 80 new shrub and grass species were recorded within 13 years of plantation establishment[67]. Dominant species include *Cleistogenes songorica*, *Thymus vulgaris*, *Lespedeza daurica*, and *Stipa bungeana*. Companion plants such as *Potentilla chinensis*, *Setaria viridis*, and *Artemisia lavandulaefolia* also thrive in the ecosystem[68]. This rich vegetation fosters habitat formation, attracting a wide range of wildlife. In mature *H. rhamnoides* forests, 10–30 species of wild animals-including snakes, birds like *Phasianus colchicus* and *Alectoris mantchurica*, and mammals such as red foxes, rabbits, and badgers-have been observed, contributing to ecological balance and sustainability[69].

7.4 Prevention of Soil Erosion and Desertification

After 4-5 years, *H. rhamnoides* plantations develop a dense canopy and an undergrowth of 10-20 lush plant species. These include *Ranunculus japonicus*, *Thalictrum minus*, and *Bupleurum chinense*. A thick litter layer, ranging from 2–6 cm, accumulates, significantly improving the soil's ability to retain water-over twice its weight in moisture[70]. The root system, primarily spreading within the 20–80 cm soil layer, forms a strong underground network that stabilizes the soil. This, combined with dense vegetation, helps intercept rainfall, reduce runoff velocity, and capture silt, thus minimizing erosion. Field studies from the Ansai Research Station reported a reduction in runoff to 66.2 %, 65 %, and 78 % in 2-, 3-, and 4-year-old plantations, respectively, and a corresponding decrease in soil erosion by 39 %, 37 %, and 47 %. In older plantations, incidents of gully erosion and landslides significantly decreased. Moreover, experiments conducted in wind-sand regions of Inner Mongolia and Shaanxi Province validated *H. rhamnoides*' ability to stabilize drifting sand and improve soil conditions, positioning it as a key solution in mitigating desertification and restoring degraded landscapes[71].

8. MEDICINAL USES

Seabuckthorn is highly valued for its many therapeutic uses and have many health benefits Table 1, which are mostly due to its high concentration of bioactive substances including flavonoids, carotenoids, and vital fatty acids. These phytochemicals support the plant's diverse medicinal qualities, which have been well studied in both Europe and Asia[71-72]. Seabuckthorn's therapeutic benefits were first recognised in the 1950s by Russian research, and both traditional and contemporary medicine have since extensively documented its uses[73].

8.1 Skincare and Dermatological Uses

Seabuckthorn's usage in skincare is among its most well-known applications. Its oil, which is extracted from the berries and seeds, is well known for encouraging skin repair and renewal. Some of the significant conditions that it is applied in the treatment of include burns, pressure sores, wounds, infections, and radiation-induced skin

Table 1. Table gives the health benefits of Seabuckthorn, which consists of properties that show the highlight of the experimental model, bioactive compounds, and the results that shows the therapeutic potential of Seabuckthorn.

S. No.	Properties of Seabuckthorn	Effective concentration/ time	Experimental model	Bioactive compounds	Results	Reference
1			**Anticancer**			
	Polyphenols extraction	50 mg/kg	BALB/c nude mouse Xenograft model		Reduced tumor growth size and slowed tumor growth rate	Wu[82], *et al*
		80 and 120 µg/ mL	Human carcinoma of the colon cell	Kaempferol and its derivatives	Downregulation of cyclins accompanied by suppressed cellular growths	
	Extract from leaves	6.2,62 µg/mL	Glioma cells in rats C6	Phenolics	Rat C6 glioma cells showed increased pre-apoptosis and decreased intracellular ROS.	Masoodi[83], *et al*
	Aqueous extract from leaves	3.12, 6.25, 12.5, 25, 50 µg/mL	C4-2 and LNCaP cells		Reduced prostate cancer cell migration and proliferation	Kim[84], *et al*
	Isorhamnetin	12.5, 15 µg/mL	MKN-45 cell growth is maximized in the CoCl2-induced hypoxia paradigm.	Isorhamnetin	Reduced adaptive autophagy mediated by PI3K AKT mTOR Increased apoptosis of MKN-45 gastric cancer cells in a hypoxic setting	Li[85], *et al*
2			**Antioxidant**			
	Seabuckthorn fruit phenolic fraction	0.5-50 µg/mL	Plasma or platelets of human blood treated with H2O2 or H2O2/ Fe	Flavonoides	Reduced carbonylation of proteins and peroxidation of plasma lipids. 60% of plasma lipid peroxidation was inhibited at 50 µg/mL.	Mohamed[86], *et al*
	Extract of Seabuckthorn	100 mg/kg.bw	Hyperlipidemic rats	Polyphenols	Reduced harm caused by lipid peroxidation	Cho[87], *et al*
	Seabuckthorn seed oil	500ng/mL	UV-Induced human skin cells	Fatty acids, phytosterols, vitamin A, and E	reduced production of ROS by about 25%	Gegotek[88], *et al*
	Extract of Seabuckthorn leaves	5, 10 and 20 µg/mL	PC-12 cells	Ellagic acid, gallic acid, isorhamnetin	Lower proportion of PC-12 cells that undergo apoptosis	Serban[89], *et al*
3			**Anti-obesity**			
	Polysaccharide from Seabuckthorn	0.1%	Male C57BL/6 mice fed a high-fat diet	Polysaccharide	Reduction in weight growth and cholesterol buildup	Ma[90], *et al*
	Oil from Seabuckthorn fruit	50, 100, and 200 mg/kg	Golden Syrian hamster model with elevated cholesterol	Palmitoleic acid	Weight loss and increased blood sugar	Gao[91], *et al*
	Seabuckthorn seed extract enhanced with flavonoids	100 and 300 mg/kg	An obese mouse model generated by a high-fat diet	Flavonoid	Reduced levels of liver and serum triglycerides in a dose-dependent fashion	Yang[92], *et al*
	Seabuckthorn powder that has been freeze-dried	4 mg(g.d.) body weight	Obesity in mice caused by high-fat fat		Decreased body weight gain	Guo[93], *et al*
4			**Antimicrobial**			
	Seabuckthorn leaf extracts	5%	Common pathogens of the skin and wounds	-	Gram-positive bacteria have decreased.	Verma[94], et al

	Extract from Seabuckthorn berries	0.15 mg/mL	Human cells called keratinocytes	-	Reduced levels of apoptotic pathways and inflammatory cytokines	Shah[95], *et al*
	Seabuckthorn berries leaf extract	6 mg/mL	Staphylococcus aureus	-	prevents MSRA from growing	Qadir[96], *et al*
5			**Anti-inflammatory**			
	Extract from Seabuckthorn peel	50 mg/kg	Models of 48/80 produced rat paw edema	Ursolic acid, oleanolic acid	Decreased Edema volume	Upadhyay[97], *et al*
	Seabuckthorn branches, berries and leave extract	10µg/mL	264.7 RAW macrophages	Phenolic compounds	The incidence of NO inhibition rose from 73 to 98%.	Dudau[99], *et al*
	Seabuckthorn leave extract	0.05, 5, 50 µg/mL	Peritoneal macrophages in mice	Tannins, proteins, and carbohydrate groups	Reduced levels of pro-inflammatory cytokines	Tanwar[99], *et al*
	Seabuckthorn fruit powder	5, 10, 25, 50, and 100 µg/mL	RAW 264.7	1,5-dimethyl citrate	Decreased LPS-induced NO production	Redei[100] *et al*
	Seabuckthorn flavonoids	0.06%, 0.31% w/w	Obese mice caused by HFFD	Flavonoids	Reduced levels of inflammatory cytokines and mediators, including iNOS, COX-2, and 1L-1β	Zheng[101], *et al*
6			**Dermatological**			
	Extract from Seabuckthorn	8 weeks(twice daily)	Ten patients with psoriasis	-	Reduced dermatology life quality index scores and psoriasis area severity index	Boca[102], *et al*
	Seabuckthorn oil	100, 200 mg/kg p.o. 20 µL topical application	TPA-stimulated CD-1 mice that resemble psoriasis	Fatty acids	Ear edema decreased by 30.45 ± 8.90% and 34.05 ± 7.65%, respectively. 31.80 ± 6.90 µm and 21.91 ± 5.07 µm, respectively, in ear epidermal thickness	Balkrishna[103], *et al*
	Seabuckthorn oil	1 mL/kg 4 weeks	Mice model of AD-like lesions produced by DNCB	-	Reduced severity of AD caused by DNCB	Hou[104,] *et al*
	Cream of Seabuckthorn	3-mm thickness	55 individuals who suffered second-degree burns	-	Reduced time for wound healing and the second-degree burn treatment process	Abdullahzadeh[105], *et al*
	Oil from Seabuckthorn seeds	500 ng/mL	UV-induced skin cells in humans	Fatty acids, phytosterols, vitamin A and E	Reduced redox and lipid metabolism abnormalities in skin fibroblasts and keratinocytes brought on by UV	Gegotek[106], *et al*

damage. Seabuckthorn oil is also applied in sunscreens due to its natural ability to prevent ultraviolet (UV) radiation[74]. Its regenerative nature renders it especially useful in the treatment of skin diseases like eczema and dermatitis.

8.2 Gastrointestinal Health

Historically Seabuckthorn was applied to treat digestive problems, especially stomach and duodenal ulcers. These traditional applications have been confirmed by modern studies, in particular, the therapeutic properties of its seed oil on the healing of ulcers. Research has also revealed that Seabuckthorn extracts have the potential of preventing ulcers of the stomach due to stress and other drugs such as indomethacin and as a natural treatment to the gastrointestinal health[75].

8.3 Anti-Tumour and Radiation Protection

In the 1950s and 1960s initial studies of the Seabuckthorn bark discovered a compound known as 5-hydroxytryptamine (hippophan) which had the potential to prevent tumor growth. The anti-tumor action of Seabuckthorn, particularly using oil extracts, has also been testified by clinical trials done in China[76]. Moreover, the extracts containing flavonoids have been demonstrated to have protective effects on bone marrow cells, which safeguard these cells against the effects of radiation and

chemotherapy. These properties render Seabuckthorn a potential complement of cancer treatments and recovery.

8.4 Cardiovascular Benefits

Seabuckthorn also plays a major role in cardiovascular well-being. It is used in treating high blood pressure, high cholesterol and coronary heart disease. In a trial of patients with ischemic heart disease, the participants who were treated with Seabuckthorn flavonoids in six weeks had radically enhanced heart functioning, cholesterol reduction, and a reduction in angina attacks; which are of paramount significance in heart disease prevention.[77] Seabuckthorn juice antioxidants also inhibit major risk factors like LDL (bad) cholesterol oxidation and platelet aggregation which are of central importance in heart disease prevention.

8.5 Liver Health and Detoxification

Clinical and laboratory research has confirmed the liver-protective effect of Seabuckthorn. It has been established to normalize liver enzymes which were increased and inflammation in liver tissue. Treatment of chronic hepatitis B patients with Seabuckthorn extracts with antiviral medication accelerated liver enzyme levels to normal[78].

9. WIDER THERAPEUTIC APPLICATIONS

The health value of Seabuckthorn is not limited to particular organs and systems. It has been utilised as therapy in autoimmune conditions and general immunological deficiency as well as in improving overall immune[79]. It has anti-inflammatory and antioxidant properties and it makes people more resilient to infection and chronic inflammation. In 1977, the reputation of Seabuckthorn as a dependable medicinal plant was secured when it became a formal part of China's national Pharmacopoeia[80]. Its applications continue to grow in modern medicine, supported by ongoing research and traditional knowledge passed down through generations[81].

10. CONCLUSION

Seabuckthorn is an extremely distinctive species with phenomenal ecological, nutritional, and medicinal significance. It is a true superfruit in all aspects because it contains concentrated vitamins, essential fatty acids, antioxidants, and bioactive compounds. This adaptive shrub is the epitome of an environmental rejuvenation tool because it can thrive in harsh climates and serves as a key contribute to the enrichment and erosion prevention of the soil and biodiversity. Seabuckthorn has stood out as a health and well-being product because it has a wide range of properties, such as immune strengthening, liver-activation, and heart-stimulating properties, among other skin-healing properties. Its seed and berry oils are particularly valued in their anti-oxidant and anti-inflammatory properties. The richness in carotenoids and vitamin C helps to reduce oxidative stress and slow cell aging. Besides conventional medicine, Seabuckthorn finds application in conventional nutraceuticals, cosmetics, and functional foods. Seabuckthorn has also been utilised to treat ulcers, control cholesterol levels, and as an adjuvant drug in cancer therapy because of its radioprotective properties. Its flexibility, as well as multi-purpose character, makes the plant a health- and sustainability-related icon. Additional studies and research are uncovering additional applications and Seabuckthorn is becoming the key to human health and environmental balance in the future. The truth is that, Seabuckthorn is not actually a plant but rather the apothecary of nature and harbinger of recovery, wellness, and a stable environment.

11. FUTURE PROSPECTS

Seabuckthorn possesses gigantic potentials in the future as a health promoting natural species, and as a source of sustainable development. The market of the product based on Seabuckthorn is sure to increase several times with the increase in the global demand on natural remedies and plant-based nutrition. It is inherent in the new trends in health particularly in functional foods, nutritional supplements and cosmetics since its distinctive nutritional profile is abundant in omega fatty acids, antioxidants, flavonoids and vitamins. Due to its nitrogen-fixing roots and erosion-controlling capability, Seabuckthorn possesses extremely high potential for raising soil fertility, reclaiming degraded land, and combating desertification from an environmental perspective. Its application in eco-rehabilitation projects, especially in arid and semi-arid areas, can be expected to increase even more with increased emphasis on climate-resilient agriculture. In the pharma field, research continues to explore its anti-inflammatory, anti-cancer, and liver protective aspects. Improvements in extraction techniques and product formulation will unlock even more therapeutic values from its berries, seeds, and leaves. Moreover, improvements in biotechnology could enhance the productivity of the plant and the concentration of bioactive compounds. Seabuckthorn's future is also in sustainable agriculture and agroforestry systems, where it can provide both ecological worth and economic advantages for rural economies. As its holistic worth gains popularity, Seabuckthorn is on the cusp of environmental natural healing remedies and green technology leader globally. Essentially, the future of Seabuckthorn is golden with possibilities ranging from health to environment, agriculture, and industry assuring it as a highly pertinent plant for future generations.

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