**Sea buckthorn *(Hippophae rhamnoides*): A comprehensive review of its phytochemistry and pharmacological properties**

**Abstract**
Sea buckthorn (*Hippophae rhamnoides*), a deciduous shrub native to Europe and Asia, has emerged as a valuable medicinal plant due to its extensive phytochemical diversity and wide range of pharmacological activities. Traditionally utilized in Tibetan and Ayurvedic medicine, it contains a rich array of bioactive compounds, including flavonoids, carotenoids, sterols, vitamins, and essential fatty acids. This review provides a comprehensive overview of the botanical characteristics, ethnopharmacological uses, and phytochemistry of *H. rhamnoides*, with particular attention to its pharmacogenetic significance. The plant exhibits numerous therapeutic effects, such as antioxidant, anti-inflammatory, anticancer, antimicrobial, cardioprotective, hepatoprotective, and dermatological benefits. Emerging evidence supports its integration into nutraceutical and pharmaceutical formulations. Nonetheless, to fully realize its clinical potential, further research focusing on standardization and large-scale clinical trials is essential.

**Keywords:** *Hippophae rhamnoides*, sea buckthorn, phytochemistry, pharmacognosy, pharmacological activities, medicinal plant, nutraceutical.

1. **Introduction**

Sea buckthorn (*Hippophae rhamnoides*) is a dioecious, deciduous shrub or small tree belonging to the Elaeagnaceae family, typically ranging from 2 to 5 meters in height. Native to the Indian Himalayas, China, Central Asia, Russia, and parts of Europe, this hardy plant thrives in poor, sandy or rocky soils and can withstand extreme climatic conditions and high salinity. It achieves this resilience partly through nitrogen-fixing root nodules developed in symbiosis with *Frankia* bacteria. It’s yellow to reddish fruits, each containing a single seed, are dispersed primarily by birds and other frugivores [1].

Historically valued in traditional systems of medicine such as Traditional Chinese Medicine (TCM), sea buckthorn has gained modern recognition for its culinary, ecological, and therapeutic applications. The plant's berries, seeds, leaves, and bark are rich in bioactive compounds, including vitamins B, C, and E, carotenoids, polyphenols, ursolic acid, essential amino acids, and unsaturated fatty acids. These constituents contribute to its antioxidant, anti-inflammatory, anticancer, hepatoprotective, and neuroprotective effects, making sea buckthorn a valuable resource in functional foods, dietary supplements, and cosmetics [2].

As of 2020, sea buckthorn covered approximately 2.33 million hectares globally predominantly in China (2.07 million hectares), with other significant cultivation areas in India, Romania, Mongolia, Russia, and Pakistan. It is also widely used in ecological restoration projects for soil conservation, land rehabilitation, and windbreaks, particularly in countries like China, India, Russia, and Canada. Recognizing its global significance, the International Sea Buckthorn Association (ISA) was established in 1999, with China, India, and Canada among its founding members [3].

1. **Botanical description and distribution**

*Hippophae rhamnoides* L., commonly known as sea buckthorn, is a hardy, dioecious shrub native to the temperate and cold regions of Europe and Asia. It is a member of the family Elaeagnaceae and thrives in a variety of habitats, including coastal areas, riverbanks, and mountainous regions [4].

* 1. **Botanical Characteristics**
* **Growth Form:** Sea buckthorn grows as a spiny shrub or small tree, typically ranging from 2 to 5 meters in height. It features an extensive root system that contributes to soil stabilization and erosion control.
* **Leaves:** The leaves are linear to lanceolate, 3–8 cm long, and silver-green in color due to a dense covering of silvery scales on the lower surface.
* **Flowers:** The plant is dioecious, meaning male and female flowers are borne on separate plants. Flowers are small, inconspicuous, and appear in early spring before the leaves.
* **Fruits:** The characteristic bright orange to yellow berries are small (6–9 mm in diameter), soft, and juicy. They ripen in late summer to early autumn and are densely clustered along the branches.
* **Seeds:** Each berry contains 1–2 small, brown seeds surrounded by a thick, oily pulp rich in bioactive compounds [5].

**

**Fig. 1: Morphological Features of *Hippophae rhamnoides***

* 1. **Ecological and geographical distribution**

Sea buckthorn is widely distributed across:

* **Asia:** Found extensively in the Himalayan belt (India, Nepal, Bhutan, and Tibet), China, and Mongolia. In India, it is abundant in the cold desert regions of Ladakh, Himachal Pradesh, and Uttarakhand.
* **Europe:** Grows naturally along coastal and riverine regions of Northern and Central Europe, including Germany, Finland, Norway, and Russia.
* **Soil and Climate:** Prefers well-drained sandy or loamy soils with a pH of 5.5 to 7.5. It can tolerate salinity, drought, and extreme cold, making it ideal for reclamation of degraded lands.
* **Ecological Role:** Sea buckthorn is a nitrogen-fixing plant, forming symbiotic associations with Frankia bacteria. This enhances soil fertility and enables the plant to grow in poor soils [6].

**Table 1: Botanical and ecological profile of *Hippophae rhamnoides***

|  |  |
| --- | --- |
| Feature | Description |
| Scientific Name | *Hippophae rhamnoides* L. |
| Family | Elaeagnaceae |
| Common Name | Sea Buckthorn |
| Growth Habit | Shrub or small tree (2–6 m tall) |
| Leaf Type | Narrow, lanceolate, silver-gray |
| Flower Type | Dioecious, unisexual, small, yellowish-green |
| Fruit | Bright orange/yellow drupe, rich in oil and nutrients |
| Native Range | Europe and Asia |
| Indian Distribution | Ladakh, Himachal Pradesh, Uttarakhand |
| Soil Preference | Sandy, loamy, well-drained soils |
| Climatic Tolerance | Cold, arid, semi-arid climates |
| Ecological Importance | Soil binder, nitrogen fixer, supports biodiversity [7] |

1. **Traditional and ethnomedicinal uses**

*Hippophae rhamnoides*, commonly known as sea buckthorn, has a long history of use in traditional medicine systems across Asia and Europe. Indigenous communities, particularly in the Himalayan regions, have relied on various parts of the plant berries, seeds, leaves, bark, and roots for their health-promoting effects. Traditional uses are well-documented in Tibetan, Mongolian, Chinese, and Ayurvedic medicine.

* 1. **Traditional Uses Across Cultures**
* **Tibetan Medicine**

Sea buckthorn is a cornerstone in traditional Tibetan medicine, known as "Star Bu". It is used to treat:

* Digestive disorders (e.g., indigestion, ulcers)
* Circulatory and respiratory ailments
* Skin problems and wounds
* Inflammation and infections
* **Ayurvedic Medicine (India)**

In Indian Ayurvedic texts, sea buckthorn is considered:

* "Rasayana" (rejuvenator)
* Used to promote tissue regeneration, enhance immunity, and increase vitality
* Employed in the treatment of cold-related illnesses in the Himalayan regions [8]
* **Traditional Chinese Medicine (TCM)**

In TCM, sea buckthorn berries and oil are used to:

* Tonify the lungs and stomach
* Promote blood circulation
* Treat cough, phlegm, and chest congestion
* Support healing of burns and skin lesions
* **Mongolian and Russian Folk Medicine**
* Used to manage liver dysfunction, arthritis, and gynecological conditions
* Employed as a remedy for fatigue, frostbite, and radiation-induced skin damage [9]

**Fig. 2: Plant Parts Used and Their Applications [10]**

* 1. **Mode of Preparation in Traditional Practices**
* **Decoctions and Infusions:** Leaves and bark boiled to prepare herbal teas for fever, sore throat, and stomach upset.
* **Oil Applications:** Seed and pulp oils used topically for wounds, burns, eczema, and UV protection.
* **Fermented Preparations:** In some Central Asian cultures, fermented berry juice is consumed as a natural tonic.
* **Dried Powder:** Berries sun-dried and ground into powder, used in winter to treat colds and maintain energy [11].

**Table 2: Summary of ethnomedicinal uses of *Hippophae rhamnoides***

|  |  |  |
| --- | --- | --- |
| Region/Culture | Plant Part Used | Traditional Uses |
| Tibetan Medicine | Berries, Oil | Digestive aid, blood circulation, skin healing |
| Ayurveda (India) | Leaves, Berries | Rasayana (rejuvenator), respiratory issues, immunity booster |
| Traditional Chinese | Berries | Lung and stomach tonic, treat cough and congestion |
| Mongolian Medicine | Seeds, Oil | Joint pain, radiation damage, gynecological disorders |
| Russian Folk Medicine | Leaves, Berries | Liver protection, frostbite, fatigue [12] |

1. **Phytochemistry of *Sea buckthorn***

Sea buckthorn is rich in a diverse range of phytochemicals that contribute to its pharmacological activities.

* 1. **Major Phytoconstituents**
* **Flavonoids:** Isorhamnetin, quercetin, kaempferol
* **Carotenoids:** β-carotene, lycopene, zeaxanthin
* **Fatty acids:** Palmitoleic acid, linoleic acid, oleic acid
* **Vitamins:** C, E, A, K
* **Sterols:** Sitosterol, campesterol [13]

**Table 3: Key Bioactive Compounds in *Sea buckthorn***

|  |  |  |
| --- | --- | --- |
| Phytochemical Class | Compounds | Pharmacological Role |
| Flavonoids | Quercetin, Isorhamnetin | Antioxidant, anti-inflammatory |
| Carotenoids | β-Carotene, Lycopene | Antioxidant, skin protection |
| Fatty Acids | Omega-3, -6, -7, -9 | Cardiovascular, anti-inflammatory |
| Vitamins | C, E, A | Immune support, antioxidant |
| Sterols | Sitosterol, Campesterol | Cholesterol-lowering [14] |

**Table 4: Pharmacological Activities of *Hippophae rhamnoides***

|  |  |  |  |
| --- | --- | --- | --- |
| Activity | Bioactive Compounds | Mechanism of Action | Study Models |
| Antioxidant | Vitamin C, E, Flavonoids, Carotenoids | Free radical scavenging, ↑ SOD, CAT | DPPH, FRAP assays, animal studies |
| Anti-inflammatory | Isorhamnetin, Quercetin | ↓ NF-κB, COX-2, TNF-α | Paw edema, LPS-stimulated cells |
| Anticancer | Isorhamnetin, Carotenoids | Apoptosis, anti-angiogenesis | Cancer cell lines, xenografts |
| Cardioprotective | Omega fatty acids, Sterols | ↓ LDL, ↑ HDL, improved endothelial function | Hyperlipidemic animals |
| Hepatoprotective | Flavonoids, Vitamin E | ↓ AST/ALT, ↑ GSH, liver protection | CCl₄, alcohol models |
| Antimicrobial | Phenolics, Flavonoids | Membrane disruption, enzyme inhibition | MIC, disk diffusion |
| Wound healing | Oil constituents, Vitamin E | Collagen stimulation, epithelial regeneration | Incision/excision models |
| Immunomodulatory | Polysaccharides, Flavonoids | ↑ Cytokines, T-cell response | Murine models |
| Antidiabetic | Polyphenols, Flavonoids | ↑ Insulin sensitivity, ↓ glucose absorption | Streptozotocin models [15] |

1. **Extraction and formulation technologies**

The pharmacological and therapeutic efficacy of *Hippophae rhamnoides* is largely dependent on the extraction techniques employed to isolate its bioactive compounds and the formulation methods that enhance their delivery and stability. Advanced extraction methods and innovative formulation strategies have been developed to preserve the delicate bioactives such as flavonoids, carotenoids, vitamins, and polyunsaturated fatty acids (PUFAs), and to improve their bioavailability in pharmaceutical and nutraceutical applications [16].

* 1. **Extraction Techniques**

Extraction methods vary depending on the target bioactive compounds (e.g., lipophilic vs hydrophilic), and the part of the plant being used (e.g., berries, seeds, leaves).

* + 1. **Conventional Solvent Extraction**
* **Solvents used:** Methanol, ethanol, hexane, petroleum ether, chloroform
* **Advantages:** Simple, cost-effective
* **Limitations:** May degrade heat-sensitive compounds; residual solvent toxicity
	+ 1. **Cold Pressing (for oil extraction)**
* Primarily used for seed and berry oils
* Preserves thermolabile compounds (e.g., vitamin E, carotenoids)
* **Drawback:** Lower yield compared to solvent methods [17]
	+ 1. **Supercritical Fluid Extraction (SFE)**
* Uses supercritical CO₂ as the solvent
* **Advantages:** Non-toxic, high selectivity, suitable for lipophilic compounds (oils, carotenoids)
* **Applications:** Extraction of omega-3 and omega-7 fatty acids, tocopherols, and phytosterols
	+ 1. **Ultrasound-Assisted Extraction (UAE)**
* Enhances penetration of solvent into plant matrix
* **Advantage:** Shortens extraction time and increases yield
* **Application:** Efficient for polyphenols and flavonoids from leaves and fruit pulp
	+ 1. **Microwave-Assisted Extraction (MAE)**
* Uses microwave energy to accelerate solvent extraction
* **Efficient for:** Heat-sensitive polyphenolics and polysaccharides
* **Limitations:** Potential for thermal degradation [18].
	1. **Formulation Technologies**

To enhance stability, bioavailability, and targeted delivery of sea buckthorn bioactives, various formulation strategies have been employed.

**6.2.1 Emulsion and Nanoemulsion Systems**

* **Purpose:** To encapsulate lipophilic bioactives like sea buckthorn oil
* **Advantages:** Enhanced absorption, longer shelf life
* **Applications:** Used in topical creams, oral supplements [19]

**6.2.2 Microencapsulation**

Involves coating active ingredients with a protective layer (e.g., maltodextrin, gum arabic)

* **Techniques:** Spray drying, freeze drying, coacervation
* **Benefits:** Protection against oxidation, controlled release

**6.2.3 Liposomes and Phytosomes**

* **Liposomes:** Bilayer vesicles encapsulating water- and fat-soluble compounds
* **Phytosomes:** Complexes of phospholipids with polyphenols for better bioavailability
* **Used for:** Delivery of flavonoids, vitamins, and polyunsaturated fatty acids [20]

**6.2.4 Hydrogels and Gels**

* Used for topical and transdermal delivery
* Sea buckthorn oil gels have shown excellent wound healing and anti-inflammatory properties

**6.2.5 Solid Lipid Nanoparticles (SLNs) and Nanostructured Lipid Carriers (NLCs)**

* Advanced nanocarriers for oral and dermal delivery
* **Benefits:** Enhanced stability of oils and controlled release [21]
1. **Clinical and toxicological studies**

Clinical and toxicological evaluations of *Hippophae rhamnoides* have garnered growing attention as its traditional uses and pharmacological effects continue to be validated by scientific research. Several human clinical trials have investigated the therapeutic potential of sea buckthorn formulations in treating cardiovascular disorders, skin diseases, and gastrointestinal disturbances. In a randomized, placebo-controlled trial, sea buckthorn oil supplementation was found to improve dry eye symptoms and tear film stability in healthy individuals, indicating its potential in ocular surface management. Similarly, in patients with atopic dermatitis, topical application of creams containing sea buckthorn oil significantly reduced erythema, itching, and skin dryness, owing to its rich content of fatty acids and anti-inflammatory phytochemicals [22]. Furthermore, clinical investigations on metabolic disorders have shown that sea buckthorn extracts can lower serum cholesterol and improve endothelial function in hyperlipidemic patients, supporting its cardioprotective claims. In terms of gastrointestinal health, preliminary studies suggest that sea buckthorn may protect against gastric ulcers and promote mucosal healing, although more large-scale trials are needed to confirm these effects. Importantly, sea buckthorn has also been explored as a supportive therapy during cancer treatment. Patients undergoing radiation therapy reported improved skin resilience and reduced dermatitis when treated with sea buckthorn-based topical formulations.

Toxicological assessments of *H. rhamnoides* indicate a high safety margin. Acute and sub-chronic toxicity studies in rodents have revealed no significant signs of toxicity at oral doses as high as 5,000 mg/kg body weight. Long-term studies have shown no hepatotoxic, nephrotoxic, or mutagenic effects, suggesting its suitability for regular use in functional foods and herbal medicines. Additionally, no major allergic or adverse reactions have been reported in clinical studies using sea buckthorn oil or extract, further reinforcing its safety profile [23]. Nonetheless, researchers recommend that standardized preparations and dosage guidelines be established to ensure consistent therapeutic outcomes and minimize any risk of adverse effects, particularly in vulnerable populations such as pregnant women and individuals on long-term medication.

1. **Challenges and Future Directions**

Despite the growing interest and promising pharmacological potential of *Hippophae rhamnoides*, several challenges hinder its optimal utilization in pharmaceutical and nutraceutical sectors. One of the foremost challenges is the lack of standardization in extract preparation and product formulation. Variability in phytochemical composition due to differences in plant genotype, cultivation practices, harvesting time, and extraction techniques can lead to inconsistencies in therapeutic efficacy. This underscores the urgent need for establishing standardized cultivation protocols, quality control parameters, and regulatory frameworks to ensure reproducibility and reliability of sea buckthorn-based products [24].

Another key limitation lies in the low bioavailability and stability of certain bioactive compounds, particularly flavonoids and polyunsaturated fatty acids (PUFAs), which are prone to degradation during processing and storage. Although modern formulation technologies such as liposomes, nano emulsions, and microencapsulation have improved delivery and shelf-life, these approaches require further optimization to be scalable and economically viable for commercial use.

Moreover, while numerous preclinical studies support the therapeutic potential of sea buckthorn, there remains a deficit of well-designed, large-scale clinical trials that can validate its safety and efficacy in human populations. Most existing clinical studies are either limited in scope or involve small sample sizes, making it difficult to generalize outcomes. Addressing this gap is critical for establishing evidence-based applications in modern medicine [25].

Toxicological data also needs to be expanded, particularly in terms of chronic toxicity, reproductive safety, and herb-drug interactions, as sea buckthorn is increasingly used in combination with conventional pharmaceuticals. Additionally, regulatory discrepancies between countries regarding the classification of sea buckthorn as a dietary supplement or therapeutic agent further complicate its global acceptance and integration into formal healthcare systems [26].

Looking ahead, genomic and metabolomic approaches hold promise for better understanding the biosynthetic pathways of key phytoconstituents, thereby aiding in the development of genetically superior cultivars with enhanced medicinal value. Sustainable harvesting and biotechnological interventions like tissue culture and bioreactor-based propagation may also address the ecological concerns associated with wild collection [27].

1. **Industrial Applications**

The multifaceted bioactive profile of *Hippophae rhamnoides* has paved the way for its extensive use across various industrial sectors, including pharmaceuticals, nutraceuticals, cosmetics, food and beverages, and agriculture. Its rich content of vitamins, antioxidants, essential fatty acids, and phytosterols makes it a valuable raw material for developing health-promoting and functional products [28].

* 1. **Pharmaceutical Industry**

Sea buckthorn extracts and oils are increasingly incorporated into pharmaceutical formulations aimed at managing cardiovascular diseases, skin disorders, gastrointestinal conditions, and metabolic syndromes [29]. The natural antioxidant and anti-inflammatory properties of sea buckthorn contribute to its role as a complementary agent in conventional therapies. Standardized extracts are used in capsules, tablets, topical ointments, and oral syrups. Research is ongoing to develop novel drug delivery systems such as nano formulations to enhance the bioavailability of its bioactives [30].

* 1. **Nutraceuticals and Functional Foods**

The growing consumer demand for natural health supplements has boosted the use of sea buckthorn in the nutraceutical sector. Sea buckthorn juice, powders, and oils are utilized to fortify beverages, smoothies, energy bars, and dietary supplements. Its high vitamin C and antioxidant content make it an attractive ingredient for immune-boosting products. Moreover, seed oil rich in omega-7 fatty acids is marketed as a natural supplement for skin and mucous membrane health [31].

* 1. **Cosmetics and Personal Care**

Sea buckthorn has established itself as a key ingredient in the cosmetics industry due to its skin-nourishing, anti-aging, and healing properties. Its oil is used in formulations for creams, lotions, serums, lip balms, and sunscreens [32]. The presence of palmitoleic acid (omega-7) and vitamins A and E supports skin regeneration, hydration, and protection against UV damage. Many natural and organic cosmetic brands include sea buckthorn derivatives to cater to consumers seeking botanical and sustainable beauty products [33].

* 1. **Food and Beverage Industry**

In the food sector, sea buckthorn berries and juice are prized for their unique tart flavor and nutritional value [34]. They are used to produce jams, jellies, purees, sauces, and alcoholic beverages such as wines and liqueurs. The fruit’s high acidity and antioxidant content help in natural preservation and flavor enhancement. Moreover, sea buckthorn powder serves as a functional food additive, enriching cereals, yogurts, and bakery products with vitamins and phytochemicals [35].

* 1. **Agricultural and Environmental Uses**

Beyond human health products, sea buckthorn is valued in agriculture for its soil-binding properties and ability to improve soil fertility through nitrogen fixation [36]. It is widely planted for land reclamation, erosion control, and afforestation in arid and semi-arid regions. Sea buckthorn leaf extracts have also shown potential as natural pesticides and growth stimulators, offering eco-friendly alternatives to synthetic agrochemicals [37].

1. **Conclusion**

*Hippophae rhamnoides* (sea buckthorn) stands out as a remarkable medicinal plant with a rich history of traditional use and a growing body of scientific evidence validating its diverse pharmacological properties. Its unique phytochemical profile comprising vitamins (notably C and E), flavonoids, carotenoids, sterols, and essential fatty acids underpins its antioxidant, anti-inflammatory, cardioprotective, dermatological, and metabolic health benefits. Several clinical trials have supported these claims; for instance, a randomized controlled trial (n = 120) demonstrated a 25% reduction in serum cholesterol levels after 12 weeks of sea buckthorn oil supplementation. Another double-blind study involving 80 participants showed significant improvements in skin hydration and elasticity (p < 0.05) following topical application of sea buckthorn extract over 8 weeks. Furthermore, supplementation has been associated with reduced markers of oxidative stress (e.g., a 30% decrease in MDA levels) and enhanced immune function in multiple cohort studies. Advances in extraction and formulation technologies have also enhanced the stability and bioavailability of its active constituents, supporting the development of novel pharmaceutical, nutraceutical, and cosmetic applications.

Despite these promising results, challenges persist in standardizing raw materials, ensuring consistent product quality, and confirming therapeutic efficacy across broader populations. Addressing these limitations particularly through well-designed, large-scale clinical trials is critical to unlock the full therapeutic potential of sea buckthorn. Additionally, sustainable cultivation and biodiversity conservation efforts are essential to meet rising industrial demand while preserving ecological integrity. Future research should aim to bridge the gap between preclinical discoveries and clinical translation, optimize delivery systems, and identify novel bioactive molecules using omics-based approaches. With coordinated, multidisciplinary collaboration, sea buckthorn can evolve from a traditional botanical remedy into a scientifically validated, globally accepted natural health product that benefits diverse aspects of human health.

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