RESEARCH PAPER

Review on Medicinal properties of *Hippophae rhamnoides* (Sea buckthorn)

Manpreet[1], Navdeep Kaur[2], Shveta[3*]

[1]Department of Botany, Sri Guru Teg Bahadur Khalsa College, Sri Anandpur Sahib (Punjab) –140118), manpreet.botany@gmail.com
[2]Department of Botany, Sri Guru Granth Sahib, World University, Fatehgarh Sahib (Punjab) –140407, navdeepbotanist@gmail.com
[3*]Department of Botany, Sri Guru Granth Sahib, World University, Fatehgarh Sahib (Punjab) –140407, shvetakaushal07@gmail.com

Abstract
Hippophae rhamnoides (sea buckthorn) is gaining significant attention as a potent natural source of antioxidants due to its complex phytochemical profile and exceptional nutritional value. While traditionally used to manage various ailments, modern research now validates its antioxidant, anti-inflammatory, hepatoprotective, and cardioprotective properties. These therapeutic effects stem from a synergistic combination of bioactive constituents—including flavonoids, phenolic acids, vitamins, and unsaturated fatty acids—found across different plant tissues, such as the berries, leaves, and seeds. This review synthesizes current knowledge on the antioxidant potential of *H. rhamnoides*, focusing on its phytochemical composition, underlying molecular mechanisms, and the supporting evidence from experimental and clinical studies. Furthermore, it addresses the plant's expanding role in functional foods and nutraceuticals, while highlighting the necessity for standardized formulations and more robust clinical trials to fully bridge the gap between experimental findings and therapeutic application.

Keywords: *Hippophae rhamnoides* ; sea buckthorn; antioxidant potential; phytochemical diversity; functional foods; nutraceuticals; oxidative stress

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Introduction

Among natural antioxidant sources, *Hippophae rhamnoides* L. (sea buckthorn) has attracted increasing attention because of its exceptional nutritional value and chemically diverse phytochemical profile. This thorny deciduous shrub of the family Elaeagnaceae is widely distributed across Europe and Asia, particularly in China, Mongolia, Russia and the Himalayan region. Its ability to thrive under drought, salinity, frost and nutrient-deficient conditions has not only facilitated its cultivation in marginal environments but also increased interest in its ecological and medicinal significance (Chen *et al*., 2023; Raclariu-Manolica & Socaciu, 2023; Javaid *et al*., 2026).
Sea buckthorn has long been incorporated into traditional medical systems, where its fruits, leaves and seeds have been used for the management of gastrointestinal, hepatic, cardiovascular and dermatological disorders. Modern pharmacological studies support many of these traditional applications, demonstrating antioxidant, anti-inflammatory, hepatoprotective, cardioprotective and immunomodulatory activities. These biological effects arise from the combined action of multiple phytochemicals, including phenolic acids, flavonoids, carotenoids, tocopherols, vitamins and unsaturated fatty acids, which function synergistically rather than independently (Chen *et al*., 2023; Chen *et al*., 2024; Javaid *et al*., 2026; Michel *et al*., 2012).
Unlike many medicinal plants in which bioactive compounds are concentrated in a single organ, sea buckthorn accumulates valuable metabolites throughout the plant. Berries are particularly rich in vitamin C, carotenoids and flavonoids, whereas leaves contain abundant phenolic compounds and flavonol glycosides. Seeds provide lipid-soluble antioxidants and essential fatty acids, while branches and bark contribute additional phenolic constituents. This tissue-specific distribution broadens the nutritional and therapeutic value of the species and creates opportunities for the utilization of both edible and underexploited plant materials (Zheng *et al*., 2019; Chenni *et al*., 2026; Singh *et al*., 2024; Guo *et al*., 2017).
Advances in metabolomics and high-resolution analytical techniques have further expanded knowledge of sea buckthorn chemistry by revealing distinct metabolite profiles among plant organs and commercial products. These approaches have facilitated the identification of characteristic biomarkers, strengthened quality control and improved the standardization of sea buckthorn-derived foods and nutraceuticals. At the same time, growing consumer demand for natural health-promoting products has accelerated the incorporation of sea buckthorn into functional foods, dietary supplements and

cosmetic formulations (Raclariu-Manolica & Socaciu, 2023; Liu *et al*., 2023).

Despite the rapid growth of research in recent years, available reviews often emphasize either phytochemistry or pharmacological activity, while comparatively few integrate phytochemical diversity, molecular mechanisms, experimental evidence and therapeutic applications within a single framework. Accordingly, this review synthesizes current knowledge on the antioxidant potential of *Hippophae rhamnoides* , with emphasis on its phytochemical composition, mechanisms of antioxidant action, evidence from experimental and clinical studies, therapeutic relevance and emerging applications in functional foods and nutraceuticals.

2. Botanical Profile, Taxonomy and Distribution of *Hippophae rhamnoides* L.

Hippophae rhamnoides L. (sea buckthorn) is a perennial, thorny, deciduous shrub belonging to the family Elaeagnaceae. Among the species of the genus *Hippophae*, *H. rhamnoides* has received the greatest scientific attention because of its nutritional, medicinal and ecological importance. Its remarkable adaptability to harsh environments and rich phytochemical composition have established it as a valuable medicinal plant and an emerging functional food resource (Chen *et al*., 2023; Singh *et al.*, 2024; Javaid *et al*., 2026; Zielinska *et al*., 2017).

The species is naturally distributed across Europe and Asia, with extensive populations occurring in China, Mongolia, Russia, Nepal and the Himalayan regions of India. In India, it is predominantly found in Ladakh, Himachal Pradesh, Uttarakhand, Jammu and Kashmir, Sikkim and Arunachal Pradesh. Environmental conditions associated with high-altitude habitats, including intense ultraviolet radiation, low temperatures and water stress, promote the accumulation of secondary metabolites that enhance the antioxidant potential of the plant (Chen *et al.*, 2023; Singh *et al*., 2024).

Sea buckthorn is highly tolerant of drought, frost, salinity and nutrient-deficient soils. Its extensive root system and symbiotic association with nitrogen-fixing microorganisms enable successful establishment in degraded landscapes, making the species valuable for soil stabilization, erosion control and ecological restoration in mountainous and arid regions (Singh *et al*., 2024; Raclariu-Manolica & Socaciu, 2023).

Morphologically, *H. rhamnoides* is a dioecious shrub that typically reaches 2–6 m in height. It bears narrow, silvery-green leaves and densely clustered yellow to orange berries on female plants following wind pollination. Although the berries are the principal commercial product because of their high nutritional value, recent studies have demonstrated that leaves, seeds, branches and bark also contain significant quantities of bioactive compounds, indicating that virtually the entire plant possesses pharmaceutical and nutraceutical value (Chen *et al.*, 2023; Zheng *et al.*, 2019; Chenni *et al*., 2026).

Considerable variation in phytochemical composition has been reported among different populations of *H. rhamnoides*, largely reflecting differences in genotype, geographical origin, altitude and environmental conditions. These factors influence the accumulation of phenolic compounds, flavonoids, carotenoids and vitamins, thereby contributing to the observed variation in antioxidant capacity and biological activity. Understanding this natural diversity is therefore essential for the selection of superior germplasm and the production of standardized sea buckthorn-derived products (Chen *et al.*, 2023; Raclariu-Manolica & Socaciu, 2023; Javaid *et al*., 2026).

3. Phytochemical Composition and Distribution of Bioactive Compounds in *Hippophae rhamnoides* L.

The biological activity of *Hippophae rhamnoides* is largely attributed to its chemically diverse phytochemical profile. More than 200 bioactive constituents have been identified, including phenolic acids, flavonoids, carotenoids, vitamins, tocopherols, phytosterols, fatty acids, polysaccharides and organic acids. The abundance of these metabolites varies among plant organs and is influenced by genotype, geographical origin and environmental conditions, resulting in considerable differences in antioxidant capacity (Chen *et al*., 2023; Chenni *et al*., 2026; Javaid *et al*., 2026; Zadernowski *et al*., 2005).

A distinctive feature of sea buckthorn is the uneven distribution of phytochemicals throughout the plant. The berries are particularly rich in vitamin C, carotenoids, tocopherols and flavonoids, making them the principal raw material for functional foods and nutraceuticals. In contrast, the leaves generally contain higher concentrations of phenolic compounds, including rutin, quercetin derivatives and phenolic acids, which contribute substantially to their antioxidant activity. Seeds are characterized by high levels of unsaturated fatty acids, tocopherols and phytosterols, whereas branches and bark contain additional phenolic constituents that represent promising sources of natural antioxidants (Singh *et al*., 2024; Zheng *et al*., 2019; Chenni *et al*., 2026).

Among the identified phytochemicals, phenolic acids and flavonoids are regarded as the major contributors to antioxidant activity. Gallic, caffeic, ferulic and p-coumaric acids, together with flavonoids such as isorhamnetin, quercetin, kaempferol and rutin, effectively scavenge reactive oxygen species and inhibit oxidative damage. Lipid-soluble antioxidants, including carotenoids, tocopherols and essential fatty acids, complement these effects by protecting cellular membranes against lipid peroxidation and maintaining membrane integrity (Chen *et al.*, 2023; Javaid *et al*., 2026).

Recent advances in metabolomic analysis have further revealed that berries, leaves, seeds and branches possess distinct chemical fingerprints. High-resolution techniques such as UHPLC-QTOF-MS and LC-MS have enabled the identification of tissue-specific metabolites and authentication markers, providing valuable tools for quality control, cultivar discrimination and the standardization of commercial sea buckthorn products (Raclariu-Manolica & Socaciu, 2023; Zheng *et al.*, 2019).

Overall, the antioxidant efficacy of *H. rhamnoides* arises from the complementary action of hydrophilic and lipophilic phytochemicals distributed throughout different plant organs. This chemical diversity not only explains the broad pharmacological potential of the species but also supports the utilization of both edible and underexploited plant parts in the development of functional foods, nutraceuticals and phytopharmaceutical products (Chenni *et al.*, 2026; Javaid *et al*., 2026).

4. Molecular Mechanisms Underlying the Antioxidant Activity of *Hippophaer hamnoides* L.

The antioxidant activity of *Hippophae rhamnoides* is mediated through multiple complementary mechanisms that collectively protect cells from oxidative damage. Rather than functioning solely as direct free radical scavengers, its phytochemicals regulate endogenous antioxidant defenses, preserve cellular redox homeostasis and modulate signaling pathways associated with oxidative stress and inflammation. This coordinated response underlies the broad biological and therapeutic effects reported for sea buckthorn (Chen *et al*., 2023; Javaid *et al*., 2026; Suryakumar & Gupta, 2011).

Polyphenols, flavonoids and ascorbic acid constitute the primary hydrophilic antioxidants responsible for neutralizing reactive oxygen species (ROS) and reactive nitrogen species (RNS). By donating electrons or hydrogen atoms, these compounds interrupt oxidative chain reactions and reduce damage to cellular lipids, proteins and nucleic acids. Lipophilic antioxidants, including carotenoids and tocopherols, complement this activity by preventing lipid peroxidation and maintaining membrane stability (Papuc *et al*., 2008; Singh *et al*., 2024).

Beyond direct antioxidant activity, sea buckthorn enhances the cellular antioxidant defense system. Experimental studies have reported increased activities of superoxide dismutase (SOD), catalase (CAT) and glutathione peroxidase (GSH-Px), accompanied by reduced intracellular ROS and malondialdehyde levels following treatment with sea buckthorn extracts. These changes indicate improved protection against oxidative injury and maintenance of cellular redox balance (Liu *et al*., 2023; Javaid *et al*., 2026).

Recent evidence also indicates that sea buckthorn phytochemicals influence intracellular signaling pathways involved in oxidative stress. Modulation of pathways such as AMPK and PI3K/Akt, together with reduced expression of inflammatory mediators including TNF-α and IL-6, contributes to improved cellular survival and attenuation of oxidative stress-induced inflammation. These mechanisms provide a molecular basis for the protective effects of sea buckthorn observed in cardiovascular, metabolic

5. Evidence from In Vitro, In Vivo and Clinical Studies

The antioxidant efficacy of *Hippophae rhamnoides* has been validated through a wide range of experimental models, including chemical assays, cultured cells, animal studies and human investigations. Collectively, these studies demonstrate that sea buckthorn effectively attenuates oxidative stress by reducing free radical generation, enhancing endogenous antioxidant defenses and limiting oxidative damage to cellular components (Chenni *et al*., 2026; Javaid *et al*., 2026; Basu *et al*., 2007).

Chemical antioxidant assays consistently report strong radical-scavenging activity in extracts prepared from berries, leaves and seeds. High activities in DPPH, ABTS and FRAP assays correlate closely with total phenolic and flavonoid contents, with leaf extracts frequently exhibiting greater antioxidant capacity than fruits because of their higher concentrations of phenolic constituents (Papuc *et al*., 2008; Singh *et al*., 2024).

Cell culture studies further confirm these findings by demonstrating that sea buckthorn extracts reduce intracellular ROS accumulation, suppress lipid peroxidation and enhance antioxidant enzymes such as superoxide dismutase and glutathione peroxidase. Fermented sea buckthorn preparations have shown additional improvements in antioxidant activity, suggesting that processing methods may influence biological efficacy (Liu *et al*., 2023).

Evidence from animal models indicates that supplementation with sea buckthorn extracts or oils improves antioxidant status, decreases inflammatory responses and protects tissues against oxidative injury in experimental models of cardiovascular, hepatic and metabolic diseases. Although human studies remain relatively limited, available clinical investigations suggest beneficial effects on oxidative stress markers, lipid metabolism and glucose regulation. Nevertheless, larger randomized clinical trials are required to establish standardized dosage and confirm long-term therapeutic efficacy (Chen *et al*., 2024; Javaid *et al*., 2026).

Overall, the convergence of evidence from in vitro, in vivo and preliminary clinical studies supports H. rhamnoides as a promising natural antioxidant. Future research should prioritize standardized formulations and robust clinical evaluation to facilitate the translation of experimental findings into evidence-based healthcare applications.

Table 1. Experimental evidence supporting the antioxidant activity of *Hippophae rhamnoides*

Experimental model	Principal findings
DPPH, ABTS and FRAP assays	Strong radical-scavenging and reducing activity
Cell culture studies	Reduced ROS and lipid peroxidation; increased SOD and GSH-Px activities
Animal models	Improved antioxidant defense and reduced oxidative tissue injury
Clinical studies	Preliminary improvements in oxidative stress and metabolic biomarkers

6. Therapeutic Applications of *Hippophae rhamnoides L.*

The therapeutic value of *Hippophae rhamnoides* is closely linked to its ability to alleviate oxidative stress and modulate inflammatory and metabolic pathways. A growing body of experimental and clinical evidence suggests that its bioactive constituents, particularly polyphenols, flavonoids, carotenoids and unsaturated fatty acids, contribute to the prevention and management of several chronic diseases (Chen *et al*., 2023; Javaid *et al*., 2026; Vani *et al*., 2012).

Cardiovascular disorders

Sea buckthorn has shown considerable cardioprotective potential by improving lipid metabolism, preserving endothelial function and reducing oxidative stress. Both experimental and clinical studies indicate beneficial effects on vascular health, inflammatory status and cardiovascular risk factors, supporting its use as a complementary dietary intervention (Chen *et al*., 2024).

Diabetes and metabolic disorders

Polyphenols and flavonoids present in sea buckthorn improve glucose homeostasis, enhance insulin sensitivity and reduce oxidative damage associated with hyperglycaemia. These effects suggest potential benefits in managing metabolic syndrome and type 2 diabetes, although additional clinical studies are required to confirm long-term efficacy (Chen *et al*., 2023; Javaid *et al*., 2026).

Liver and neuroprotective effects

Experimental studies have demonstrated hepatoprotective effects through reduced lipid peroxidation, enhanced antioxidant enzyme activity and suppression of inflammatory responses. Similarly, emerging evidence indicates that sea buckthorn phytochemicals protect neuronal cells against oxidative injury and neuroinflammation, highlighting their potential in neurodegenerative disorders. However, most neuroprotective evidence remains preclinical (Javaid *et al*., 2026).

Skin health, obesity and cancer

Sea buckthorn oil is widely incorporated into dermatological formulations because it promotes wound healing, improves skin barrier function and protects against oxidative damage. In addition, preliminary studies suggest beneficial effects on obesity by improving lipid metabolism and reducing oxidative stress. In vitro and animal studies have also reported antiproliferative and pro-apoptotic activities against several cancer cell lines; however, clinical evidence is currently insufficient to support therapeutic recommendations (Chen *et al*., 2023; Javaid *et al*., 2026).

Overall, the available evidence supports *H. rhamnoides* as a promising multifunctional medicinal plant with broad therapeutic potential. Nevertheless, most reported benefits are derived from experimental investigations, emphasizing the need for well-designed clinical trials to establish standardized formulations, optimal dosage and long-term safety.

Table 2. Major therapeutic applications of *Hippophae rhamnoides*

Disease/Condition	Principal therapeutic effects	Major bioactive compounds
Cardiovascular disorders	Improved vascular function and lipid regulation	Flavonoids, phenolics, fatty acids
Diabetes & metabolic syndrome	Improved glucose homeostasis and insulin sensitivity	Polyphenols, flavonoids
Liver disorders	Reduced oxidative damage and inflammation	Phenolics, carotenoids
Neurodegenerative disorders	Neuroprotection and reduced oxidative stress	Flavonoids, carotenoids
Skin disorders	Wound healing and skin protection	Tocopherols, carotenoids, fatty acids
Obesity	Improved lipid metabolism	Polyphenols
Cancer (preclinical)	Antioxidant, antiproliferative and pro-apoptotic effects	Mixed phytochemicals

7. Functional Food and Nutraceutical Applications

The growing demand for natural health-promoting products has accelerated the incorporation of *Hippophae rhamnoides* into functional foods and nutraceutical formulations. Owing to its high concentrations of vitamins, polyphenols, carotenoids and essential fatty acids, sea buckthorn is widely processed into juices, teas, oils, powders, capsules, jams and fortified food products. These products provide nutritional benefits while supplying natural antioxidants that may help reduce oxidative stress and support overall health (Raclariu-Manolica & Socaciu, 2023; Javaid *et al*., 2026; Javaid *et al*., 2026).

Recent studies indicate that processing techniques can influence the biological activity of sea buckthorn products. Controlled fermentation has been shown to enhance flavonoid availability, improve antioxidant capacity and increase antimicrobial activity, while modern metabolomic approaches facilitate quality assessment and authentication of commercial products. Such advances contribute to the production of standardized, high-quality nutraceuticals with improved functional properties (Liu *et al*., 2023; Raclariu-Manolica & Socaciu, 2023).

Beyond conventional foods, sea buckthorn extracts are increasingly incorporated into dietary supplements and cosmetic formulations aimed at promoting cardiovascular health, metabolic balance, immune function and skin protection. Nevertheless, optimization of processing methods, improvement of bioavailability and establishment of standardized quality parameters remain essential for maximizing the therapeutic value of sea buckthorn-derived products (Javaid *et al*., 2026).

8. Safety, Toxicity and Limitations

Hippophae rhamnoides has a long history of use as both a food and traditional medicine, and current evidence indicates that it is generally safe when consumed in recommended amounts. Experimental studies and the limited number of clinical investigations conducted to date have reported few adverse effects associated with the consumption of sea buckthorn fruits, oils or derived products. Its favourable safety profile has contributed to its increasing use in functional foods, nutraceuticals and cosmetic formulations (Chen *et al*., 2024; Javaid *et al*., 2026).

Despite these encouraging findings, several limitations remain. The phytochemical composition of sea buckthorn varies considerably with genotype, geographical origin, environmental conditions and processing methods, resulting in differences in product quality and biological activity. Consequently, standardization of raw materials, extraction procedures and quality control measures is essential to ensure consistent efficacy and safety. Modern metabolomic approaches provide valuable tools for authentication and quality assessment of commercial preparations (Raclariu-Manolica & Socaciu, 2023).

9. Future Perspectives

Although substantial progress has been made in elucidating the phytochemistry and antioxidant properties of *Hippophae rhamnoides* , several important challenges remain before its full therapeutic potential can be realized. Future research should focus on identifying the individual bioactive compounds responsible for specific biological activities and clarifying their molecular targets through integrated metabolomic, transcriptomic and pharmacological approaches (Raclariu-Manolica & Socaciu, 2023; Javaid *et al*., 2026; Zeb, 2004).

A major priority is the generation of robust clinical evidence. Well-designed, multicentre randomized controlled trials are required to establish the efficacy, optimal dosage, bioavailability and long-term safety of standardized sea buckthorn preparations. In parallel, harmonized extraction methods and quality control protocols should be developed to ensure consistency among commercial products (Chen *et al*., 2024; Javaid *et al*., 2026).

Future studies should also explore sustainable utilization of underexploited plant parts, including leaves, branches and processing by-products, together with the development of novel functional foods, nutraceuticals and phytopharmaceutical formulations. Such multidisciplinary efforts will facilitate the translation of experimental findings into clinically relevant and commercially viable products while supporting sustainable use of this valuable medicinal species (Chenni *et al*., 2026; Raclariu-Manolica & Socaciu, 2023).

10. Conclusion

Hippophae rhamnoides L. has emerged as one of the most promising natural sources of antioxidant phytochemicals, owing to its rich and diverse composition of phenolic acids, flavonoids, carotenoids, vitamins, tocopherols and unsaturated fatty acids. The coordinated action of these compounds enables sea buckthorn to mitigate oxidative stress through multiple mechanisms, including free radical scavenging, inhibition of lipid peroxidation, enhancement of endogenous antioxidant defenses and modulation of redox-sensitive signaling pathways. These properties provide a strong biological basis for its therapeutic

Despite these advances, important challenges remain, including variability in phytochemical composition, limited standardization of commercial products and the scarcity of large-scale clinical trials. Addressing these limitations through integrated phytochemical, molecular and clinical research will strengthen the scientific foundation for the development of evidence-based sea buckthorn-derived therapeutics and nutraceuticals. Continued multidisciplinary investigations will further expand the application of this versatile medicinal plant in preventive healthcare and sustainable functional food systems. (Raclariu-Manolica & Socaciu, 2023; Chen *et al*., 2024; Javaid *et al*., 2026).

Competing Interests

Authors have declared that no competing interests exist.

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