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# Sea Buckthorn (Hippophae Rhamnoides L.): Phytochemistry, Nutritional Value and Therapeutic Potential

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**ABSTRACT:** Sea buckthorn (*Hippophae rhamnoides* L., Elaeagnaceae) is a hardy, nitrogen-fixing shrub of Eurasian cold deserts and temperate coastlines whose berries, seeds and leaves have been used for centuries in Tibetan, Mongolian, Chinese and Central Asian systems of medicine, yet its chemical complexity and clinical relevance have been consolidated only in recent decades. This review synthesises current knowledge of the phytochemistry, nutritional composition and therapeutic potential of *H. rhamnoides*, drawing on compositional surveys, mechanistic studies and human trials published largely over the past three decades. The berry combines exceptional ascorbic acid concentrations (up to 2500 mg/100 g in some subspecies) with carotenoids, tocopherols, phytosterols, flavonol glycosides dominated by isorhamnetin and quercetin derivatives, proanthocyanidins and two compositionally distinct oils, a pulp oil uniquely rich in palmitoleic acid (16:1n-7) and a seed oil with a near 1:1 ratio of linoleic to alpha-linolenic acid. These constituents underpin experimentally supported antioxidant, cardioprotective, hepatoprotective, dermatological, anti-inflammatory, gastroprotective, antimicrobial, antidiabetic, radioprotective and antiproliferative activities, several of which are corroborated by randomised controlled trials in dry eye disease, atopic dermatitis, vaginal atrophy and liver fibrosis. The evidence base nevertheless remains uneven: subspecies-dependent compositional variability, heterogeneous extracts and inconsistent clinical endpoints complicate translation. Standardised preparations, compound-level pharmacokinetics and adequately powered trials are identified as priorities for converting a nutritionally remarkable wild resource into an evidence-based functional food and phytopharmaceutical.

## 1. INTRODUCTION

Sea buckthorn (*Hippophae rhamnoides* L.) is a deciduous, dioecious, thorny shrub of the family Elaeagnaceae distributed across the cold-arid and temperate zones of Europe and Asia, from Atlantic coastal dunes to the Himalayan and Central Asian mountain systems above 3000 m [1,2]. The plant tolerates temperature extremes from approximately −43 °C to +40 °C, fixes atmospheric nitrogen through actinorhizal symbiosis with *Frankia*, stabilises fragile slopes with an extensive root system, and produces dense clusters of orange-yellow berries that persist on the branches through winter [3]. These agronomic attributes have made it a favoured species for soil conservation and desertification control in China, Russia, Mongolia and the Indian trans-Himalaya, while the berry, seed and leaf have a documented history of use in Tibetan, Mongolian, Chinese and Central Asian medicine for cough, digestive complaints, circulatory disorders, skin disease and wound care [4,5].

Scientific interest in sea buckthorn accelerated from the 1990s onward, when systematic compositional work revealed a chemical profile unusual among temperate fruits: ascorbic acid concentrations exceeding those of citrus by one to two orders of magnitude in some populations, a fruit-flesh oil dominated by the rare palmitoleic acid, a seed oil balancing the two essential fatty acids in a near-equimolar ratio, and a dense complement of flavonol glycosides, carotenoids, tocopherols and phytosterols [6,7,8]. Parallel pharmacological work, much of it from Chinese, Indian, Russian and Finnish groups, has attributed antioxidant, cardioprotective, hepatoprotective, dermatological, anti-inflammatory, immunomodulatory, antimicrobial, antidiabetic, radioprotective and antiproliferative activities to different fractions of the plant [5,9,10]. A smaller but growing number of randomised human trials has begun to test these claims directly [11,12,13].

The literature is nonetheless fragmented across food science, pharmacology and horticulture, and is complicated by pronounced compositional differences among subspecies, origins and processing methods, which help to explain inconsistent bioactivity data obtained with nominally similar materials [14,15,16]. This review consolidates current knowledge of the phytochemistry and nutritional value of *H. rhamnoides* and critically appraises the experimental and clinical evidence for its therapeutic potential, with attention to the mechanisms proposed for individual constituent classes and to the gaps that limit translation into standardised nutraceutical and pharmaceutical products.

## 2. METHODOLOGY

This review was compiled through structured searches of PubMed, Scopus, ScienceDirect, Web of Science and Google Scholar covering literature published between 1971 and 2025. The search combined the taxonomic terms *Hippophae rhamnoides*, sea buckthorn, seabuckthorn and *Hippophae* with the topic terms phytochemistry, chemical composition, nutritional composition, fatty acids, flavonoids, carotenoids, tocopherols, phytosterols, clinical trial and pharmacological activity, together with each of the specific activities examined in Section 6 (antioxidant, cardioprotective, hepatoprotective, dermatological, anti-inflammatory, antimicrobial, antidiabetic, anticancer, radioprotective, gastroprotective and ocular). Reference lists of retrieved articles and of earlier reviews were screened manually to recover primary sources that the database searches had missed.

Records were retained when they reported original compositional analyses, mechanistic experiments in cellular or animal systems, or human intervention studies on defined preparations of *H. rhamnoides* or a named subspecies, and when the plant fraction tested (berry, juice, pulp oil, seed oil, press-cake, leaf or bark) was stated. Studies were excluded when the plant material was unidentified beyond genus, when the preparation was a multi-herb formulation from which the sea buckthorn contribution could not be separated, when the report was available only as a conference abstract, and when full text could not be obtained in English. Secondary reviews were consulted for orientation and for access to non-English primary literature, but quantitative values and experimental outcomes reported in this article are attributed to the primary source wherever the primary source could be retrieved.

Because compositional values for this species vary by an order of magnitude between subspecies, growing sites, harvest dates and extraction methods, figures are reported here as ranges across the retrieved studies rather than as single representative values, and the plant fraction and, where stated by the original authors, the subspecies are specified alongside each finding. Bibliographic details of every cited work, including volume, issue, pagination and digital object identifier, were checked against the publisher record or a bibliographic database. One previously influential controlled trial of seed oil in hypertensive subjects was identified as retracted during this process and was excluded from the evidence considered in Section 6.2.

## 3. BOTANICAL DESCRIPTION, TAXONOMY AND DISTRIBUTION

The genus *Hippophae* L. comprises wind-pollinated, dioecious shrubs and small trees bearing silvery-lepidote lanceolate leaves and thorny branchlets. In the classical revision of Rousi [1], *H. rhamnoides* was treated as a single polymorphic species with nine subspecies, including ssp. *rhamnoides* along the Atlantic and Baltic coasts, ssp. *fluviatilis* in the Alps, ssp. *carpatica* in the Carpathians, ssp. *caucasica* in the Caucasus, ssp. *turkestanica* in Central Asia, and ssp. *sinensis*, *mongolica* and *yunnanensis* in China, Mongolia and adjacent regions; later molecular treatments recognise additional species such as *H. salicifolia*, *H. tibetana* and *H. neurocarpa* in the Himalayan region [3]. The taxon of commerce is almost always *H. rhamnoides* in the broad sense, but the subspecies identity is chemically consequential: berries of ssp. *sinensis* are small, intensely acidic and extraordinarily rich in ascorbic acid, whereas the cultivated Russian and Baltic material derived from ssp. *mongolica* and ssp. *rhamnoides* bears larger, milder fruit with markedly lower vitamin C but higher oil in the flesh [14,15].

The plant is a pioneer coloniser of riverbanks, glacial outwash, sand dunes and degraded slopes. Root nodulation with the actinomycete *Frankia* permits substantial annual nitrogen fixation in dense stands, and the species is consequently planted at

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large scale for erosion control and land reclamation, most extensively on the Loess Plateau of China [2,3]. Female plants begin bearing three to four years after establishment and yield several tonnes of berries per hectare under orchard management. In India, natural stands of *H. rhamnoides* ssp. *turkestanica* and *H. salicifolia* in Ladakh, Lahaul-Spiti, Uttarakhand, Sikkim and Arunachal Pradesh constitute an under-exploited resource whose nutritional relevance for high-altitude populations has been specifically documented [17]. This combination of ecological service functions and a harvestable, bioactive-dense fruit underlies the description of sea buckthorn as a multipurpose crop [2].

## 4. NUTRITIONAL COMPOSITION

The sea buckthorn berry is a compositional outlier among temperate fruits because nutritionally significant fractions occur in all three of its compartments: the juice-rich flesh, the oil-bearing soft seed and the surrounding peel. Whole berries typically contain 60–85% moisture, 3–8% total sugars (mainly glucose and fructose), 1–4% organic acids dominated by malic and quinic acids, and 0.5–1.5% protein, with the low sugar-to-acid ratio accounting for the strongly tart flavour of the raw fruit [6,8]. Total lipid reaches 1.5–3.5% of fresh flesh and 8–18% of the seed, so that whole-berry processing yields two oils of distinct composition, discussed in Section 5.4 [7]. Representative values for the major nutrient groups in berry, seed and leaf are compiled in Table 1.

Ascorbic acid is the signature nutrient. Reported concentrations span 28–201 mg/100 g in European ssp. *rhamnoides*, 200–800 mg/100 g in ssp. *mongolica* and cultivated Central Asian material, and 460–2500 mg/100 g in Chinese ssp. *sinensis*, values at the upper end exceeding orange juice by roughly thirty-fold [8,14]. Because the fruit lacks ascorbate oxidase activity of practical significance, vitamin C is comparatively stable during juice processing and storage, a technologically important trait [6]. The berry additionally supplies vitamin E as tocopherols and tocotrienols, provitamin A carotenoids, vitamin K1, folate, and B-complex vitamins in nutritionally relevant amounts [14,18].

The mineral fraction of the fruit includes potassium as the dominant element (300–380 mg/100 g), with appreciable calcium, magnesium, phosphorus, iron, zinc, manganese and copper; concentrations vary with soil and subspecies but consistently place the berry above common orchard fruit [8,18]. All eighteen common amino acids have been detected in berry and leaf protein, including the full set of indispensable amino acids, and the seed residue after oil extraction contains 25–30% crude protein, supporting its valorisation as a feed and food ingredient [19,20]. The leaves, often discarded during harvest, contain 15–20% crude protein, a high proportion of total phenolics on a dry-weight basis, carotenoids, vitamin C and minerals, and have accordingly been developed into herbal teas and livestock feed supplements with measurable physiological effects [20,21]. Sea buckthorn is therefore better regarded as a set of complementary raw materials, juice, pulp oil, seed oil, press-cake and leaf, than as a single commodity, and nutritional claims in the literature must always be read against the specific fraction and origin analysed [16].

**Table 1.** Representative nutritional composition of sea buckthorn berry, seed and leaf. Values are on a fresh-weight basis for berry and a dry-weight basis for seed and leaf; ranges reflect subspecies and origin effects.

| Constituent | Berry (fresh) | Seed (dry) | Leaf (dry) | References |
|---|---|---|---|---|
| Moisture (%) | 60–85 | 6–10 | 8–12 (dried) | [6,8] |
| Total lipid (%) | 1.5–3.5 (flesh) | 8–18 | 2–4 | [6,7] |
| Protein (%) | 0.5–1.5 | 25–30 (press-cake) | 15–20 | [19,20] |
| Total sugars (%) | 3–8 | – | – | [6,15] |
| Organic acids (%) | 1–4 (malic, quinic) | – | – | [6,15] |
| Ascorbic acid (mg/100 g) | 28–2500 | trace | 100–350 | [8,14,18] |
| Total carotenoids (mg/100 g) | 1–20 | 2–4 | 20–40 | [8,24] |

| Constituent | Berry (fresh) | Seed (dry) | Leaf (dry) | References |
|---|---|---|---|---|
| Tocopherols + tocotrienols (mg/100 g) | 1–16 | 10–20 | 10–30 | [14,24] |
| Total phenolics (mg GAE/100 g) | 100–2000 | 400–900 | 2000–6000 | [24,26] |
| Potassium (mg/100 g) | 300–380 | – | 900–1400 | [8,18] |

## 5. PHYTOCHEMISTRY

More than 190 bioactive constituents have been reported from sea buckthorn berry and seed and a further set from the leaf and bark, spanning flavonoids, phenolic acids, proanthocyanidins, carotenoids, tocochromanols, phytosterols, triterpenes, fatty acids and glycerolipids, vitamins and organic acids [4,5,16,22]. The major classes, their principal representatives and typical concentrations are summarised in Table 3, following the discussion of the lipid fraction in Table 2.

### 5.1 Flavonoids and other phenolics

The flavonoid fraction of berry and leaf is dominated by flavonol glycosides of isorhamnetin, quercetin and kaempferol, with isorhamnetin-3-O-glucoside, isorhamnetin-3-O-rutinoside, quercetin-3-O-glucoside and rutin as principal constituents; total flavonol content commonly falls between 100 and 1000 mg/kg in berries and substantially higher in leaves [23,24]. The predominance of isorhamnetin, the 3'-O-methyl ether of quercetin, is a chemotaxonomic peculiarity shared with few food plants and is pharmacologically relevant because methylation increases metabolic stability and membrane permeability relative to quercetin while retaining radical-scavenging and signalling activity. Human absorption of sea buckthorn flavonols has been demonstrated directly, with plasma isorhamnetin and quercetin rising after ingestion of berry preparations [25]. Catechin, gallocatechin, epigallocatechin and oligomeric proanthocyanidins occur in berry, seed coat and press residues, and structure–activity analysis of sea buckthorn juice phenolics indicates that these flavan-3-ols and proanthocyanidins, rather than the flavonol glycosides, account for the greater part of measured antioxidant efficiency [23]. Phenolic acids, including gallic, protocatechuic, p-coumaric, ferulic and salicylic acids, complete the hydrophilic phenolic profile, and gallic acid has repeatedly emerged as a dominant free phenolic acid in leaf extracts [24,26]. Hydrolysable tannins of the leaf (casuarinin, hippophaenin and related ellagitannins) contribute to its astringency and to several of its reported bioactivities [5].

### 5.2 Carotenoids

The orange colour of the berry reflects a carotenoid pool of 1–20 mg/100 g fresh weight in the flesh and considerably higher concentrations in the extracted pulp oil, composed chiefly of beta-carotene, zeaxanthin (largely as esters), lycopene, lutein and beta-cryptoxanthin [8,24]. Esterification of xanthophylls with the abundant palmitic and palmitoleic acids of the flesh increases their lipophilicity and stability, and co-ingestion with the pulp oil matrix favours micellisation and absorption. Beta-carotene and beta-cryptoxanthin provide provitamin A activity relevant to populations with marginal vitamin A status, while zeaxanthin and lutein are of specific interest for macular physiology, one plausible contributor, alongside omega-3 fatty acids, to the benefit of sea buckthorn oil observed in dry eye disease [12,27].

### 5.3 Tocochromanols and phytosterols

Sea buckthorn accumulates tocopherols and tocotrienols in both seed and flesh, with total vitamin E generally in the range of 100–500 mg/kg depending on fraction and subspecies. Alpha-tocopherol predominates in the flesh, whereas seeds contain substantial gamma-tocopherol in addition to the alpha homologue, a pattern documented in detail for ssp. *sinensis* and ssp. *mongolica* [14]. The sterol fraction, roughly 0.3–2% of the oils, is led by beta-sitosterol with campesterol, stigmasterol, isofucosterol and citrostadienol as minor components, and beta-sitosterol is also concentrated in the fruit soft parts [27,28]. These constituents furnish two mechanistically distinct contributions: chain-breaking inhibition of lipid peroxidation by the tocochromanols, and interference with intestinal cholesterol micellisation by the phytosterols, the latter offering one explanation for hypocholesterolaemic effects of seed-oil feeding in animal models [29].

### 5.4 Fatty acids and glycerolipids

The most distinctive chemical feature of sea buckthorn is the coexistence of two oils of sharply divergent composition within one fruit (Table 2). Pulp (flesh and peel) oil contains roughly 25–45% palmitoleic acid (16:1n-7) together with 25–40% palmitic acid and appreciable cis-vaccenic acid, a profile essentially unique among edible plant oils, whereas seed oil is devoid of significant palmitoleate and instead combines linoleic acid (30–40%) and alpha-linolenic acid (20–36%) in a ratio close to 1:1, with oleic acid and its cis-vaccenic isomer at a combined 13–20% [7,30]. Palmitoleic acid has attracted attention as a lipokine influencing hepatic lipogenesis, insulin sensitivity and inflammatory signalling, and as a structural analogue of skin-surface lipids that supports epidermal barrier repair, providing a mechanistic rationale for the prominence of pulp oil in dermatological applications [31]. The balanced essential fatty acid ratio of the seed oil, coupled with its tocopherols and sterols, aligns with observations that seed-oil supplementation modifies platelet aggregation, lipid profiles and membrane fatty acid composition in humans and animals [10,29]. Subspecies and harvest date shift these proportions measurably, and comparative work across origins shows systematically higher flesh-oil content in ssp. *sinensis* than in European material, underscoring again that oil products of different provenance are not interchangeable [7,14].

**Table 2.** Typical fatty acid composition (% of total fatty acids) of sea buckthorn pulp (flesh) oil and seed oil.

| Fatty acid | Symbol | Pulp oil (%) | Seed oil (%) | References |
|---|---|---|---|---|
| Palmitic acid | 16:0 | 25–40 | 7–10 | [7,30] |
| Palmitoleic acid | 16:1n-7 | 25–45 | <4 | [7,30,31] |
| Stearic acid | 18:0 | 0.5–2 | 2–4 | [7,30] |
| Oleic acid | 18:1n-9 | 1–12 | 13–20 | [7,30] |
| cis-Vaccenic acid | 18:1n-7 | 5–10 | 2–4 | [7,30] |
| Linoleic acid | 18:2n-6 | 8–15 | 30–40 | [7,30] |
| Alpha-linolenic acid | 18:3n-3 | 1–5 | 20–36 | [7,30] |

### 5.5 Vitamins, organic acids and minor constituents

Beyond ascorbic acid, the berry supplies vitamin K1 at levels unusual for fruit, folate, thiamine, riboflavin and vitamin B6 [18]. Malic and quinic acids dominate the organic acid pool, and the aroma is shaped by esters of short-chain acids that develop during ripening [15]. Minor constituents with documented bioactivity include triterpenes such as ursolic and oleanolic acids in fruit and bark, serotonin (5-hydroxytryptamine) at exceptional concentrations in the bark, and zeaxanthin dipalmitate as a defined hepatoprotective principle of the fruit [4,32]. This breadth of chemistry means that different extraction schemes, aqueous juice, ethanolic leaf extract, supercritical CO2 oil, capture largely non-overlapping subsets of constituents, an obvious but frequently neglected source of variability in the pharmacological literature [26].

**Table 3.** Principal phytochemical classes of Hippophae rhamnoides with representative constituents, main plant part and typical reported contents.

| Class | Representative constituents | Main part | Typical content | References |
|---|---|---|---|---|
| Flavonol glycosides | Isorhamnetin-3-O-glucoside, isorhamnetin-3-O-rutinoside, quercetin-3-O-glucoside, rutin, kaempferol glycosides | Berry, leaf | 100–1000 mg/kg (berry); higher in leaf | [23,24] |

| Class | Representative constituents | Main part | Typical content | References |
|---|---|---|---|---|
| Flavan-3-ols and proanthocyanidins | Catechin, gallocatechin, epigallocatechin, oligomeric procyanidins and prodelphinidins | Berry, seed coat | 0.1–1% of press residues | [23] |
| Phenolic acids and tannins | Gallic, protocatechuic, p-coumaric, ferulic acids; casuarinin, hippophaenin | Leaf, berry | Gallic acid dominant in leaf | [24,26] |
| Carotenoids | Beta-carotene, zeaxanthin (esters), lycopene, lutein, beta-cryptoxanthin | Flesh, pulp oil | 1–20 mg/100 g fresh berry | [8,24] |
| Tocochromanols | Alpha- and gamma-tocopherol, tocotrienols | Seed, flesh | 100–500 mg/kg | [14,27] |
| Phytosterols | Beta-sitosterol, campesterol, stigmasterol, isofucosterol | Seed and pulp oils | 0.3–2% of oil | [27,28] |
| Fatty acids | Palmitoleic (pulp); linoleic and alpha-linolenic (seed) | Pulp oil, seed oil | See Table 2 | [7,30] |
| Vitamins and organic acids | Ascorbic acid, vitamin K1, folate; malic and quinic acids | Berry | Vitamin C 28–2500 mg/100 g | [8,18] |
| Triterpenes and others | Ursolic and oleanolic acids, serotonin (bark), zeaxanthin dipalmitate | Fruit, bark | Minor (mg/kg range) | [4,32] |

## 6. THERAPEUTIC POTENTIAL

Pharmacological investigation of sea buckthorn spans cell-free antioxidant assays, cellular and rodent models and a modest but informative body of randomised human trials. The principal lines of evidence are reviewed below and summarised in Table 4, with attention to the fraction tested and to inconsistencies within the literature.

### 6.1 Antioxidant activity

Extracts of berry, seed and leaf consistently scavenge DPPH, ABTS, superoxide and hydroxyl radicals, chelate transition metals and inhibit lipid peroxidation in vitro, with activity broadly proportional to phenolic content and therefore highest in leaf and seed preparations [26,33,34]. Mechanistically the plant deploys complementary systems: water-soluble ascorbate and phenolics regenerate one another and quench aqueous radicals, while carotenoids and tocochromanols intercept singlet oxygen and peroxyl radicals in lipid phases. Beyond direct scavenging, sea buckthorn extracts limit chromium(VI)- and hypoxia-induced oxidative injury in lymphocytes, restore glutathione and antioxidant enzyme activities, and prevent DNA strand breaks, indicating engagement of cellular redox defence rather than mere stoichiometric quenching [34,35]. Contribution analyses nevertheless caution against attributing juice antioxidant capacity to the flavonol glycosides that dominate chromatograms; flavan-3-ols, proanthocyanidins and ascorbate carry most of the measured activity [23]. Antioxidant action is best regarded as the common substrate of the organ-specific effects below rather than a therapeutic claim in its own right.

### 6.2 Cardiovascular and cardiometabolic effects

Animal studies show that seed oil lowers plasma total and LDL cholesterol and triglycerides, raises HDL, improves acetylcholine-induced vasorelaxation and reduces the atherogenic index in cholesterol-fed rabbits, effects attributable jointly to its essential fatty acids, phytosterols and tocopherols [29]. Flavonoid fractions inhibit platelet aggregation and modulate thrombogenesis in vitro and in vivo, and the collected evidence for berry phenolics and oils in vascular protection has been reviewed in detail [10]. Human data are more equivocal. In healthy male smokers, sea buckthorn juice consumed for eight weeks did not significantly alter plasma lipids or the oxidation resistance of LDL despite delivering substantial flavonols, although a trend toward slower LDL oxidation was noted [11]; flavonol supplementation from berries likewise produced measurable plasma appearance of isorhamnetin and quercetin without clear movement of emerging risk markers [25]. Interventions in overweight and obese women produced small and mostly favourable shifts in variables associated with metabolic disease [37], and a randomised crossover trial in the same population found that serum metabolite responses to sea buckthorn differed systematically according to baseline metabolic profile [36]. The pattern suggests that benefit concentrates in individuals with baseline dyslipidaemia or elevated oxidative stress rather than in healthy volunteers, and in lipid-based rather than juice-based preparations. This inference must be drawn cautiously: a frequently cited controlled trial reporting blood-pressure and lipid benefit from seed oil in hypertensive subjects has since been retracted, and any assessment of the cardiometabolic literature that predates the retraction overstates the strength of the human evidence.

**6.3 Hepatoprotective effects**

Seed oil pre-treatment protects mice against carbon tetrachloride-induced hepatotoxicity, normalising transaminases, restoring glutathione and reducing lipid peroxidation and histological injury [38], and a phenolic-rich leaf fraction affords comparable protection in rats [39]. The flavonoid and zeaxanthin-ester constituents plausibly act through attenuation of CYP2E1-derived radical load and stabilisation of hepatocyte membranes. Clinical evidence, though limited, is direct: in patients with liver cirrhosis, sea buckthorn extract administration shortened the time to normalisation of aminotransferases and reduced serum markers of fibrogenesis, including laminin and collagen types III and IV, relative to control treatment [40]. Larger controlled trials with defined preparations remain absent, and the fraction responsible, hydrophilic phenolics versus lipophilic seed-oil constituents, cannot yet be assigned, since both protect in animal models.

**6.4 Dermatological effects and wound healing**

The dermatological reputation of sea buckthorn rests on the palmitoleic-rich pulp oil, the essential fatty acids of the seed oil and the tannin- and flavonoid-rich leaf. In a placebo-controlled trial in atopic dermatitis, dietary pulp oil for four months improved symptoms and raised plasma palmitoleate, whereas seed oil, despite favourably altering plasma essential fatty acid patterns, did not outperform placebo on dermatitis scores, an instructive dissociation implying that 16:1n-7 delivery, not essential fatty acid supply, drove the clinical signal [41]. Topical and oral leaf extracts accelerate excision-wound closure in rodents, increasing hydroxyproline and hexosamine deposition, tensile strength and antioxidant status of granulation tissue [42]. Sea buckthorn preparations similarly promote healing of burn and radiation-injured skin in experimental systems, and the ethnomedicinal, phytochemical and dermatological evidence has been comprehensively catalogued [43]. A related mucosal application is supported by a randomised, double-blind trial in which oral seed-plus-pulp oil improved vaginal epithelial integrity in postmenopausal women with vaginal atrophy [13]. The recurring mechanism across these settings is restoration of lipid barriers combined with pro-proliferative and antioxidant signalling in keratinocytes and fibroblasts [31].

**6.5 Anti-inflammatory and immunomodulatory effects**

Alcoholic leaf extract suppresses lipopolysaccharide-induced nitric oxide and pro-inflammatory cytokine production in murine macrophages and inhibits adjuvant-induced arthritis in rats, reducing paw oedema and inflammatory mediators [21,44]. Berry and leaf preparations also enhance lymphocyte proliferation and protect immune cells from oxidant- and hypoxia-induced apoptosis, supporting an adaptogenic characterisation developed extensively in Indian high-altitude research [5,35]. In humans, frozen berry purée consumed for ninety days did not reduce the incidence or duration of common cold or gastrointestinal infections in a randomised trial, but did significantly lower serum C-reactive protein, indicating a measurable systemic anti-inflammatory effect without demonstrable anti-infective efficacy at the dose studied [45]. The distinction matters for product claims: the trial evidence supports modulation of low-grade inflammation rather than immune-boosting in the colloquial sense.

**6.6 Antimicrobial activity**

Seed, leaf and berry extracts inhibit a taxonomically broad panel of bacteria, including *Staphylococcus aureus*, *Bacillus cereus*, *Pseudomonas aeruginosa* and enteric Gram-negatives, with methanolic and hydro-alcoholic extracts generally most active and phenolic content again the best correlate of potency [26,33,34]. Tannins and flavonoid aglycones are presumed to act through membrane perturbation, metal sequestration and enzyme inhibition. Antiviral activity has been reported for leaf constituents in vitro, and hippophaenin-type ellagitannins are candidate principles, but in vivo confirmation is lacking and the antiviral literature remains preliminary relative to the antibacterial data [5]. Present evidence positions sea buckthorn extracts as food-preservation and topical-antisepsis adjuncts rather than systemic antimicrobials.

### 6.7 Antidiabetic and metabolic effects

Sea buckthorn phenolics inhibit alpha-glucosidase in vitro [46], and in healthy volunteers co-ingestion of berry fractions flattened the postprandial insulin response and modified glycaemic excursion after a sucrose load, with the effect localised to the ethanol-soluble, phenolic-containing fraction [47]. In diet-induced obese mice, leaf extracts and their flavonoid glycosides reduced adiposity, hepatic steatosis, insulin resistance and inflammatory gene expression [48], consistent with AMPK-mediated and incretin-independent mechanisms proposed for isorhamnetin and quercetin derivatives. Palmitoleate from pulp oil adds a lipokine dimension, having been linked in broader nutritional literature to improved hepatic insulin signalling [31]. No adequately powered trial in type 2 diabetes has yet been reported, and the human evidence is confined to acute postprandial and overweight cohorts; the metabolic indication therefore remains promising but unproven.

### 6.8 Anticancer and radioprotective activities

Berry extracts inhibit proliferation of human colon (Caco-2) and hepatoma (HepG2) cells in vitro [49], and constituents including ursolic acid and hydrolysable tannins suppress tumour promotion in murine two-stage carcinogenesis [32]. Proposed mechanisms encompass antioxidant limitation of genotoxic load, cell-cycle arrest and apoptosis induction by flavonoids, and inhibition of pro-inflammatory signalling. These data are uniformly preclinical, and extrapolation to chemoprevention in humans would be premature. Better developed is the radioprotection literature: the berry-derived preparation RH-3 administered before whole-body lethal irradiation conferred survival of more than 80% of mice at thirty days, protecting the gastrointestinal crypt and haematopoietic compartments through free-radical scavenging, DNA protection and possibly transient metal-ion chelation [50]. Radioprotective efficacy at whole-organism level, achieved with a crude standardised extract, is among the more striking pharmacological findings for the species and has sustained defence-related interest in India.

### 6.9 Gastrointestinal and ocular effects

Both seed and pulp oils prevent acetic acid-, pylorus-ligation- and reserpine-induced gastric ulcers in rats and accelerate healing of established lesions, effects ascribed to enhanced mucosal hydrophobicity, mucus secretion and epithelial repair supported by the oils' fatty acids, sterols and carotenoids [51]. In the eye, a double-blind, randomised trial in adults with dry eye disease found that oral sea buckthorn oil over three months attenuated the seasonal rise in tear-film osmolarity and reduced redness and burning symptoms, without changing tear secretion or break-up time, suggesting an effect on meibomian lipid quality or ocular-surface inflammation rather than on aqueous production [12]. These two indications illustrate the general pattern of sea buckthorn pharmacology: epithelial and barrier tissues, gastric mucosa, skin, ocular surface, vaginal epithelium, respond most consistently, in keeping with a chemistry rich in barrier lipids, carotenoids and epitheliotrophic signals.

**Table 4.** Selected pharmacological and clinical evidence for Hippophae rhamnoides preparations.

| Activity | Preparation and part | Model | Principal outcome | References |
|---|---|---|---|---|
| Antioxidant and cytoprotective | Leaf and seed extracts | In vitro assays; lymphocytes | Radical scavenging; protection against Cr(VI)-induced oxidative injury and apoptosis | [33,34,35] |
| Cardioprotective | Seed oil | Cholesterol-fed rabbits | Reduced total and LDL cholesterol and atherogenic index; improved vasorelaxation | [29] |
| Cardiometabolic (clinical) | Juice; berries and berry fractions | Healthy smokers; overweight and obese women | No lipid change in healthy smokers; small favourable metabolic shifts, dependent on baseline profile | [11,36,37] |
| Hepatoprotective | Seed oil; leaf phenolic fraction; extract | CCl4-injured mice and rats; cirrhotic patients | Normalised transaminases; reduced fibrosis markers (laminin, collagen III and IV) | [38,39,40] |

| Activity | Preparation and part | Model | Principal outcome | References |
|---|---|---|---|---|
| Atopic dermatitis | Pulp oil (oral) | Randomised trial, adults, 4 months | Symptom improvement with pulp oil; seed oil not superior to placebo | [41] |
| Wound healing | Leaf extract (topical and oral) | Excision wounds, rats | Faster closure; increased hydroxyproline, tensile strength, antioxidant status | [42] |
| Anti-inflammatory | Leaf extract; berry purée | LPS-stimulated macrophages; arthritis model; randomised trial | Reduced nitric oxide and cytokines; lower serum CRP; no reduction in infection episodes | [21,44,45] |
| Antidiabetic | Berry phenolic fraction; leaf flavonoids | Postprandial trial in adults; obese mice | Attenuated postprandial insulin response; reduced adiposity and insulin resistance | [47,48] |
| Gastroprotective | Seed and pulp oils | Gastric ulcer models, rats | Prevention of ulceration and accelerated healing | [51] |
| Radioprotective | Berry extract RH-3 | Lethally irradiated mice | Survival above 80% at 30 days with pre-irradiation dosing | [50] |
| Antiproliferative | Berry extracts; isolated constituents | Caco-2 and HepG2 cells; mouse skin | Inhibited proliferation; suppressed tumour promotion | [32,49] |
| Dry eye disease | Seed plus pulp oil (oral) | Randomised trial, 3 months | Attenuated rise in tear-film osmolarity; reduced symptoms | [12] |
| Vaginal atrophy | Seed plus pulp oil (oral) | Randomised trial, postmenopausal women | Improved integrity of vaginal epithelium | [13] |

## 7. SAFETY AND TOXICOLOGICAL CONSIDERATIONS

Sea buckthorn berries, juices and oils have a long dietary history across Eurasia and are generally recognised as safe at food-relevant intakes. Acute and subchronic toxicity studies of berry, oil and leaf preparations in rodents report no mortality or organ toxicity at doses far exceeding human dietary exposure, and haematological and biochemical parameters remain within normal ranges [5,52]. Human trials of juices, purées and oils lasting up to several months record adverse-event profiles comparable to placebo, with occasional mild gastrointestinal complaints [12,13,45]. Points requiring attention nonetheless remain: the antiplatelet activity of berry flavonoids and seed-oil fatty acids counsels caution with anticoagulant co-medication; standardisation is complicated by subspecies- and process-dependent variation in vitamin C, flavonoid and carotenoid content [16]; and quality control of commercial oils must address oxidative deterioration of their highly unsaturated seed-oil fraction. Formal genotoxicity, reproductive toxicity and drug-interaction datasets for concentrated extracts, as opposed to traditional foods, are still incomplete and merit generation before pharmaceutical-grade claims are advanced [52].

## 8. CONCLUSION

*Hippophae rhamnoides* unites, in one hardy and ecologically valuable shrub, a nutritional density rare among temperate fruits and a phytochemical portfolio, isorhamnetin-dominated flavonols, proanthocyanidins, carotenoid esters, tocochromanols, phytosterols, palmitoleate-rich pulp oil and an essential fatty acid-balanced seed oil, that maps coherently onto its demonstrated bioactivities. The strongest translational signals concern epithelial and barrier tissues and hepatic injury: randomised or controlled trials support benefit in dry eye disease, atopic dermatitis, vaginal atrophy and liver fibrosis, while animal and cellular work substantiates gastroprotective, anti-inflammatory, radioprotective and antiproliferative actions. The evidence base is nevertheless constrained by heterogeneous, often uncharacterised preparations, by compositional divergence among subspecies that renders cross-study comparison hazardous, and by clinical studies that are small, short and rarely stratified by baseline risk; the retraction of a prominent cardiovascular trial has further thinned the human dataset in precisely the area where commercial claims are most confident. Future work should prioritise chemically standardised fractions with declared subspecies origin, compound-level pharmacokinetics for isorhamnetin glycosides, palmitoleate and carotenoid esters, adequately powered trials in dyslipidaemia, non-alcoholic fatty liver disease, impaired glucose tolerance and dermatological indications, and integrated valorisation of juice, oils, press-cake and leaf so that therapeutic development reinforces, rather than competes with, the ecological and livelihood roles of the crop in mountain regions. On present evidence sea buckthorn is best positioned as a scientifically credible functional food and a promising source of defined phytopharmaceutical leads, with the distance between the two to be closed by standardisation and clinical rigour rather than by further descriptive phytochemistry.

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**CONFLICT OF INTEREST**

The author declares that there is no conflict of interest.

**ETHICS STATEMENT**

This article is a literature review and did not involve studies with human participants or animals performed by the author. Ethical approval was not required for this study.

**DATA AVAILABILITY STATEMENT**

No new data were generated or analysed in this review. All data discussed are available in the cited published literature.

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