

Sea Buckthorn (*Hippophae rhamnoides* L.): Phytochemistry, Pharmacological Prospective and the Emerging Opportunity for Anti Oxidant Tablet Formulation

Subhra Swaraj^{1*}, Mr. Rahul Sharma², Dr. Subhranshu Panda³

¹M. Pharm, Researc Scholar, Jaipur National University, Jaipur

²Associate Professor, Jaipur National University, Jaipur

³Director, School of Pharmaceutical Science

DOI: <https://doi.org/10.5281/zenodo.21065357>

Published Date: 30-June-2026

Abstract: Sea buckthorn, or *Hippophae rhamnoides* L., is a highly prized medicinal and nutritious plant that is found throughout Europe and Asia, especially in the Himalayan regions. It is a member of the Elaeagnaceae family. The plant's berries, leaves, seeds, and oils have historically been utilized in Tibetan, Mongolian, Chinese, Russian, and Ayurvedic medical systems to treat a variety of illnesses. Sea buckthorn's remarkable phytochemical variety and wide range of biological functions have attracted a lot of scientific attention in recent decades. The botanical traits, geographic range, ethnomedical importance, phytochemical composition, nutritional value, pharmacological activities, clinical evidence, safety profile, and commercial applications of *H. rhamnoides* are all well covered in this review. Numerous bioactive components, such as flavonoids (isorhamnetin, quercetin, kaempferol, and rutin), phenolic acids, carotenoids, tocopherols, phytosterols, vitamins, essential fatty acids, amino acids, and other antioxidant chemicals, are found in sea buckthorn, according to published research. Through a variety of molecular mechanisms including free radical scavenging, modulation of inflammatory pathways, and enhancement of endogenous antioxidant defenses, these phytochemicals collectively contribute to its powerful antioxidant, anti-inflammatory, antidiabetic, cardioprotective, hepatoprotective, neuroprotective, anticancer, gastroprotective, wound-healing, and immunomodulatory effects. Additionally, sea buckthorn's exceptional nutritional profile which includes high concentrations of vitamin C, carotenoids, dietary fiber, and special omega fatty acids supports its expanding use as a component of functional foods and nutraceuticals.

Despite significant advancements in understanding its phytochemistry and therapeutic potential, the majority of the information now available comes from in vitro and animal studies, and there are still few standardized dosage forms and carefully planned human trials. The creation of standardized solid oral formulations, especially antioxidant tablet formulations using optimal sea buckthorn extracts, has received very little attention, despite the fact that sea buckthorn has showed strong antioxidant activity. Future studies aiming at converting its antioxidant activity into evidence-based pharmaceutical formulations with enhanced stability, patient compliance, and therapeutic application should take advantage of this significant research void.

Key Words: *Hippophae rhamnoides*; sea buckthorn; phytochemistry; nutritional value; antioxidant activity; pharmacological activities; nutraceuticals; pharmaceutical formulations; antioxidant tablets.

1. INTRODUCTION

Sea buckthorn (*Hippophae rhamnoides* L.), a resistant deciduous shrub of the Elaeagnaceae family, has become a useful medicinal and nutritional plant because of its rich phytochemical content and remarkable adaptability¹. The plant is found throughout Europe and Asia, especially in the Himalayan region, Russia, China, and Northern Europe, where it has long been used for ecological, medical, and food uses. The plant is a valuable resource for sustainable agriculture and environmental conservation because of its exceptional tolerance to harsh climatic conditions, such as drought, salinity, and low temperatures².

The plethora of biologically active chemicals found in sea buckthorn has garnered significant scientific attention in recent decades³. A wide variety of phytoconstituents, including flavonoids, phenolic acids, carotenoids, tocopherols, phytosterols, triterpenoids, essential fatty acids, vitamins, and minerals, can be found in the plant's berries, seeds, leaves, bark, and roots. Among these, flavonoids including rutin, kaempferol, quercetin, and isorhamnetin are acknowledged as important bioactive markers in charge of numerous pharmacological characteristics of the plant. Its medicinal effectiveness and functional dietary value are greatly enhanced by the synergistic interactions between these phytochemicals^{4,5}.

Sea buckthorn has an equally amazing nutritional composition. The berries have significant amounts of vitamins A, E, K, and B-complex vitamins and are regarded as one of the best natural sources of vitamin C⁶. Additionally, the distinct fatty acid content of sea buckthorn oil specifically, the presence of omega-3, omega-6, omega-7, and omega-9 fatty acids sets it apart. A very uncommon fatty acid in the kingdom of plants, palmitoleic acid (omega-7) has drawn notice for its positive effects on mucosal integrity, skin health, and metabolic control^{7,8}. The fruit's nutritional and health-promoting potential is further enhanced by the presence of important amino acids, dietary fibers, and trace elements.

It has a wide range of pharmacological activities, including antioxidant, anti-inflammatory, antimicrobial, immunomodulatory, hepatoprotective, cardioprotective, neuroprotective, antidiabetic, anticancer, gastroprotective, and wound-healing effects, according to mounting data from experimental and clinical studies⁹. Its ability to regulate oxidative stress, inflammatory signaling pathways, lipid metabolism, and immunological responses is largely responsible for these biological functions. As a result, sea buckthorn has emerged as a significant contender for the creation of phytopharmaceutical formulations, functional foods, nutraceuticals, and cosmeceuticals.

Variations in phytochemical content among various plant parts, geographical origins, growth circumstances, and extraction techniques continue to pose obstacles in standardization and therapeutic evaluation despite substantial study on individual bioactive elements¹⁰. Furthermore, little is known about the mechanisms behind the pharmacokinetic behavior and synergistic interactions of several phytoconstituents. In order to ensure the quality, safety, and effectiveness of sea buckthorn-derived products and to translate traditional knowledge into evidence-based clinical uses, these restrictions must be addressed¹¹.

Thus, the goal of this review is to provide a thorough overview of *Hippophae rhamnoides*' phytochemical makeup, nutritional value, and pharmaceutical uses. The distribution of bioactive chemicals in various plant parts, their therapeutic mechanisms, and current developments in pharmaceutical, functional food, and nutraceutical research are all given particular attention¹². The development of standardized sea buckthorn-based products for therapeutic and preventative healthcare is also highlighted in this study, along with future prospects and challenges.

The antioxidant capacity of sea buckthorn has drawn special attention among its many biological functions since oxidative stress-related illnesses are becoming more common. The pathophysiology of cardiovascular illnesses, diabetes mellitus, neurological disorders, inflammatory conditions, aging, and several types of cancer is known to be significantly influenced by oxidative stress¹³. Numerous antioxidant components included in sea buckthorn, such as flavonoids, phenolic acids, carotenoids, tocopherols, and vitamin C, work together to neutralize reactive oxygen species (ROS), prevent lipid peroxidation, and shield cellular components from oxidative damage¹⁴. Sea buckthorn extracts have shown strong free radical scavenging activity in a number of in vitro and in vivo investigations using DPPH, ABTS, FRAP, and superoxide radical scavenging assays, confirming its potential as a natural antioxidant source¹⁵.

Innovative pharmaceutical formulations including sea buckthorn bioactives have been developed in response to the increased customer interest for plant-based treatments and nutraceuticals¹⁶. To increase the stability, bioavailability, and therapeutic efficacy of its active ingredients, a variety of dosage forms, including as capsules, tablets, soft gels, syrups, functional drinks, nanoformulations, and topical treatments, have been studied¹⁷⁻¹⁹. Tablet formulations, in example, provide

benefits including precise dosage, better patient compliance, ease of production, affordability, and longer shelf life. A viable method for supplying natural antioxidants and promoting preventive healthcare may be the integration of standardized sea buckthorn extracts into solid oral dose forms. Therefore, it is crucial to comprehend sea buckthorn's phytochemical makeup and antioxidant mechanisms in order to rationally design and develop pharmaceutical and nutraceutical formulations.

2. BOTANICAL DESCRIPTION AND TAXONOMY

Hippophae rhamnoides L., sometimes known as Sea Buckthorn, is a dioecious, deciduous, prickly shrub or small tree that is a member of the Rosales order and family Elaeagnaceae. Table 2 and Figure 1 show the plant's taxonomic categorization²⁰. Because of its remarkable nutritional, therapeutic, and ecological significance, *H. rhamnoides* is the most frequently cultivated and

Table 1. Taxonomic Classification of *Hippophae rhamnoides* L.

Taxonomic Rank	Classification
Kingdom	Plantae
Subkingdom	Tracheobionta
Division	Magnoliophyta
Class	Magnoliopsida
Order	Rosales
Family	Elaeagnaceae
Genus	<i>Hippophae</i>
Species	<i>Hippophae rhamnoides</i> L.

commercially significant species in the genus *Hippophae*, which includes multiple species found throughout Europe and Asia (Table 2; Figure 1)²¹⁻²⁵. Sea buckthorn is an essential species for environmental conservation and land reclamation because of its strong adaptability to a variety of climatic circumstances, such as drought, salt, harsh cold, and nutrient-deficient soils. In terms of botany, the plant usually reaches a height of 2 to 8 meters and has a large root system with many root suckers and lateral roots²⁶.

Sea buckthorn is unique in that it forms root nodules and improves soil fertility through its symbiotic relationship with nitrogen-fixing actinomycetes (*Frankia* spp.) (Figure 2; Table 1). The trunk is woody, upright, and heavily branched²⁷. Mature bark is dark brown to black, and juvenile branches frequently have sharp thorns that defend them from animals. Simple, alternating, narrow lanceolate to linear-lanceolate leaves with distinctive silvery-white scales covering their

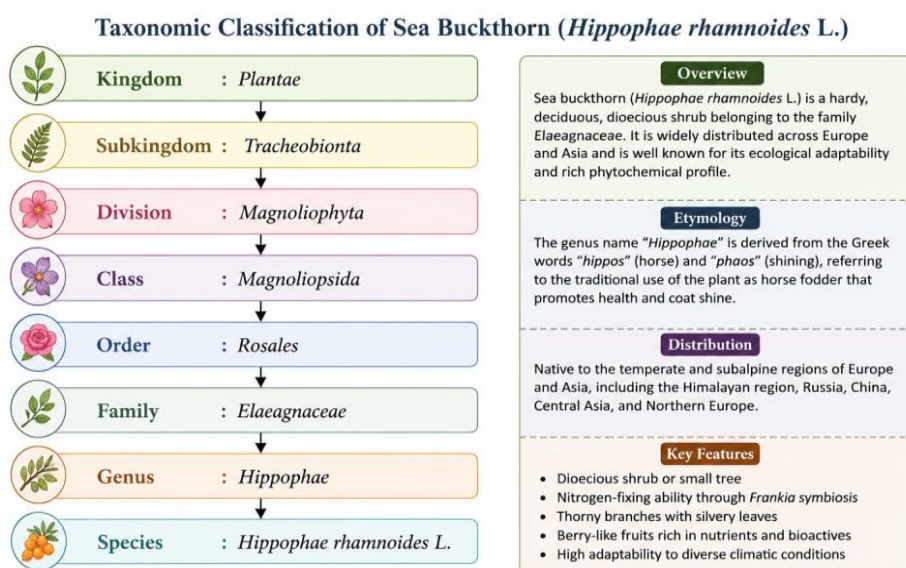


Figure 1. Taxonomic classification of *Hippophae rhamnoides* L.

Fig . No – 1 taxonomic Classification of *Hippophae rhamnoides* L.

Figure 2. Morphological Structure of Sea Buckthorn (*Hippophae rhamnoides* L.)

Fig No. – 2 Morphological Structure of Sea Buckthorn

Table 1. Botanical Characteristics and Functional Importance of Different Plant Parts of *Hippophae rhamnoides* L.

Plant Part	Morphological Characteristics	Major Constituents/Features	Functional Importance
Root	Deep, extensive root system with numerous lateral roots and root suckers	Nitrogen-fixing nodules associated with <i>Frankia</i> spp.	Improves soil fertility, nitrogen fixation, drought tolerance, erosion control, ecological restoration
Stem	Woody, erect, highly branched stem with dark brown to black bark	Lignified tissues, protective bark	Structural support, adaptation to harsh environmental conditions
Branches	Dense branching pattern with numerous sharp thorns	Modified shoots (thorns)	Protection against herbivores and environmental stress
Leaves	Simple, alternate, narrow lanceolate leaves (3-8 cm long) with silvery-white scales on lower surface	Chlorophyll, flavonoids, phenolic compounds	Photosynthesis, water conservation, antioxidant activity
Male Flowers	Small, yellowish-green flowers arranged in clusters	Pollen grains	Reproduction and pollination
Female Flowers	Solitary, yellowish-green flowers with single ovary	Ovule-containing reproductive structures	Fruit formation and seed production
Fruit (Berry-like Achene)	Oval to spherical orange or reddish-orange fleshy fruits	Vitamin C, carotenoids, flavonoids, organic acids, sugars	Nutritional value, antioxidant activity, pharmaceutical and nutraceutical applications
Seed	Small, dark brown seeds enclosed within fleshy fruit	Essential fatty acids, tocopherols, phytosterols, proteins	Source of seed oil used in pharmaceutical, cosmetic and nutraceutical products
Fruit Pulp	Soft, juicy, orange-colored fleshy tissue	Omega-7 fatty acids, carotenoids, vitamins	Skin health, mucosal protection, antioxidant effects
Seed Oil	Yellow-orange viscous oil extracted from seeds	Omega-3, Omega-6, Omega-9 fatty acids, tocopherols	Cardioprotective, anti-inflammatory and antioxidant properties
Leaf Biomass	Green aerial vegetative part	Polyphenols, tannins, flavonoids	Herbal tea production, antioxidant and immunomodulatory applications

bottom surface aid in improving adaptability to arid settings by reducing transpiration (Figure 2; Table 1). Male and female blooms appear on different plants, making sea buckthorn a dioecious species. The tiny yellowish-green blooms are wind-pollinated, with the female flowers developing into fruits after fertilization and the male flowers producing copious amounts of pollen²⁸.

The fruit is a bright yellow to orange or reddish-orange berry-like achene that grows in dense clusters along the branches and is encased in a fleshy hypanthium. These fruits greatly enhance the nutritional and pharmacological value of the plant since they are high in vitamin C, carotenoids, flavonoids, organic acids, and important fatty acids (Figure 2; Table 1). The tiny, dark brown seeds, which are encased in the meaty fruit, are rich in proteins, oils, tocopherols, phytosterols, and polyunsaturated fatty acids²⁹⁻³⁰. These compounds have drawn a lot of attention for use in medicinal and nutraceutical products. Fruit quality, bioactive composition, and therapeutic potential have all been found to be impacted by morphological and phytochemical differences among diverse subspecies and ecotypes of *H. rhamnoides* across different geographic locations³¹.

For germplasm conservation, cultivar selection, pharmaceutical standardization, and the creation of superior sea buckthorn-based functional foods, nutraceuticals, and medicinal formulations, precise taxonomic identification and thorough botanical characterization are crucial.

3. GEOGRAPHICAL DISTRIBUTION AND CULTIVATION

One of the world's most versatile medicinal plants, sea buckthorn (*Hippophae rhamnoides* L.) is found in many temperate and subarctic regions of Europe and Asia. Its natural range spans an estimated 3.0 million hectares, from the mountainous regions of East and Central Asia to the Atlantic shores of Northern Europe. China, Russia, Mongolia, India, Nepal, Pakistan, Bhutan, Finland, Germany, Sweden, Romania, and several Central Asian nations are the main locations for the plant³². Nearly 90% of the world's sea buckthorn population is found in China, which has the largest natural and cultivated sea buckthorn resources. The species has been widely used for food processing, pharmaceutical applications, and ecological restoration. In India, sea buckthorn is mostly found at elevations between 2,500 and 5,200 meters above sea level in the cold, arid Himalayan areas of Ladakh, Himachal Pradesh, Uttarakhand, Sikkim, and Arunachal Pradesh³³. The plant is a crucial species for preventing desertification and repairing damaged ecosystems because of its exceptional resistance to harsh environmental conditions, such as temperatures between -40°C and 40°C, prolonged drought, salinity, strong winds, high UV radiation, and nutrient-deficient soils.

The genus *Hippophae* has a number of subspecies that are geographically adapted, such as *H. rhamnoides* subsp. *rhamnoides*, *mongolica*, *turkestanica*, *sinensis*, *yunnanensis*, and *caucasica*³⁴. The morphological features, fruit output, and phytochemical content of these subspecies are strongly influenced by variations in climate, altitude, soil properties, and genetic background. Research has shown that berries grown at higher elevations typically have higher levels of vitamin C, flavonoids, carotenoids, and phenolic components, which increases their antioxidant and medicinal potential³⁵. As a result, geographic provenance has become a significant factor in determining the nutritional content and therapeutic potential of sea buckthorn products.

Due to the growing demand for sea buckthorn's fruits, seed oil, leaf extracts, and value-added nutraceutical goods, sea buckthorn farming has increased significantly in recent decades. For optimal development and fruit production, the plant needs full sunlight and prefers well-drained sandy or loamy soils with a pH between 5.5 and 7.5. Waterlogging negatively impacts root development and plant productivity, despite its tolerance for poor soils. Seeds, root suckers, hardwood and softwood cuttings, layering, and micropropagation methods are frequently used to accomplish proliferation³⁶.

Vegetative propagation is the best of these techniques for preserving desired genetic characteristics and guaranteeing consistency in commercial crops. Male and female plants must be grown together to enable efficient wind pollination because sea buckthorn is a dioecious species. Depending on plantation density, a male-to-female ratio of 1:6 to 1:9 is advised.

Fruit production typically starts on commercial plantations three to five years after they are established, and maximum output is reached after seven to eight years of growth. Due to the berries' tight arrangement and the presence of sharp thorns, fruit harvesting is still one of the biggest obstacles. Modern methods including branch freezing, mechanized harvesting, and selective breeding for thornless cultivars are being investigated to increase harvesting efficiency because traditional hand harvesting is time-consuming and labor-intensive. The development of high-yielding cultivars with improved fruit quality

and higher concentrations of bioactive compounds has been aided by recent developments in tissue culture, germplasm characterisation, agronomic techniques, and breeding initiatives³⁷.

Sea buckthorn has become known as a multipurpose species of ecological, agricultural, nutritional, and medicinal significance due to its capacity to enhance soil fertility through symbiotic nitrogen fixation with *Frankia* spp., prevent soil erosion through extensive root systems, and produce nutrient-rich fruits with significant pharmaceutical potential³⁸. For sustainable use, genetic resource conservation, phytochemical quality optimization, and large-scale production of standardized raw materials for functional foods, nutraceuticals, cosmeceuticals, and pharmaceutical formulations, it is crucial to comprehend its geographic distribution and cultivation methods.

4. MEDICINAL USES

It has been used ethnomedically for centuries, and traditional healthcare systems in Europe and Asia have long acknowledged it as a valuable therapeutic plant. According to historical accounts, sea buckthorn's therapeutic qualities were recorded in ancient Tibetan, Mongolian, Chinese, Russian, and Ayurvedic literature³⁹. Various parts of the plant, such as berries, leaves, seeds, bark, and oils, were used to prevent and treat a variety of illnesses. Originating from the Greek words "hippos" (horse) and "phaos" (shining), the species name *Hippophae* indicates its early use as animal feed to enhance horses' health, stamina, and attractiveness. Sea buckthorn was used in ancient Tibetan medicine to treat skin conditions, respiratory conditions, digestive issues, and circulatory illnesses⁴⁰.

In a similar vein, Mongolian medicine used the fruits and oils to treat digestive issues, encourage the healing of wounds, boost blood flow, and improve overall health. Sea buckthorn preparations have been widely used in traditional Chinese medicine to treat sputum-related illnesses, improve cardiovascular health, boost immunity, ease coughing, and facilitate digestion⁴¹⁻⁴⁴.

Sea buckthorn berries are traditionally consumed by local communities in the Himalayan regions of India, especially in Ladakh and other high-altitude areas, as juices, herbal teas, syrups, jams, and fermented beverages to prevent nutritional deficiencies during harsh winters, improve physical stamina, and fight fatigue⁴⁵.

While leaf decoctions have been used to treat fever, liver diseases, hypertension, and metabolic disorders, fruit pulp and seed oils have been administered topically to treat burns, frostbite, dermatitis, and other inflammatory skin conditions. Because of its regenerative and anti-inflammatory qualities, sea buckthorn oil has been used in Russian traditional medicine to treat gastric ulcers, radiation-induced injuries, oral mucositis, gynecological diseases, and mucosal lesions. The herb has also been used in Central Asian traditional medicine to boost reproductive health, increase appetite, improve vision, and lengthen life⁴⁶⁻⁴⁷.

Sea buckthorn's rich phytochemical composition, which includes flavonoids, carotenoids, tocopherols, phytosterols, vitamins, and polyunsaturated fatty acids, is directly linked to its wide range of ethnomedical uses. By establishing the antioxidant, anti-inflammatory, immunomodulatory, antibacterial, hepatoprotective, cardioprotective, gastroprotective, and wound-healing properties of sea buckthorn extracts and oils, modern pharmacological studies have confirmed a number of these conventional claims. These results demonstrate its promise as a source of evidence-based phytotherapeutics and offer scientific backing for its long-standing usage in traditional medicine⁴⁸. However, the need for standardization and clinical validation is highlighted by differences in traditional preparation techniques, dosage schedules, geographic origin, and plant part selection.

Therefore, the creation of safe, efficient, and standardized sea buckthorn-based nutraceuticals and pharmaceutical formulations for preventative and therapeutic healthcare may be facilitated by the combination of ethnobotanical knowledge with contemporary scientific methods.

Sea buckthorn's traditional knowledge is still very important in directing current research to find new bioactive chemicals and medicinal uses. In addition to helping to conserve biodiversity, the preservation and documenting of this ethnomedical legacy offers important information for future drug development and the sensible use of this multipurpose medicinal plant (Table -3).

Table 5. Traditional Ethnomedicinal Uses of Different Parts of *Hippophae rhamnoides L.*

Plant Part	Traditional Preparation	Ethnomedicinal Uses	Traditional System/Region
Fruits	Juice, syrup, decoction	Fatigue, cough, digestive disorders, nutritional supplementation	Tibetan, Chinese, Himalayan
Seed Oil	Topical application	Burns, wounds, ulcers, frostbite, skin diseases	Russian, Mongolian
Fruit Oil	Oral and topical use	Gastric ulcers, mucosal healing, inflammation	Russian, Chinese
Leaves	Decoction, herbal tea	Fever, liver disorders, hypertension	Himalayan, Central Asian
Bark	Extracts and decoctions	Digestive complaints and general weakness	Folk medicine
Whole Plant	Functional foods and tonics	Immunity enhancement and vitality	Eurasian traditional medicine

5. PHYTOCHEMICAL COMPOSITION

Hippophae rhamnoides L.'s unique phytochemical makeup is largely responsible for its remarkable medicinal and nutritional benefits. The plant's fruits, seeds, leaves, bark, and roots have all been found to contain up to 200 bioactive chemicals. Subspecies, geographic origin, climate, maturation stage, and extraction techniques all affect the qualitative and quantitative distribution of these components⁴⁹. Flavonoids, phenolic acids, carotenoids, vitamins, fatty acids, phytosterols, and amino acids are the main types of phytochemicals found in sea buckthorn. Together, these substances support sea buckthorn's antioxidant, anti-inflammatory, cardioprotective, hepatoprotective, immunomodulatory, and neuroprotective properties⁵⁰. Additionally, compared to isolated constituents, the synergistic interactions between these metabolites are thought to improve the overall biological efficacy of crude extracts.

Flavonoids

One of the most prevalent polyphenolic families in sea buckthorn is flavonoids, which are thought to be the main sources of the plant's antioxidant capacity. Sea buckthorn berries and leaves contain about 40–50 different flavonoid chemicals. The predominant flavonoids are isorhamnetin and its glycosides, which are commonly employed as marker chemicals for quality assessment. Quercetin, kaempferol, myricetin, catechin, epicatechin, rutin, gallic acid, and proanthocyanidins are further significant flavonoids⁵¹⁻⁵³.

These substances donate hydrogen atoms and stabilize reactive oxygen species (ROS), demonstrating strong free radical scavenging capabilities. Apart from their antioxidant properties, flavonoids have been shown to have anti-inflammatory, anti-diabetic, anti-cancer, vasoprotective, and neuroprotective actions by regulating cellular antioxidant enzymes, inhibiting lipid peroxidation, and modulating NF- κ B signaling. While berry flavonoids are thought to be especially significant for nutraceutical uses, the quantity of flavonoids is typically higher in leaves than in fruits⁵⁴.

Phenolic acid

Another significant class of antioxidants found in sea buckthorn is phenolic acids. These substances can be found free or bound to sugars and other plant metabolites. Gallic acid, caffeic acid, chlorogenic acid, ferulic acid, p-coumaric acid, salicylic acid, protocatechuic acid, syringic acid, vanillic acid, and ellagic acid are among the main phenolic acids found. By chelating transition metals involved in oxidative processes and neutralizing free radicals, phenolic acids considerably increase sea buckthorn's overall antioxidant activity. Numerous studies have shown that these substances have anti-inflammatory, antibacterial, and hepatoprotective properties in addition to preventing oxidative stress-induced cellular damage. Fruit maturity and environmental factors have a significant impact on the phenolic composition, which differs significantly between cultivars⁵⁵⁻⁵⁷.

Carotenoids

Sea buckthorn berries are known to be among the most abundant natural sources of carotenoids, which give the fruits their distinctive yellow to orange-red hue. Sea buckthorn has been shown to contain over 20 carotenoid components; the most common ones are β -carotene, lycopene, zeaxanthin, lutein, β -cryptoxanthin, and violaxanthin.

Because they quench singlet oxygen and prevent lipid peroxidation, carotenoids are potent antioxidants. Additionally, β -carotene is a precursor of vitamin A, which supports immunological response, epithelial integrity, and eyesight. Because they shield retinal tissues from photooxidative damage, zeaxanthin and lutein are especially crucial for eye health. Fruits grown at high altitudes frequently show increased carotenoid accumulation, and the concentration of carotenoids varies greatly between subspecies and geographical areas⁵⁸.

Vitamins

Because of its remarkable vitamin concentration, sea buckthorn is frequently referred to as a "natural vitamin reservoir". Ascorbic acid, or vitamin C, is found in high concentrations in berries; reports range from 50 to 900 mg/100 g of fresh fruit, depending on the cultivar and ambient conditions. This concentration is higher than that of several fruits that are often eaten. Sea buckthorn is a good source of vitamin C as well as vitamins E (tocopherols and tocotrienols), A, K, and various B-complex vitamins, such as thiamine, riboflavin, niacin, pyridoxine, folic acid, and pantothenic acid. While vitamin E shields membrane lipids from oxidative deterioration, vitamin C aids in collagen production, immunological strengthening, and antioxidant defense. The nutritional and medicinal value of sea buckthorn products is greatly increased by the presence of both lipid-soluble and water-soluble vitamins⁵⁹.

Fatty acid

Its lipid fraction has a distinct fatty acid content that is uncommon in plant sources. Nutritious saturated and unsaturated fatty acids are present in both pulp oil and seed oil, although their compositions are very different. While seed oil has significant amounts of linoleic acid and α -linolenic acid, pulp oil is especially rich in palmitoleic acid. Palmitic acid, palmitoleic acid, oleic acid, linoleic acid, α -linolenic acid, and vaccenic acid are the main fatty acids found in sea buckthorn. These fatty acids are essential for preserving the integrity of membranes, controlling inflammatory reactions, bolstering cardiovascular health, and encouraging mucosal and skin healing. Because of its purported advantages in wound healing, epithelium regeneration, metabolic regulation, and dermatological applications, omega-7 fatty acid has garnered significant scientific attention⁶⁰.

Phytosterols

Another significant class of bioactive components in sea buckthorn are phytosterols, which share structural similarities with cholesterol. Sea buckthorn lipids have been reported to contain fourteen sterol constituents. The most common phytosterol is β -sitosterol, which is followed by campesterol, stigmasterol, Δ^5 -avenasterol, citrostadienol, cycloartenol, and 24-methylenecycloartanol.

These substances are known to prevent cardiovascular illnesses by lowering intestinal cholesterol absorption. Phytosterols also have antioxidant, immunomodulatory, anti-inflammatory, and anticancer properties. Cultivar, extraction technique, and the particular plant portion used all affect the sterol level; seed and pulp oils often have the highest quantities.

Amino acid

Additionally, sea buckthorn is a good source of proteins and amino acids. Its fruits, leaves, and seeds have been shown to contain both necessary and non-essential amino acids. Lysine, leucine, isoleucine, valine, methionine, threonine, phenylalanine, tryptophan, arginine, histidine, alanine, glycine, serine, glutamic acid, aspartic acid, and proline are the main amino acids mentioned.

These amino acids support immunological response, nitrogen metabolism, tissue healing, and enzyme synthesis. Essential amino acids improve the nutritional value of sea buckthorn-derived products and facilitate their use in dietary supplements and functional foods. According to recent studies, the amino acid makeup of sea buckthorn preparations may also affect their biological activity and sensory qualities.

Overall, *Hippophae rhamnoides*' varied phytochemical architecture underpins its broad pharmacological profile and facilitates its use as a multipurpose source of pharmaceutical raw materials, nutraceutical compounds, and natural antioxidants. For the creation of evidence-based sea buckthorn formulations and their successful use in clinical practice, thorough characterization and standardization of these components are still essential⁶¹.

6. NUTRITION VALUE

As one of the most nutrient-dense medicinal plants, sea buckthorn (*Hippophae rhamnoides* L.) has drawn a lot of interest as a functional food ingredient because of its remarkable nutritional profile. A wide range of macronutrients, including carbs, dietary fibers, proteins, amino acids, vital fatty acids, vitamins, minerals, and different antioxidant compounds, are found in the fruits, seeds, and leaves. Subspecies, geographic origin, climate, harvesting stage, and processing techniques all affect how concentrated these nutrients are. However, sea buckthorn continuously exhibits better nutritional qualities than many traditional fruits and berries, which supports its growing use in food, medicinal, and nutraceutical goods⁶².

The berries, which are the most desirable edible part of the plant, are a plentiful supply of carbohydrates, mostly fructose and glucose, which are easily available sources of energy. The fruits have significant amounts of dietary fiber, including both soluble and insoluble components, in addition to natural sugars. By increasing intestinal motility, controlling bowel function, boosting satiety, and promoting a healthy gut microbiome, dietary fibers enhance gastrointestinal health. Moreover, the relatively low calorie value paired with a high nutrient density makes sea buckthorn an attractive dietary component for health-conscious consumers and patients with metabolic problems

Table 8. Major Nutritional Components of *Hippophae rhamnoides* L., Their Approximate Levels, and Physiological Functions

Nutrient Class	Major Components	Approximate Content/Range	Physiological Importance
Carbohydrates	Glucose, Fructose	3–7 g/100 g FW	3–7 g/100 g FW
Dietary Fiber	Soluble and insoluble fibers	4–7 g/100 g FW	4–7 g/100 g FW
Vitamin C	Ascorbic acid	50–900 mg/100 g FW	50–900 mg/100 g FW
Vitamin A	β -Carotene and provitamin A carotenoids	Variable	Variable
Vitamin E	Tocopherols and tocotrienols	5–18 mg/100 g	5–18 mg/100 g
Vitamin K	Phylloquinone	Variable	Variable
B-Complex Vitamins	B1, B2, B3, B5, B6, B9	Trace–moderate amounts	Trace–moderate amounts
Fatty Acids	Omega-3, Omega-6, Omega-7, Omega-9	Oil content: 5–20%	Oil content: 5–20%
Protein	Fruit and seed proteins	1–4%	1–4%
Essential Amino Acids	Lysine, Leucine, Isoleucine, Valine, Methionine, etc.	Variable	Variable
Carotenoids	β -Carotene, Lycopene, Zeaxanthin, Lutein	10–40 mg/100 g	10–40 mg/100 g
Flavonoids	Isorhamnetin, Quercetin, Kaempferol, Rutin	Variable by cultivar	Variable by cultivar
Minerals	Potassium, Calcium, Magnesium, Phosphorus	Potassium predominant	Potassium predominant
Trace Elements	Iron, Zinc, Copper, Manganese, Selenium	Variable	Variable
Phytosterols	β -Sitosterol, Campesterol, Stigmasterol	Variable	Variable
Phenolic Compounds	Phenolic acids and polyphenols	Variable	Variable

Sea buckthorn is sometimes referred to as a "natural multivitamin source" because of its exceptional vitamin concentration⁶³. Ascorbic acid, or vitamin C, is the most prevalent and biologically relevant of these nutrients. The concentration of vitamin C in fresh berries has been reported to range from about 50 to 900 mg/100 g fresh weight, depending on cultivar, environmental factors, and maturity stage. This is significantly higher than the levels found in many commonly consumed fruits, including oranges, apples, and grapes. Because it neutralizes reactive oxygen species, vitamin C is essential for collagen formation, wound healing, immune system strengthening, iron absorption, and antioxidant defense⁶⁴.

It is a good source of ascorbic acid, fat-soluble vitamins (A, E, and K), and numerous B-complex vitamins (thiamine (B1), riboflavin (B2), niacin (B3), pyridoxine (B6), folic acid (B9), and pantothenic acid (B5)). Together, these vitamins support healthy vision, brain function, blood coagulation, energy metabolism, and cellular defense against oxidative damage. Because the lipid portion of sea buckthorn has a balanced composition of unsaturated and saturated fatty acids, it has special nutritional value. In contrast to many plant oils, sea buckthorn is a botanical source that provides omega-3, omega-6, omega-7, and omega-9 fatty acids.

While palmitoleic acid (omega-7), a relatively uncommon fatty acid in the plant kingdom, is present in significant amounts in pulp oil, linoleic acid (omega-6) and α -linolenic acid (omega-3) are found in approximately equal amounts in seed oil. These fatty acids support cardiovascular health, maintain membrane fluidity, control inflammatory responses, improve skin hydration, encourage mucosal repair, and enhance metabolic balance. As a result, sea buckthorn oils are now highly prized components of dermatological formulations, newborn nutrition products, and dietary supplements.

The nutritional value of sea buckthorn-derived products is further improved by the presence of protein and amino acid components. Lysine, leucine, valine, isoleucine, methionine, threonine, phenylalanine, tryptophan, arginine, glutamic acid, glycine, and proline are among the essential and non-essential amino acids found in the fruits, seeds, and leaves. Growth, tissue healing, enzyme synthesis, neurotransmitter production, and immunological function are all aided by essential amino acids. Sea buckthorn's amino acid composition enhances the nutritional advantages offered by its vitamins and fatty acids, even though it is not usually thought of as a protein-rich meal.

Hippophae rhamnoides is a nutritionally outstanding botanical resource due to its exceptional combination of vitamins, vital fatty acids, amino acids, minerals, dietary fibers, and antioxidant phytochemicals. Its versatile nutritional qualities enable its use as a functional food and nutraceutical ingredient as well as a promising part of medicinal formulations intended to enhance quality of life, prevent oxidative stress-related illnesses, and promote health⁶⁵.

7. PHARMACOLOGICAL ACTIVITIES

Over the past 20 years, *Hippophae rhamnoides* L.'s wide range of pharmacological activity has drawn a lot of attention from scientists. Its wide range of bioactive components, which include flavonoids, phenolic acids, carotenoids, tocopherols, phytosterols, vitamins, and polyunsaturated fatty acids, are mainly responsible for these medicinal qualities. Sea buckthorn has been shown to have important antioxidant, anti-inflammatory, antidiabetic, cardioprotective, hepatoprotective, neuroprotective, anticancer, gastroprotective, wound-healing, and immunomodulatory properties in preclinical, experimental, and limited clinical trials. These phytochemicals' synergistic interactions greatly enhance their multifunctional therapeutic potential and facilitate their increasing use in pharmaceutical and nutraceutical formulations⁶⁶.

Antioxidant activity

One of the pharmacological characteristics of sea buckthorn that has been studied the most is its antioxidant activity. Rich in flavonoids (isorhamnetin, quercetin, and rutin), phenolic acids, carotenoids, tocopherols, and vitamin C, the berries, leaves, and seeds work together to counteract reactive oxygen species (ROS) and reactive nitrogen species (RNS). These substances improve natural antioxidant defense mechanisms, such as glutathione peroxidase (GPx), catalase (CAT), and superoxide dismutase (SOD), reduce lipid peroxidation, and maintain membrane integrity. Sea buckthorn extracts have shown exceptional antioxidant potential in numerous *in vitro* experiments using DPPH, ABTS, FRAP, ORAC, and superoxide radical scavenging assays. Additionally, research on animals has demonstrated that sea buckthorn intake lowers oxidative stress indicators and shields tissues from damage caused by free radicals. The potential application of sea buckthorn as a natural antioxidant in formulation development and preventive healthcare is supported by these findings⁶⁷.

Anti-inflammatory activity

Many chronic diseases are caused by inflammation, and sea buckthorn has shown encouraging anti-inflammatory qualities. Sea buckthorn contains flavonoids, triterpenoids, and unsaturated fatty acids that inhibit the synthesis of pro-inflammatory mediators like cyclooxygenase-2 (COX-2), inducible nitric oxide synthase (iNOS), interleukin-1 β (IL-1 β), interleukin-6

(IL-6), and tumor necrosis factor-alpha (TNF- α). According to research, sea buckthorn extracts reduce inflammatory reactions by blocking the nuclear factor-kappa B (NF- κ B) signaling pathway. Sea buckthorn's anti-inflammatory properties help treat inflammatory bowel illnesses, cardiovascular diseases, dermatological ailments, and mucosal injuries⁶⁸.

Anti diabetic activity

Sea buckthorn may enhance glycemic control and lower the risk of complications related to diabetes, according to new research. By blocking digestive enzymes like α -amylase and α -glucosidase, polyphenols and flavonoids control the metabolism of carbohydrates by decreasing the absorption of glucose after meals. Sea buckthorn has also been shown to boost pancreatic β -cell function, increase insulin sensitivity, and alter glucose transporter activity. Studies on animals have shown that administering sea buckthorn extracts reduces oxidative stress, lipid abnormalities, and fasting blood glucose levels. These results suggest that sea buckthorn could be used as an additional therapeutic agent to treat metabolic syndrome and diabetes mellitus⁶⁷.

Cardioprotective Activity

Because sea buckthorn is rich in flavonoids, phytosterols, tocopherols, and omega fatty acids, it has substantial cardioprotective potential. By raising levels of high-density lipoprotein (HDL) and lowering concentrations of triglycerides, low-density lipoprotein (LDL), and total cholesterol, these components enhance lipid metabolism. Additionally, sea buckthorn enhances endothelial function, prevents oxidative damage to vascular tissues, and inhibits platelet aggregation. Regular use of sea buckthorn products may lower cardiovascular risk factors and help prevent atherosclerosis and coronary heart disease, according to experimental and clinical research⁶⁸.

Hepatoprotective activity

Several experimental models of chemically induced liver injury have shown that sea buckthorn possesses hepatoprotective properties. Antioxidant components protect hepatocyte membranes, lower hepatic oxidative stress, and inhibit inflammatory reactions in hepatic tissues. Sea buckthorn extract administration has been linked to decreases in serum liver enzymes, such as alkaline phosphatase (ALP), aspartate aminotransferase (AST), and alanine aminotransferase (ALT). Additionally, histopathological research shows that sea buckthorn reduces fatty degeneration, necrosis, and hepatic fibrosis. These findings provide credence to its possible use in preventing metabolic and toxin-induced liver diseases⁶⁹.

Neuroprotective activity

Neurodegenerative diseases are largely caused by oxidative stress and neuroinflammation. Flavonoids and carotenoids produced from sea buckthorn have neuroprotective properties by scavenging free radicals, preventing neuronal death, and modifying inflammatory pathways. According to experimental research, these substances boost cognitive function, maintain neural integrity, and improve mitochondrial function. Although more clinical research is necessary, sea buckthorn's antioxidant qualities may help slow the development of age-related neurological disorders like Parkinson's disease and Alzheimer's disease⁷⁰.

Antioxidant activity

The anticancer potential of sea buckthorn extracts and extracted phytoconstituents has been documented in a number of in vitro and in vivo investigations. Through the induction of apoptosis, cell cycle arrest, inhibition of angiogenesis, and modification of signaling pathways implicated in carcinogenesis, flavonoids, carotenoids, and phenolic chemicals prevent the growth of tumor cells. Hepatic, breast, stomach, and colon cancer cells are among the cancer cell lines against which sea buckthorn components have shown inhibitory effects. However, the majority of the information that is now available is still preclinical, and carefully planned clinical trials are required to determine their safety and effectiveness in the treatment of cancer⁷¹.

Wound healing activity

Wound care is one of the most well-known traditional uses for sea buckthorn. Palmitoleic acid, carotenoids, tocopherols, and phytosterols, which promote tissue regeneration and repair, are abundant in the oils extracted from fruits and seeds. Sea buckthorn lowers oxidative stress and microbial invasion at the wound site while increasing collagen synthesis, angiogenesis, fibroblast proliferation, and epithelialization. Burns, cuts, frostbite, radiation damage, and chronic wounds

have all benefited from topical treatments. The use of sea buckthorn oils in dermatological and cosmeceutical formulations has been made easier by these discoveries⁷².

Immunomodulatory activity

It has been shown that sea buckthorn can influence both innate and adaptive immune responses. Vitamins, fatty acids, polysaccharides, and flavonoids all increase macrophage activity, promote lymphocyte proliferation, and control cytokine production. Following the administration of sea buckthorn extracts, improvements in humoral and cellular immunity have been shown in experimental trials. Furthermore, sea buckthorn's immunomodulatory properties may help maintain immunological homeostasis, facilitate recovery from physiological stress, and increase resistance to infections. One of the main flavonoids in sea buckthorn, isorhamnetin, has been especially linked to immune-boosting qualities⁷³.

Table 9. Pharmacological Activities of *Hippophae rhamnoides* and Their Proposed Mechanisms of Action

Activity	Major Bioactive Compounds	Proposed Mechanism
Antioxidant	Flavonoids, Vitamin C, Tocopherols	ROS scavenging, enhancement of SOD, CAT, GPx
Anti-inflammatory	Flavonoids, Triterpenoids	NF- κ B inhibition, cytokine suppression
Antidiabetic	Polyphenols, Flavonoids	α -Glucosidase inhibition, improved insulin sensitivity
Cardioprotective	Phytosterols, Omega fatty acids	Lipid regulation, anti-platelet activity
Hepatoprotective	Flavonoids, Tocopherols	Reduction of hepatic oxidative stress
Neuroprotective	Carotenoids, Flavonoids	Anti-apoptotic and antioxidant effects
Anticancer	Polyphenols, Carotenoids	Apoptosis induction and cell cycle arrest
Gastroprotective	Sea buckthorn oil	Mucosal regeneration and antioxidant effects
Wound Healing	Palmitoleic acid, Tocopherols	Collagen synthesis and epithelialization
Immunomodulatory	Isorhamnetin, Polysaccharides	Regulation of immune cell function

When taken as a whole, these pharmacological activities demonstrate *Hippophae rhamnoides*' therapeutic flexibility and validate many of its traditional ethnomedical applications. The available data strongly support the ongoing investigation of sea buckthorn as a promising source of bioactive compounds for the development of functional foods, nutraceuticals, and evidence-based pharmaceutical formulations, even though the majority of the evidence has come from in vitro and animal studies. To successfully translate it into contemporary therapeutic practice, more carefully planned clinical investigations and standardized preparations are necessary⁷⁴.

8. MECHANISM OF ACTION FOR ANTI-OXIDANT ACTIVITY

Because sea buckthorn (*Hippophae rhamnoides* L.) contains a variety of bioactive substances, such as flavonoids (isorhamnetin, quercetin, kaempferol, rutin), phenolic acids, carotenoids, tocopherols (vitamin E), and ascorbic acid (vitamin C), it has exceptional antioxidant activity. Together, these phytochemicals neutralize reactive nitrogen species (RNS) and reactive oxygen species (ROS), shielding cellular components from oxidative damage. Numerous in vitro and in vivo studies have demonstrated sea buckthorn's antioxidant capacity, suggesting its potential role in preventing oxidative stress-associated disorders like cancer, diabetes mellitus, neurodegenerative diseases, cardiovascular diseases, and aging-related complications⁷⁵.

Direct scavenging of free radicals is the main antioxidant mechanism. By giving unstable free radicals hydrogen atoms or electrons, flavonoids and phenolic substances transform them into more stable molecules and stop chain oxidation events (Fig. no -3). Singlet oxygen species are effectively quenched by carotenoids, especially β -carotene, lutein, and zeaxanthin, while oxidative breakdown of cellular lipids and proteins is inhibited by vitamins C and E. Together, these processes lower lipid peroxidation and maintain membrane integrity⁷⁶.

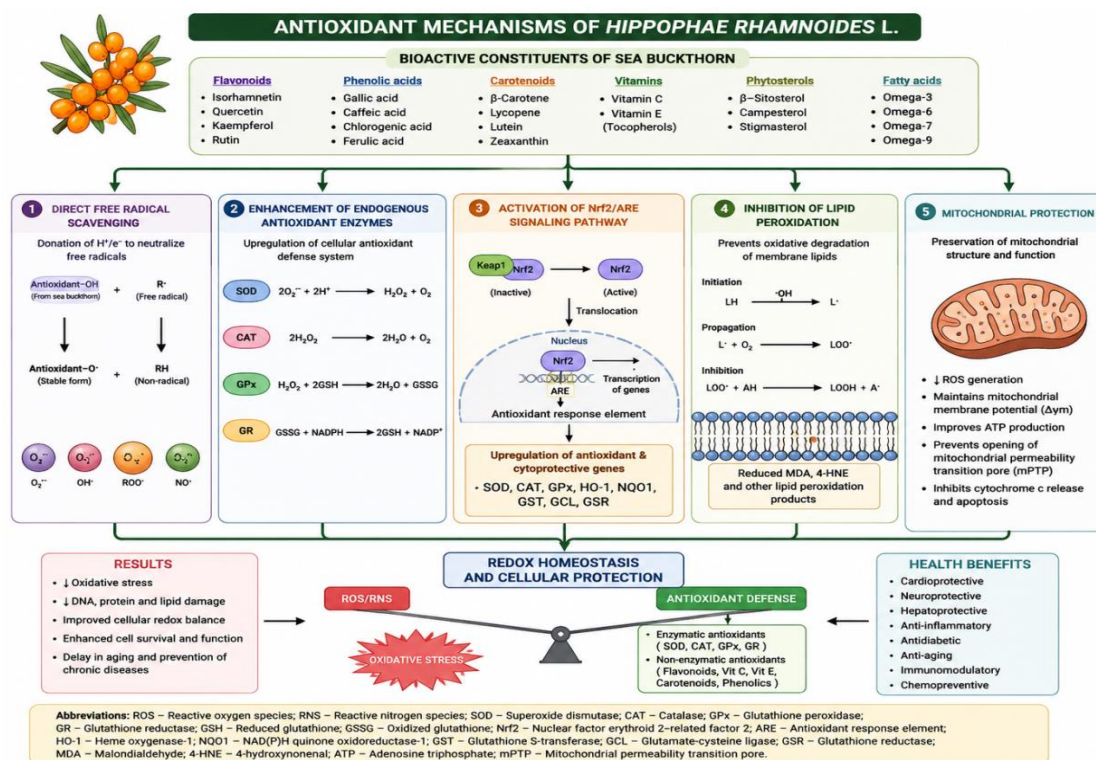


Fig No – 3 Anti oxidant Mechanism of *Hippophae rhamnoides* L.

Sea buckthorn improves endogenous antioxidant defense systems in addition to directly scavenging radicals. Antioxidant enzyme activity, including superoxide dismutase (SOD), catalase (CAT), glutathione peroxidase (GPx), and glutathione reductase (GR), have been found to significantly increase after sea buckthorn preparations are administered. By transforming hydrogen peroxide and superoxide radicals into less dangerous molecules, these enzymes serve as the main cellular defense mechanism against oxidative stress⁷⁷.

Activation of the nuclear factor erythroid 2-related factor 2 (Nrf2) signaling pathway is another significant mechanism. Sea buckthorn contains bioactive flavonoids that facilitate Nrf2's translocation into the nucleus by dissociating it from its cytoplasmic inhibitor Keap1. Heme oxygenase-1 (HO-1), NAD(P)H quinone oxidoreductase-1 (NQO1), glutathione-S-transferase (GST), SOD, CAT, and GPx are among the antioxidant and detoxification genes that are expressed when activated Nrf2 binds to antioxidant response elements (AREs). This process increases tolerance to oxidative damage and fortifies cellular antioxidant defenses⁷⁸.

Additionally, sea buckthorn prevents lipid peroxidation, which damages membranes and produces hazardous aldehydes like malondialdehyde. Following supplementation with sea buckthorn extracts or oils, several animal studies have shown decreased MDA levels and enhanced antioxidant status in tissues. Its phytoconstituents maintain ATP synthesis, lower mitochondrial ROS production, protect the integrity of the mitochondrial membrane, and stop oxidative stress-induced apoptosis⁷⁹.

Overall, sea buckthorn's antioxidant effectiveness is mediated by a number of complementary mechanisms, such as direct scavenging of free radicals, activation of Nrf2-dependent signaling pathways, enhancement of endogenous antioxidant enzymes, inhibition of lipid peroxidation, and maintenance of mitochondrial function. These mechanisms offer a solid foundation for the development of antioxidant pharmaceutical formulations and sea buckthorn-based nutraceuticals for the management and prevention of disorders linked to oxidative stress⁸⁰.

9. CLINICAL STUDIES AND SAFETY PROFILE

Despite the fact that most research on *Hippophae rhamnoides* L. has been done in vitro and on animals, a number of clinical studies have shown that it may be beneficial to human health. Consuming sea buckthorn-derived products, such as juices, oils, and berry extracts, may enhance antioxidant status, regulate lipid metabolism, lower cardiovascular risk factors, and promote skin and mucosal health, according to clinical research. Sea buckthorn supplementation has been linked to

improvements in plasma antioxidant capacity and decreases in oxidative stress indicators, indicating its potential significance in the prevention of illnesses connected to oxidative stress⁸¹.

Furthermore, because of its special tocopherol and omega fatty acid content, sea buckthorn oil has demonstrated positive effects in preserving skin hydration and reducing symptoms related to dry eye syndrome and mucosal atrophy. Studies on humans have also assessed the cardiometabolic advantages of sea buckthorn. Consuming sea buckthorn products on a regular basis has been shown to benefit cardiovascular health by influencing platelet aggregation, improving blood lipid profiles, and lowering sensitivity to lipid oxidation⁸². Furthermore, preliminary research indicates that supplementing with sea buckthorn may boost recovery and strengthen the immune system in physiologically stressful situations; however, large-scale randomized controlled trials are needed to validate these results⁸³.

When used as food, functional drinks, dietary supplements, or pharmaceutical preparations within suggested dosage limits, sea buckthorn is generally regarded as safe and well tolerated. There is little indication of acute or chronic harm in experimental models, according to toxicological investigations⁸⁴. The most common adverse events are restricted to minor gastrointestinal discomfort, such as nausea, bloating, or temporary digestive abnormalities. Clinical investigations have also indicated good tolerability. Although they seem uncommon, allergic reactions cannot be totally ruled out in those who are vulnerable. In certain populations, vigilance should be used despite its positive safety profile.

Sea buckthorn preparations should be used under medical supervision by patients on anticoagulant or antiplatelet therapy because to its possible effects on lipid metabolism and platelet aggregation⁸⁵. Additionally, there is still a lack of sufficient safety information about its usage in pediatric groups, during pregnancy, and during lactation. The significance of product standardization and quality control is further highlighted by variations in phytochemical content brought about by variations in cultivar, geographic origin, extraction processes, and formulation techniques⁸⁶. The research that is now available indicates that sea buckthorn has a promising therapeutic potential and a positive clinical safety profile. However, the majority of clinical studies have used short intervention times and comparatively small sample sizes.

In order to determine the best dosage schedules, validate clinical efficacy, and enable the evidence-based integration of sea buckthorn into contemporary healthcare practice, future carefully planned randomized controlled trials, pharmacokinetic investigations, and long-term safety evaluations are crucial⁸⁷.

10. COMMERCIAL AND PHARMACOLOGICAL ACTIVITY

Hippophae rhamnoides L. has transitioned from a traditional medicinal plant to a commercially valuable raw material in the pharmaceutical, nutraceutical, food, and cosmetic industries thanks to its remarkable nutritional composition and wide range of pharmacological activities. The development of commercial formulations based on sea buckthorn has increased due to the growing customer preference for natural products and preventative healthcare. Sea buckthorn has become a promising component for novel medicinal and health-promoting products due to its abundance of flavonoids, carotenoids, vitamins, tocopherols, phytosterols, and important fatty acids⁸⁸.

Nutraceutical application

Because of its immunomodulatory, cardioprotective, and antioxidant qualities, sea buckthorn is widely used in the nutraceutical industry. Sea buckthorn extracts or oils are included in a variety of commercial goods that are sold all over the world to boost immunity, promote cardiovascular wellness, improve skin health, and lessen fatigue⁸⁹. These items include capsules, soft gels, powders, syrups, and dietary supplements. Sea buckthorn is a useful component of preventive healthcare solutions that target oxidative stress and metabolic problems since it contains omega-3, omega-6, omega-7, and omega-9 fatty acids in addition to vitamins C and E⁹⁰.

Functional food and beverage application

Sea buckthorn berries have been used into several functional food products due to its high nutritional density and pleasant acidic flavor. Juices, jams, jellies, squashes, herbal teas, fermented drinks, fruit wines, yogurts, ice creams, baked goods, and fortified snacks are examples of commercially accessible preparations⁹¹. These goods offer bioactive substances that might lessen oxidative damage and enhance general health in addition to nutritional advantages. The worldwide market for products produced from sea buckthorn has grown dramatically due to the rising demand for functional meals.

Table 13. Commercial and Pharmaceutical Applications of Sea Buckthorn

Sector	Commercial Products	Major Bioactive Constituents	Health/Industrial Benefits
Nutraceuticals	Capsules, soft gels, powders	Flavonoids, vitamins, omega fatty acids	Antioxidant, immune support
Functional Foods	Juices, jams, yogurts, teas	Vitamin C, carotenoids, polyphenols	Nutritional enhancement
Cosmeceuticals	Creams, lip balms, shampoos	Omega-7, tocopherols, carotenoids	Skin regeneration and anti-aging
Pharmaceuticals	Tablets, syrups, ointments	Standardized extracts and oils	Therapeutic applications
Novel Drug Delivery	Nanoemulsions, phytosomes, nanoparticles	Encapsulated phytoconstituents	Improved bioavailability
Industrial Uses	Value-added products	Whole plant utilization	Economic and environmental benefits

Cosmetic and cosmeceutical application

Because of its moisturizing, anti-aging, anti-inflammatory, and regeneration qualities, sea buckthorn oil has become very popular in the cosmetics business. High levels of carotenoids, tocopherols, phytosterols, and palmitoleic acid (omega-7) promote better skin suppleness, increased barrier function, and quicker tissue repair⁹². Sea buckthorn is therefore added to lip balms, shampoos, conditioners, soaps, sunscreens, moisturizers, anti-aging formulas, and after-sun care products. The development of specific dermatological treatments for burns, scars, and radiation-induced skin damage has also benefited from its capacity to heal wounds⁹³.

Pharmaceutical Application

Sea buckthorn is becoming more and more acknowledged by the pharmaceutical industry as a useful source of bioactive chemicals for formulation development. Capsules, pills, soft gelatin capsules, syrups, suspensions, topical creams, gels, ointments, and oral sprays are just a few of the dosage forms in which standardized extracts and oils have been studied⁹⁴. Preparations made from sea buckthorn have shown promise in the treatment of skin injuries, liver dysfunction, inflammatory diseases, stomach ulcers, and cardiovascular conditions.

The creation of oral antioxidant formulations with standardized sea buckthorn extracts has received special attention. Accurate dosing, better patient compliance, convenience of administration, cost-effectiveness, large-scale manufacturability, and improved stability are just a few benefits of tablet dosage forms. One promising approach to managing oxidative stress-related illnesses and preventative healthcare is the addition of sea buckthorn antioxidants to solid oral dose forms⁹⁵. Additionally, improvements in formulation science have made it possible to optimize production procedures and excipient selection in order to maintain the stability and biological activity of delicate phytoconstituents.

Novel drug delivery system

Certain sea buckthorn phytochemicals have drawbacks such limited water solubility, volatility, and inconsistent absorption despite their promise for medicinal use. Numerous innovative drug delivery strategies have been investigated to address these issues. Microemulsions, polymeric nanoparticles, phytosomes, liposomes, nanoencapsulation systems, and nanoemulsions have all shown increased absorption after administration and protection of bioactive substances against degradation⁹⁶.

While lowering the necessary dosage and minimizing variability, these cutting-edge delivery technologies provide targeted distribution, controlled release, and increased therapeutic efficacy. These methods have the potential to greatly improve the therapeutic application of chemicals obtained from sea buckthorn and facilitate their conversion into pharmaceutical medicines that are supported by data.

11. CHALLENGES, LIMITATIONS AND FUTURE PERSPECTIVE

A number of obstacles still prevent *Hippophae rhamnoides* L. from evolving from a traditional medicinal plant to an evidence-based therapeutic treatment, despite the plant's increasing economic and scientific interest. The significant variation in phytochemical content among various subspecies, cultivars, geographic regions, harvesting seasons, and environmental circumstances is one of the main issues. The content of flavonoids, carotenoids, vitamins, and fatty acids is greatly affected by these fluctuations, which can result in inconsistent biological activity and therapeutic effects⁹⁷. Additionally, variations in extraction methods, processing strategies, and storage conditions may change the stability and effectiveness of bioactive components, making it more difficult to standardize sea buckthorn-derived products⁹⁸.

The current literature's prevalence of *in vitro* and animal studies is another significant drawback. There are still few well-designed human clinical trials, despite the fact that many studies have shown encouraging antioxidant, anti-inflammatory, cardioprotective, and wound-healing properties. It is challenging to draw firm conclusions about efficacy, ideal dosage, treatment duration, and long-term safety because the majority of current clinical studies have very small sample numbers, brief intervention periods, and heterogeneous study methods⁹⁹. There are very few thorough pharmacokinetic studies assessing the key sea buckthorn phytochemicals' absorption, distribution, metabolism, and excretion. As a result, many active ingredients' bioavailability and *in vivo* behavior are still poorly known¹⁰⁰.

Another difficulty is the intricacy of sea buckthorn phytochemistry. Rather than the activity of a single component, the medicinal efficacy of crude extracts frequently stems from synergistic interactions among several substances. Nevertheless, the precise chemical processes that underlie these connections remain unclear. Furthermore, the possibility of Pan-Assay Interference Compounds (PAINS) among some phenolic constituents highlights the significance of using rigorous validation strategies during pharmacological investigations and calls for careful interpretation of experimental bioactivity data¹⁰¹.

A number of formulation-related limitations need to be addressed from a pharmacological standpoint. Numerous bioactive substances that have been extracted from sea buckthorn have low oral bioavailability, chemical instability, oxidation susceptibility, and poor water solubility. These restrictions may limit their successful integration into traditional dosage forms and lessen their therapeutic efficacy¹⁰². While innovative drug delivery systems like nanoemulsions, phytosomes, liposomes, polymeric nanoparticles, and microencapsulation technologies have demonstrated encouraging outcomes in enhancing stability and absorption, more research is necessary to determine their viability for large-scale production, regulatory acceptance, and cost-effectiveness¹⁰³.

Additional obstacles to commercialization include regulatory standardization and quality control. There are currently no widely recognized standards for sea buckthorn product quality evaluation, phytochemical fingerprinting, marker-based standardization, and authentication. To guarantee batch-to-batch uniformity, safety, and effectiveness, approved analytical procedures utilizing spectroscopic and chromatographic techniques must be developed¹⁰⁴. Harmonized regulatory frameworks for phytopharmaceuticals and nutraceuticals are also required to promote consumer confidence and global market adoption.

The prospects for sea buckthorn are still very bright despite these obstacles. Deeper understanding of the biosynthesis, biological roles, and molecular targets of its phytoconstituents is anticipated as a result of developments in metabolomics, proteomics, transcriptomics, and systems biology¹⁰⁵. Prioritizing large-scale randomized controlled trials will help establish evidence-based treatment recommendations and support conventional claims. Future studies should also concentrate on finding new biomarkers, clarifying how bioactive substances work in concert, and carrying out thorough pharmacokinetic and toxicological analyses.

The creation of standardized antioxidant compositions utilizing sea buckthorn extracts should receive special attention. Incorporating it into pharmaceutical dosage forms including tablets, capsules, and controlled-release systems presents significant prospects for the management of oxidative stress-related illnesses and preventative healthcare due to its remarkable antioxidant profile. Formulation performance and product repeatability may be further improved by optimizing extraction techniques, choosing appropriate excipients, and putting Quality-by-Design (QbD) concepts into practice¹⁰⁶.

In conclusion, the full therapeutic exploitation of *Hippophae rhamnoides* is now hampered by a number of scientific, technological, and regulatory constraints; nevertheless, these obstacles are likely to be overcome by ongoing multidisciplinary research and innovation. The successful creation of safe, efficient, and standardized sea buckthorn-based

products for future healthcare applications will be made possible by the integration of traditional knowledge with contemporary pharmaceutical technologies, strong clinical evidence, and thorough quality control procedures.

12. CONCLUSION

It has remarkable phytochemical richness and wide range of biological activity, *Hippophae rhamnoides* L., or sea buckthorn, has become one of the most promising therapeutic and nutritionally valuable plants. The current review emphasizes that the plant's various parts, such as berries, seeds, leaves, and oils, are abundant in flavonoids, phenolic acids, carotenoids, tocopherols, vitamins, phytosterols, amino acids, and essential fatty acids, all of which contribute to its substantial therapeutic potential¹⁰⁷. The antioxidant, anti-inflammatory, antidiabetic, cardioprotective, hepatoprotective, neuroprotective, anticancer, gastroprotective, wound-healing, and immunomodulatory qualities documented in multiple experimental and clinical studies are all explained by the synergistic effects of these bioactive constituents¹⁰⁸.

Since oxidative stress is a major factor in the pathophysiology of many chronic diseases, sea buckthorn's antioxidant capability seems to be especially significant among these activities. Sea buckthorn phytochemicals have a strong scientific basis for use in preventive healthcare because of their capacity to scavenge free radicals, improve endogenous antioxidant defense systems, activate Nrf2-mediated pathways, inhibit lipid peroxidation, and maintain cellular redox homeostasis. The creation of antioxidant-based pharmaceutical and nutraceutical compositions utilizing standardized sea buckthorn extracts is also supported by this data.

Sea buckthorn has significant commercial value in addition to its medicinal benefits. It has been effectively added to functional foods, nutritional supplements, cosmeceuticals, and pharmaceutical products. Its prospective applications have been further increased by recent developments in formulation technologies, including as nano-delivery systems and improved solid oral dosage forms. Specifically, adding standardized sea buckthorn extracts to tablet formulations is a viable way to provide natural antioxidant effects while enhancing patient compliance, dose accuracy, product stability, and accessibility.

There are still a number of restrictions in spite of these positive results. The translation of preclinical research into ordinary clinical practice is still hampered by variations in phytochemical content, a lack of standardized extraction techniques, inadequate pharmacokinetic data, and a dearth of large-scale randomized clinical trials. In order to verify efficacy and long-term safety, future research should concentrate on developing strong quality control standards, locating trustworthy phytochemical markers, clarifying synergistic mechanisms of action, and carrying out well planned clinical trials.

All things considered, sea buckthorn is a versatile botanical resource with enormous potential for use in contemporary healthcare. The creation of sea buckthorn-derived products that are safe, efficient, and supported by research may be made easier by combining traditional knowledge with modern pharmaceutical techniques. Additionally, investigating standardized antioxidant pill formulations using sea buckthorn extracts may create new opportunities to promote preventive healthcare and fight illnesses linked to oxidative stress. To fully grasp the therapeutic and economic potential of this amazing plant, multidisciplinary research encompassing phytochemistry, pharmacology, formulation science, and clinical evaluation will be necessary.

In conclusion, sea buckthorn can be considered not only as a traditional medicinal plant but also as a phytopharmaceutical candidate that is ready for the future and has the potential to bridge the gap between nutrition, prevention, and therapy through standardized and scientifically proven formulations.

REFERENCES

- [1] Yang B, Kallio HP. Fatty acid composition of lipids in sea buckthorn (*Hippophae rhamnoides* L.) berries of different origins. *J Agric Food Chem*. 2001;49(4):1939-47.
- [2] Gao X, Ohlander M, Jeppsson N, Björk L, Trajkovski V. Changes in antioxidant effects and their relationship to phytonutrients in fruits of sea buckthorn during maturation. *J Agric Food Chem*. 2000;48(5):1485-90.
- [3] Li TSC, Beveridge THJ. *Sea Buckthorn (Hippophae rhamnoides L.): Production and Utilization*. Ottawa: NRC Research Press; 2003.
- [4] Eccleston C, Baoru Y, Tahvonen R, Kallio H, Rimbach G, Minihane AM. Effects of an antioxidant-rich juice (sea buckthorn) on risk factors for coronary heart disease in humans. *J Nutr Biochem*. 2002;13(6):346-54.

- [5] Gao ZL, Gu XH, Cheng FT, Jiang FH. Effect of sea buckthorn on liver fibrosis: a clinical study. *World J Gastroenterol.* 2003;9(7):1615-7.
- [6] Johansson AK, Korte H, Yang B, Stanley JC, Kallio HP. Sea buckthorn berry oil inhibits platelet aggregation. *J Nutr Biochem.* 2000;11(9):491-5.
- [7] Suryakumar G, Gupta A. Medicinal and therapeutic potential of Sea buckthorn (*Hippophae rhamnoides* L.). *J Ethnopharmacol.* 2011;138(2):268-78.
- [8] Upadhyay NK, Kumar MSY, Gupta A. Antioxidant, cytoprotective and antibacterial effects of sea buckthorn (*Hippophae rhamnoides* L.) leaves. *Food Chem Toxicol.* 2010;48(12):3443-8.
- [9] Zeb A. Chemical and nutritional constituents of sea buckthorn juice. *Pak J Nutr.* 2004;3(2):99-106.
- [10] Michel T, Destandau E, Le Floch G, Lucchesi ME, Elfakir C. Antimicrobial, antioxidant and phytochemical investigations of sea buckthorn. *Food Chem.* 2012;131(3):754-60.
- [11] Krejcarová J, Straková E, Suchý P, Herzig I, Karásková K. Sea buckthorn (*Hippophae rhamnoides* L.) as a potential source of nutraceuticals and its therapeutic possibilities. *Acta Vet Brno.* 2015;84(3):257-68.
- [12] Olas B. Sea buckthorn as a source of important bioactive compounds in cardiovascular diseases. *Food Chem Toxicol.* 2016;97:199-204.
- [13] Fatima T, Snyder CL, Schroeder WR, Cram D, Datla R, Wishart D, et al. Fatty acid composition and lipid metabolism in sea buckthorn. *Lipids Health Dis.* 2012;11:70.
- [14] Wang Z, Zhang Y, Li C, Wang X, Wang X. Phytochemistry, health benefits, and food applications of sea buckthorn: A review. *Front Nutr.* 2022;9:1036295.
- [15] Liu M, Zhang Y, Chen X, Li J, Wang H. Ethnopharmacology, phytochemistry, and pharmacology of *Hippophae rhamnoides* L.: A comprehensive review. *Front Pharmacol.* 2026;17:1759697.
- [16] Beveridge THJ, Li TSC, Oomah BD, Smith A. Sea buckthorn products: Manufacture and composition. *J Agric Food Chem.* 1999;47(9):3480-8.
- [17] Bal LM, Meda V, Naik SN, Satya S. Sea buckthorn berries: A potential source of valuable nutrients for nutraceuticals and cosmeceuticals. *Food Res Int.* 2011;44(7):1718-27.
- [18] Patel CA, Divakar K, Santani D, Solanki HK, Thakkar JH. Remedial prospective of *Hippophae rhamnoides* Linn. (Sea Buckthorn). *ISRN Pharmacol.* 2012;2012:436857.
- [19] Singh V, Gupta RK, Sharma AK, Batra A. Pharmacological activities and nutraceutical applications of sea buckthorn (*Hippophae rhamnoides* L.): A review. *J Plant Sci Res.* 2018;34(2):145-56.
- [20] Rousi A. The genus *Hippophae* L. A taxonomic study. *Ann Bot Fenn.* 1971;8(3):177-227.
- [21] Bartish IV, Jeppsson N, Nybom H, Swenson U. Phylogeny of *Hippophae* (Elaeagnaceae) inferred from parsimony analysis of chloroplast DNA and morphology. *Syst Bot.* 2002;27(1):41-54.
- [22] Swenson U, Bartish IV. Taxonomic synopsis of *Hippophae* (Elaeagnaceae). *Nord J Bot.* 2002;22(3):369-374.
- [23] Li TSC, Schroeder WR. Sea buckthorn (*Hippophae rhamnoides* L.): A multipurpose plant. *HortTechnology.* 1996;6(4):370-380.
- [24] Singh V. Sea buckthorn (*Hippophae* L.): A multipurpose wonder plant. Vol. I: Botany and horticulture. New Delhi: Daya Publishing House; 2003.
- [25] Lu R. Sea Buckthorn: A Multipurpose Plant Species for Fragile Mountains. New Delhi: International Centre for Integrated Mountain Development (ICIMOD); 1992.
- [26] Schroeder WR. Sea buckthorn (*Hippophae rhamnoides* L.): A multipurpose plant resource. *Can J Plant Sci.* 1986;66(1):127-136.

- [27] Khan A, Qaiser M. Taxonomic studies of the genus *Hippophae* L. (Elaeagnaceae) from Pakistan. **Pak J Bot.** 2006;38(2):251–261.
- [28] Dai GH, Liu ZP, Chen CY, Chen XX. Studies on the nitrogen-fixing actinorhizal symbiosis between *Frankia* and sea buckthorn. **Acta Bot Sin.** 2004;46(5):595–600.
- [29] Yao Y, Tigerstedt PMA. Genetic diversity in *Hippophae* and its implications for breeding and germplasm conservation. **Genet Resour Crop Evol.** 1994;41(3):153–165.
- [30] Beveridge T, Li TSC, Oomah BD, Smith A. Sea buckthorn products: Manufacture and composition. **J Agric Food Chem.** 1999;47(9):3480–3488.
- [31] Zeb A. Morphological and biochemical characteristics of sea buckthorn (*Hippophae rhamnoides* L.) berries from different geographical regions. **J Food Biochem.** 2006;30(5):518–529.
- [32] Li TSC, Beveridge THJ. **Sea Buckthorn (*Hippophae rhamnoides* L.): Production and Utilization.** Ottawa: NRC Research Press; 2003.
- [33] Singh V. Sea buckthorn (*Hippophae* L.): A multipurpose wonder plant. Vol. II: Biochemistry and pharmacology. New Delhi: Daya Publishing House; 2006.
- [34] Stobdan T, Angchok D, Tundup P, Paljor E, Dawa S. Sea buckthorn: An emerging bio-resource of the cold arid trans-Himalayan region of Ladakh, India. **Indian J Tradit Knowl.** 2010;9(3):458–462.
- [35] Yao Y, Tigerstedt PMA. Geographical variation of growth, morphology and fruit characteristics in natural populations of sea buckthorn (*Hippophae rhamnoides*). **J Hortic Sci.** 1995;70(2):285–292.
- [36] Ruan CJ, Li H, Mopper S, Qin P. Physiological and molecular responses of *Hippophae rhamnoides* to environmental stresses: Implications for ecological restoration. **Plant Physiol Biochem.** 2013;70:465–472.
- [37] Padmavathamma AS, Li LY, Kumari UR. An overview of sea buckthorn cultivation, propagation techniques and utilization in Himalayan regions. **J Med Plants Res.** 2014;8(35):1043–1050.
- [38] Arimboor R, Kumar KS, Arumughan C. Sea buckthorn (*Hippophae rhamnoides*): A rich source of bioactive phytochemicals and its cultivation prospects. **Food Res Int.** 2018;112:1–11.
- [39] **Xu YJ, Kaur M, Dhillon RS, Tappia PS, Dhalla NS.** Health benefits of sea buckthorn for the prevention of cardiovascular diseases. *J Funct Foods.* 2011;3(1):2–12.
- [40] **Suryakumar G, Gupta A.** Medicinal and therapeutic potential of Sea buckthorn (*Hippophae rhamnoides* L.). *J Ethnopharmacol.* 2011;138(2):268–278.
- [41] **Zeb A.** Important therapeutic uses of sea buckthorn (*Hippophae*): A review. *J Biol Sci.* 2004;4(5):687–693.
- [42] **Singh V.** Sea buckthorn (*Hippophae* L.): A multipurpose wonder plant. Vol. III: Advances in research and development. New Delhi: Daya Publishing House; 2008.
- [43] **Stobdan T, Chaurasia OP, Korekar G, Yadav A, Singh SB.** Sea buckthorn: An emerging storehouse of bioactive compounds and its ethnobotanical importance in trans-Himalayan India. *J Tradit Complement Med.* 2013;3(1):1–8.
- [44] **Yang B, Kallio HP.** Fatty acid composition and physiological functions of sea buckthorn oils. *Trends Food Sci Technol.* 2002;13(5):160–167.
- [45] **Guliyev VB, Gul M, Yildirim A.** Hippophae rhamnoides L.: Chromatographic methods to determine chemical composition, use in traditional medicine and pharmacological effects. *J Chromatogr B Analyt Technol Biomed Life Sci.* 2004;812(1–2):291–307.
- [46] **Geetha S, Sai Ram M, Singh V, Ilavazhagan G, Sawhney RC.** Anti-oxidant and immunomodulatory properties of seabuckthorn (*Hippophae rhamnoides*)—an in vivo study. *J Ethnopharmacol.* 2002;79(3):373–378.
- [47] **Olas B.** The beneficial health aspects of sea buckthorn (*Elaeagnus rhamnoides* (L.) A. Nelson) oil. *J Ethnopharmacol.* 2018;213:183–190.

- [48] Liu M, Zhang Y, Chen X, Li J, Wang H. Ethnopharmacology, phytochemistry and pharmacology of *Hippophae rhamnoides* L.: A comprehensive review. *Front Pharmacol*. 2025;16:1466136.
- [49] Beveridge T, Li TSC, Oomah BD, Smith A. Sea buckthorn products: Manufacture and composition. *J Agric Food Chem*. 1999;47(9):3480–3488.
- [50] Yang B, Kallio HP. Composition and physiological effects of sea buckthorn lipids. *Trends Food Sci Technol*. 2002;13(5):160–167.
- [51] Zeb A. Chemical and nutritional constituents of sea buckthorn juice. *Pak J Nutr*. 2004;3(2):99–106.
- [52] Guliyev VB, Gul M, Yildirim A. *Hippophae rhamnoides* L.: Chromatographic methods to determine chemical composition, use in traditional medicine and pharmacological effects. *J Chromatogr B Analyt Technol Biomed Life Sci*. 2004;812(1–2):291–307.
- [53] Bal LM, Meda V, Naik SN, Satya S. Sea buckthorn berries: A potential source of valuable nutrients for nutraceuticals and cosmeceuticals. *Food Res Int*. 2011;44(7):1718–1727.
- [54] Fatima T, Snyder CL, Schroeder WR, Cram D, Datla R, Wishart D, et al. Fatty acid composition and lipid metabolism in sea buckthorn (*Hippophae rhamnoides* L.) berries and seeds. *Lipids Health Dis*. 2012;11:70.
- [55] Olas B. The beneficial health aspects of sea buckthorn (*Elaeagnus rhamnoides* (L.) A. Nelson) oil. *J Ethnopharmacol*. 2018;213:183–190.
- [56] Krejcarová J, Straková E, Suchý P, Herzig I, Karásková K. Sea buckthorn as a potential source of nutraceuticals and its therapeutic possibilities – a review. *Acta Vet Brno*. 2015;84(3):257–268.
- [57] Arimboor R, Kumar KS, Arumughan C. Sea buckthorn (*Hippophae rhamnoides*): A rich source of bioactive phytochemicals and its nutraceutical applications. *Food Res Int*. 2018;112:1–11.
- [58] Wang Z, Zhang Y, Li C, Wang X, Wang X. Phytochemistry, health benefits and food applications of sea buckthorn: A review. *Front Nutr*. 2022;9:1036295.
- [59] Liu M, Zhang Y, Chen X, Li J, Wang H. Ethnopharmacology, phytochemistry and pharmacology of *Hippophae rhamnoides* L.: A comprehensive review. *Front Pharmacol*. 2025;16:1466136.
- [60] Michel T, Destandau E, Le Floch G, Lucchesi ME, Elfakir C. Antimicrobial, antioxidant and phytochemical investigations of sea buckthorn (*Hippophae rhamnoides* L.). *Food Chem*. 2012;131(3):754–760.
- [61] Bal LM, Meda V, Naik SN, Satya S. Sea buckthorn berries: A potential source of valuable nutrients for nutraceuticals and cosmeceuticals. *Food Res Int*. 2011;44(7):1718–1727.
- [62] Beveridge T, Li TSC, Oomah BD, Smith A. Sea buckthorn products: Manufacture and composition. *J Agric Food Chem*. 1999;47(9):3480–3488.
- [63] Yang B, Kallio HP. Composition and physiological effects of sea buckthorn lipids. *Trends Food Sci Technol*. 2002;13(5):160–167.
- [64] Arimboor R, Kumar KS, Arumughan C. Sea buckthorn (*Hippophae rhamnoides*): A rich source of bioactive phytochemicals and its nutraceutical applications. *Food Res Int*. 2018;112:1–11.
- [65] Wang Z, Zhang Y, Li C, Wang X, Wang X. Phytochemistry, health benefits and food applications of sea buckthorn: A review. *Front Nutr*. 2022;9:1036295.
- [66] Geetha S, Sai Ram M, Singh V, Ilavazhagan G, Sawhney RC. Anti-oxidant and immunomodulatory properties of seabuckthorn (*Hippophae rhamnoides*)—an in vivo study. *J Ethnopharmacol*. 2002;79(3):373–378.
- [67] Upadhyay NK, Kumar MSY, Gupta A. Antioxidant, cytoprotective and antibacterial effects of sea buckthorn (*Hippophae rhamnoides* L.) leaves. *Food Chem Toxicol*. 2010;48(12):3443–3448.
- [68] Xu YJ, Kaur M, Dhillon RS, Tappia PS, Dhalla NS. Health benefits of sea buckthorn for the prevention of cardiovascular diseases. *J Funct Foods*. 2011;3(1):2–12.

- [69] Olas B. Sea buckthorn as a source of important bioactive compounds in cardiovascular diseases. *Food Chem Toxicol.* 2016;97:199–204.
- [70] Patel CA, Divakar K, Santani D, Solanki HK, Thakkar JH. Remedial prospective of *Hippophae rhamnoides* Linn. *ISRN Pharmacol.* 2012;2012:436857.
- [71] Michel T, Destandau E, Le Floch G, Lucchesi ME, Elfakir C. Antimicrobial, antioxidant and phytochemical investigations of sea buckthorn (*Hippophae rhamnoides* L.). *Food Chem.* 2012;131(3):754–760.
- [72] Olas B. The beneficial health aspects of sea buckthorn (*Elaeagnus rhamnoides* (L.) A. Nelson) oil. *J Ethnopharmacol.* 2018;213:183–190.
- [73] Wang Z, Zhang Y, Li C, Wang X, Wang X. Phytochemistry, health benefits and food applications of sea buckthorn: A review. *Front Nutr.* 2022;9:1036295.
- [74] Liu M, Zhang Y, Chen X, Li J, Wang H. Ethnopharmacology, phytochemistry and pharmacology of *Hippophae rhamnoides* L.: A comprehensive review. *Front Pharmacol.* 2025;16:1466136.
- [75] Gao X, Ohlander M, Jeppsson N, Björk L, Trajkovski V. Changes in antioxidant effects and their relationship to phytonutrients in fruits of sea buckthorn during maturation. *J Agric Food Chem.* 2000;48(5):1485–1490.
- [76] Suryakumar G, Gupta A. Medicinal and therapeutic potential of Sea buckthorn (*Hippophae rhamnoides* L.). *J Ethnopharmacol.* 2011;138(2):268–278.
- [77] Olas B. Sea buckthorn as a source of important bioactive compounds in cardiovascular diseases. *Food Chem Toxicol.* 2016;97:199–204.
- [78] Wang Z, Zhang Y, Li C, Wang X, Wang X. Phytochemistry, health benefits and food applications of sea buckthorn: A review. *Front Nutr.* 2022;9:1036295.
- [79] Upadhyay NK, Kumar MSY, Gupta A. Antioxidant, cytoprotective and antibacterial effects of sea buckthorn leaves. *Food Chem Toxicol.* 2010;48(12):3443–3448.
- [80] Michel T, Destandau E, Le Floch G, Lucchesi ME, Elfakir C. Antimicrobial, antioxidant and phytochemical investigations of sea buckthorn. *Food Chem.* 2012;131(3):754–760.
- [81] Fatima T, Snyder CL, Schroeder WR, Cram D, Datla R, Wishart D, et al. Fatty acid composition and lipid metabolism in sea buckthorn. *Lipids Health Dis.* 2012;11:70.
- [82] Bal LM, Meda V, Naik SN, Satya S. Sea buckthorn berries: A potential source of valuable nutrients for nutraceuticals and cosmeceuticals. *Food Res Int.* 2011;44(7):1718–1727.
- [83] Geetha S, Singh V, Ram MS, Ilavazhagan G, Sawhney RC. Antioxidant and immunomodulatory properties of sea buckthorn. *J Ethnopharmacol.* 2002;79(3):373–378.
- [84] Zeb A. Chemical and nutritional constituents of sea buckthorn juice. *Pak J Nutr.* 2004;3(2):99–106.
- [85] Liu M, Zhang Y, Chen X, Li J, Wang H. Ethnopharmacology, phytochemistry and pharmacology of *Hippophae rhamnoides* L.: A comprehensive review. *Front Pharmacol.* 2025;16:1466136.
- [86] Krejcarová J, Straková E, Suchý P, Herzig I, Karásková K. Sea buckthorn as a potential source of nutraceuticals and its therapeutic possibilities. *Acta Vet Brno.* 2015;84(3):257–268.
- [87] Patel CA, Divakar K, Santani D, Solanki HK, Thakkar JH. Remedial prospective of *Hippophae rhamnoides* Linn. *ISRN Pharmacol.* 2012;2012:436857.
- [88] Gao ZL, Gu XH, Cheng FT, Jiang FH. Effect of sea buckthorn on oxidative stress and tissue protection. *World J Gastroenterol.* 2003;9(7):1615–1617.
- [89] Singh V, Gupta RK, Sharma AK, Batra A. Pharmacological activities and nutraceutical applications of sea buckthorn: A review. *J Plant Sci Res.* 2018;34(2):145–156.

- [90] Suryakumar G, Gupta A. Medicinal and therapeutic potential of Sea buckthorn (*Hippophae rhamnoides* L.). J Ethnopharmacol. 2011;138(2):268–278.
- [91] Wang Z, Zhang Y, Li C, Wang X, Wang X. Phytochemistry, health benefits and food applications of sea buckthorn: A review. Front Nutr. 2022;9:1036295.
- [92] Olas B. Sea buckthorn as a source of important bioactive compounds in cardiovascular diseases. Food Chem Toxicol. 2016;97:199–204.
- [93] Bal LM, Meda V, Naik SN, Satya S. Sea buckthorn berries: A potential source of valuable nutrients for nutraceuticals and cosmeceuticals. Food Res Int. 2011;44(7):1718–1727.
- [94] Krejcarová J, Straková E, Suchý P, Herzig I, Karásková K. Sea buckthorn as a potential source of nutraceuticals and its therapeutic possibilities. Acta Vet Brno. 2015;84(3):257–268.
- [95] Yang B, Kallio HP. Composition and physiological effects of sea buckthorn lipids. Trends Food Sci Technol. 2002;13(5):160–167.
- [96] Zeb A. Important therapeutic uses of sea buckthorn (*Hippophae*): A review. J Biol Sci. 2004;4(5):687–693.
- [97] Wang Z, Zhang Y, Li C, Wang X, Wang X. Phytochemistry, health benefits and food applications of sea buckthorn: A review. Front Nutr. 2022;9:1036295.
- [98] Liu M, Zhang Y, Chen X, Li J, Wang H. Ethnopharmacology, phytochemistry and pharmacology of *Hippophae rhamnoides* L.: A comprehensive review. Front Pharmacol. 2025;16:1466136.
- [99] Bal LM, Meda V, Naik SN, Satya S. Sea buckthorn berries: A potential source of valuable nutrients for nutraceuticals and cosmeceuticals. Food Res Int. 2011;44(7):1718–1727.
- [100] Olas B. Sea buckthorn as a source of important bioactive compounds in cardiovascular diseases. Food Chem Toxicol. 2016;97:199–204.
- [101] Patel CA, Divakar K, Santani D, Solanki HK, Thakkar JH. Remedial prospective of *Hippophae rhamnoides* Linn. ISRN Pharmacol. 2012;2012:436857.
- [102] Baell JB, Holloway GA. New substructure filters for removal of pan assay interference compounds (PAINS) from screening libraries and bioassays. J Med Chem. 2010;53(7):2719–2740.
- [103] Michel T, Destandau E, Le Floch G, Lucchesi ME, Elfakir C. Antimicrobial, antioxidant and phytochemical investigations of sea buckthorn. Food Chem. 2012;131(3):754–760.
- [104] Upadhyay NK, Kumar MSY, Gupta A. Antioxidant, cytoprotective and antibacterial effects of sea buckthorn (*Hippophae rhamnoides*) leaves. Food Chem Toxicol. 2010;48(12):3443–3448.
- [105] Singh V, Gupta RK, Sharma AK, Batra A. Pharmacological activities and nutraceutical applications of sea buckthorn: A review. J Plant Sci Res. 2018;34(2):145–156.
- [106] Fatima T, Snyder CL, Schroeder WR, Cram D, Datla R, Wishart D, et al. Fatty acid composition and lipid metabolism in sea buckthorn. Lipids Health Dis. 2012;11:70.
- [107] Krejcarová J, Straková E, Suchý P, Herzig I, Karásková K. Sea buckthorn as a potential source of nutraceuticals and its therapeutic possibilities. Acta Vet Brno. 2015;84(3):257–268.
- [108] Wang X, Liu M, Zhang Y, Chen X. Omics approaches and future directions in sea buckthorn research: From phytochemistry to precision nutraceuticals. Front Pharmacol. 2026;17:1589247.