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SEA BUCKTHORN (*Hippophae rhamnoides*): A COMPREHENSIVE REVIEW OF ITS NUTRITIONAL AND THERAPEUTIC POTENTIAL

[1] N Asha, [1] B Bhavani, [2*] Sirigiri Sonia, [2] Siragala Manasa,
[2] Sangem Sweety, [2] Sara Jagadishwar, [2] Shettipally Jayalaxmi

[1] Assistant Professor, Department of Pharmacology, Malla Reddy College of Pharmacy, Secunderabad.

[2] Bachelor of Pharmacy, Malla Reddy College of Pharmacy, Secunderabad

Abstract:

Sea buckthorn is a hardy, nitrogen-fixing shrub of the family Elaeagnaceae, widely distributed in a cold and arid regions of Eurasia and valued both ecologically and medicinally. Its berries, leaves, and seeds are rich in vitamin (C,E,K), carotenoids, flavonoids, polyphenols, antioxidant, anti-inflammatory, Traditionally, the plant has been used for gastro intestinal aliments, skin disorders, and wound healing. In addition, sea buckthorn is increasingly exploited in functional foods, nutraceuticals, and cosmeceutical formulations. Its omega-rich oil shows promise in supporting metabolic health, immune function, and mucosal integrity, although optimal dosing, long term safety, and herb-drug interaction profiles require further systematic investigation through well-designed clinical trials. This review summarizes the botanical characteristics, phytochemical profile, pharmacological activities, and emerging applications of sea buckthorn, highlighting its promise as a valuable medicinal and nutraceutical plant.

Keywords : *Sea buckthorn, Hippophae rhamnoides, Antioxidant activity, Anti Inflammatory activity, Gastrointestinal ailments, Wound healing, Functional foods, Nutraceuticals, Cosmeceuticals, Traditional medicine.*

Corresponding author:

N Asha,
Assistant Professor,
Department of Pharmacology,
Malla Reddy College of Pharmacy, Secunderabad.

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INTRODUCTION:

BOTANICAL CHARACTERISTICS :

Morphology :[1]

Leaves are narrow, lanceolate, to linear(3-8cm) long, <7mm wide, with silver-gray undersides due to scaaly surfaces, upper surfaces appear dark gray-green. Fruits form dense clusters of small (5-8mm diameter), orange-yellow to reddish, spherical or oblate drupes with ruffled skins, persisting into winter, male plants produce inconspicious apetaalous flowers in clusterss. Bark is rough, brown to black, roots are extensive taproots to 4mm deep, laaterals to 10mm, nitrogen-fixing.

Berries of sea buckthorn :[1]

Sea buckthorn berries are small, juicy drupes averaginf 5-9mm in diameter, with an oblate to spherical shape, thin glossy skin, and oily, translucent orange flesh encasing hard brown seeds.[18]

Pulp of sea buckthorn plant :[2]

Sea buckthorn berry pulp constitutes about 68% of the fruit mass and is the primary sourcde of its characteristics orange oil layer, rich in bioactive compounds. Pulp is acidic, astringent, with strong antioxidant activity up to 88.7% processed into juices, oils for nutraceuticals, and cosmetics.

Seeds of sea buckthorn plant :[3]

Seeds of sea buckthorn plant are small, hard brown, shiny, ovate structures measuring about 2.8-4.2mm long, 2mm wide, with a longitudinal groove, thick hard coat (0.1-0.2mm), and creamy white kernel.

Role of sea buckthorn in human nutrients :[2][3]

Sea buckthorn seves as a nutrient powerhouse, providing essential vitamins, minerals, fatty acids, and antioxidants critical for human health.

Vitamins : Vitamin C,A,E,K,B-complex (B12,RIBOFLAVIN,NIACIN) supporting immunity, vision, and antioxidant defense.

Fatty acids : Rare omega-7, balanced omega-3-6(1:1 ratio) promotes cardiovascular health, skin hydration, and metabolism.

Minerals and others : potassium, calcium, magnesium, iron, zinc, polyphenols, carotenoids, amino acids.

These nutrients promotes oxidative stress, reduce inflammaation, lowers cholesterol, regulare blood sugar level, enhance liver function and boost immunity against disesses like cancer and neurodegeneration. [2][3]

Sea buckthorn (*Hippophae rhamnoides L.*) fruit is a rich source of lipophilic and hydrophilic bioactive compounds and shows notable anticancer, hepatoprotective and anti-atherogenic activities, with current evidence largely coming from in vitro, animal and limited human studies. Overall, it appears more chemopreventive than carcinogenic, but long-term safety and clinical efficacy still require robust trials.

BIOACTIVE COMPOUNDS OF SEA BUCKTHORN :

1.Polyphenols: Among plants and are defined structurally by the presence of multiple phenolic rings. In sea buckthorn, these compounds are present in all plant parts, including berries, roots, leaves, stems, and branches, but their amounts vary significantly in the fruits and leaves, depending on cultivar, geographic location, and the developmental stage of the plant. The most abundant polyphenols in sea buckthorn are phenolic acids and flavonoids. The total phenolic content, usually expressed as gallic acid equivalents, has been reported to range widely across tissues and cultivars. Free gallic acid is the most abundant phenolic acid, with its concentration significantly higher in leaves than in berries. Caffeic acid, p-coumaric acid, and ferulic acid are present in lower quantities.[4]

2.Flavanoids: Sea buckthorn berries contain much higher flavonoid levels compared with other common plants containing flavonoids, such as hawthorn, dogwood cherry, and blueberry. Among

the major phenolic compounds of this plant, flavonoid glycosides like isorhamnetin, quercetin, myricetin, and kaempferol have been widely identified. The main components of the flavonoid profile of sea buckthorn seeds are glycosides, while proanthocyanidins, catechins, triterpene saponins, polar, and hydrophobic compounds are present in smaller amounts. Flavonoid retention in final products depends much on processing methods, particularly drying ones, where the mildest methods like freeze-drying result in significantly higher concentrations compared to convective or microwave drying. These flavonoids are responsible for the potent antioxidant properties of sea buckthorn and its potential uses in functional foods and nutraceuticals.[5]

3 Fatty acids: Fatty acid profiles of sea buckthorn oil identify 19 different fatty acids, including eight saturated and eleven unsaturated types. The major components are essential polyunsaturated fatty acids: α-linolenic acid (up to 36-39% in seeds) and linoleic acid (33-42% in seeds). Noticeably, sea buckthorn oil contains very high levels of the ω-7 monounsaturated fatty acids, such as palmitoleic acid (16-54% of the total, especially in 32-42% of the pulp oil), combined with hexadecatrienoic, heptadecenoic, and vaccenic acids. Unlike the usual edible vegetable oils dominated by an 18-carbon chain or short-chain saturated triglycerides present in coconut oil and butter, sea buckthorn provides substantial amounts of palmitoleic acid, uniquely adding value to human nutrition. High dietary intake of saturated fatty acids, especially long-chain forms, is associated with an increased risk of cardiovascular disease, cholesterol increase, mitochondrial damage, insulin resistance, and endoplasmic reticulum stress. Their direct involvement in metabolic syndrome, however remains a matter of controversy. Hence, while supplementation with sea buckthorn provides an added advantage of its various fatty acids, saturated fat intake should be balanced for metabolic health.[6]

4.vitamins: Sea buckthorn is an excellent source of vitamins in all its plant parts, especially in berries, which contain extraordinarily high vitamin C concentrations, averaging 795 mg/100 g fresh weight, peaking up to 2500 mg/100 g in some subspecies like sinensis, exceeding oranges by as much as 10-12 times and surpassing fruits like kiwi, strawberry, and hawthorn. Among the B-group vitamins, the following are contained: B1 from 0.16–0.35 mg/kg, B2 from 0.30–5.0 mg/kg, B11 or folic acid up to 7.9 mg/kg fresh weight, while B3, B5, B6, and B12 are trace amounts and participate in metabolic processes. Among the fat-soluble vitamins, K and E are predominant. Vitamin E includes eight isoforms, of which four are tocopherols and four are tocotrienols; they have a very strong antioxidant action, and among them, α-tocopherol is the most bioactive form, presenting 43–223 mg/kg fresh weight and participating in skin health and in immune functions modulation. Vitamin C maintains 75-90% in pulp products after processes such as juicing, although heat and storage accelerate degradation; hence, fresh and minimal processing forms will retain better nutritional efficacy.[7]

5.Berries and seed of sea buckthorn: Sea buckthorn berries mature into dark yellow, orange, or red colors, 6–9 mm in oval shape, containing a shiny, dark brown, elliptical seed (2.8–4.2 mm long) inside juicy, pulp flesh. The chemical composition depends on the cultivar, as well as climate conditions, fruit size, and stage of maturity and postharvest treatment, hence affecting the nutritional value. The berries are rich in minerals such as calcium, phosphorus, iron, and potassium and extremely rich in vitamin C (360–2500 mg/100 g FW and 10–12 times higher than in oranges), B vitamins, especially thiamine and riboflavin, fat-soluble vitamins A, E (tocopherols and tocotrienols), and K, carotenoids (β-carotene, lycopene, lutein, and zeaxanthin), sugars (glucose, fructose, xylose; 2.7–4.8%), organic acids (malic, quinic, oxalic, citric, tartaric; 1.1–2.05%), proteins (albumins, globulins; 0.8–1.2%), fibers (1.2–4.9%), and flavonoids (quercetin, kaempferol, myricetin, isorhamnetin; 276–368 mg/100 g).[8]

6. The pulp: Sea buckthorn pulp is especially rich in carotenoids like α-carotene, β-carotene, γ-carotene, lycopene, and zeaxanthin, responsible for the bright color and antioxidant activity. B-complex vitamins are mostly represented by thiamine (B1), riboflavin (B2), pyridoxine (B6), niacin (PP/B3), and folic acid, important for the formation of nucleic acids, metabolism of energy, and nervous functions. Vitamin C concentration differs substantially among subspecies and under specific conditions of growth: Central Asian varieties usually span from 150 to 200 mg/100 g of fresh weight, while Alpine types reach about 800 mg/100 g; the overall range goes from 360 to 2500 mg/100 g. Incidentally, the lack of the enzyme ascorbinase ensures great stability upon drying and formulation in products, maintaining 75-90% in juices after processing. Moreover, 5-hydroxytryptamine is a rare neurotransmitter precursor in plants, found in the peel of stems and fruits, therapeutically used to manage symptoms of post-traumatic stress and depression. These nutrients give evidence of the role played by sea buckthorn in functional foods intended for immune support and mental health.[9]

7.Leaves: Sea buckthorn leaves are highly nutritious and bioactive, dominated by phenolic compounds providing antioxidant benefits. On average, they contain about 3.8% saccharides, 0.2% protopectin, 1% organic acids, 170 mg/100 g catechin, significant polyphenols (up to 10-15% dry weight), lycopene among carotenoids, bioflavonoids including quercetin and kaempferol, and coumarins

with potential antimicrobial effects. Vitamin C reaches up to 370 mg/100 g fresh weight, supplemented with tannins (about 8%) assisting digestion and anti-inflammatory responses; protein is on average 15-22% dry matter with a balanced composition of essential amino acids (e.g., lysine 3.9-5.2 g/16 g N), while important minerals include potassium (1.5-2.5%), calcium, and iron. These attributes make sea buckthorn leaves a potentially promising ingredient in teas, extracts, and supplements aiming at oxidative stress and metabolic health.[10]

8.Oils : One plant, sea buckthorn, produces two different oils: pulp oil from the fruit flesh (1.5–3% fresh weight, up to 20–25% in dry pulp) and seed oil (7–11% average, up to 20%). Pulp oil is rich in monounsaturated fatty acids such as palmitoleic acid (up to 43%, n-7), along with linoleic (2–30%) and α-linolenic acids, carotenoids (300–2000 mg/100 g total, including 40–100 mg β-carotene, lycopene, zeaxanthin), vitamin E (110–330 mg/100 g tocopherols/tocotrienols), and triterpenic acids (ursolic, oleanolic) with anti-inflammatory, wound-healing, hypotensive, and skin-regenerative activities. Seed oil, however, is essentially a polyunsaturated oil (up to 90%), with linoleic acid (35–47%, n-6) and α-linolenic acid (33–39%, n-3) in a rare 1 : 1 ratio, along with oleic acid (16%, n-9), minor n-7/n-9, saturated palmitic acid (5–9%), phytosterols (94 mg/100 g), and γ-tocopherol-dominant vitamin E. Oil content and profile can vary with harvest date, berry size and color, cultivar, and extraction technique; for example, supercritical CO2 extraction provides better preservation of bioactives compared with pressing.[11]

9.Carotenoids: Sea buckthorn berries are an excellent source of carotenoids. The total carotenoid concentrations and their profiles significantly vary, depending on genetic background, cultivation method, weather conditions, and harvest date. Extensive liquid chromatography analyses in different cultivars at various stages of ripeness have revealed important xanthophylls such as lutein and zeaxanthin-e.g., up to 945 µg/g dry weight in some varieties-along with carotenes like β-carotene, 104-116 µg/g dry weight, lycopene, and their esterified derivatives-for instance, zeaxanthin dipalmitate as major di-esters-which collectively range from 53 to 97 mg/100 g dry weight in berries and contribute to antioxidant activity, eye health, and color stability during processing.

EFFICACY AND MECHANISM OF SEA BUCKTHORN ACTIVE COMPOUNDS IN TREATING METABOLIC SYNDROME

Metabolic syndrome encompasses a variety of metabolic disorders, which generally include excess abdominal fat, blood pressure, blood sugar, and abnormal lipid profiles.[13] Effective management focuses on decreasing excessive fat production, enhancing lipid balance, improving insulin sensitivity, and regulating blood glucose and blood pressure, while managing other related metabolic processes. The bioactive substances in sea buckthorn have been reported to support metabolic regulation and alleviate complications associated with metabolic disorders. [13]

Clinical evidence of sea buckthorn: Sea buckthorn extracts demonstrate benefits in human trials for metabolic syndrome components. In obese children, daily pulp oil supplementation reduced triglycerides, cholesterol, blood pressure, oxidative stress, inflammation, and insulin resistance . Phenol-rich powder delayed post-meal lipid spikes and lowered harmful metabolites like 3-hydroxybutanoic acid . Puree consumption improved glucose and lipid metabolism in hypercholesterolemia patients after 90 days, despite initial sugar-related set backs .

Hyperlipidemia and obesity effects: The lipid-lowering and anti-obesity activities of sea buckthorn bioactives have been demonstrated in animal models[1]. Flavonoids such as isorhamnetin and quercetin reduced serum cholesterol, LDL-C, and liver triglycerides while increasing antioxidants and the HDL/LDL ratio in mice with a high-fat diet.Polyphenols suppressed inflammatory markers (TNF-α, IL-6) and vascular damage proteins (eNOS, LOX-1, ICAM-1) in hyperlipidemic rats.[14] Seed oil downregulated lipid absorption genes (ACAT2, MTP, ABCG8) and enhanced gut bacteria like Bacteroides for improved sterol excretion .[13]

Blood glucose and insulin regulation : Treatments enhanced glycemic control across studies.[13]The crossover trials have shown that sea buckthorn reduced postprandial glucose by 44.7% and insulin by up to 39.6%, while slightly reducing fasting glucose in impaired regulation patients.[14]Oils elevated the protective phospholipid fatty acids, including trans-palmitoleic acid, which linked to diabetes prevention. Flavonoids normalized insulin signaling and curbed neuroinflammation in high-fructose models.[13]

Key mechanisms : Several pathways explain these effects: compounds activate AMPK and Akt to further induce fatty acid oxidation, glucose uptake via GLUT4, and upregulation of antioxidant enzymes[13] ; flavonoids modulate PPAR-α/γ to inhibit adipogenesis, inflammation, and resistin, and also promote the conversion of cholesterol into bile acids ;[13] palmitoleic acid and phytosterols sensitize insulin, reduce fat accumulation, and balance gut microbiota for metabolic homeostasis.

CLINICAL TRAILS OF SEA BUCKTHORN :

Recent clinical trials have examined the potential of sea buckthorn in managing metabolic syndrome; see Table 1.[16] In one of these studies, the effects of 800 mg of sea buckthorn pulp oil supplementation per day for 60 days were assessed in a group of obese children. It was observed that this treatment prevented atherosclerosis, as evidenced by

significant reductions in triglycerides and cholesterol levels, as well as blood pressure. It also exerted minor effects on oxidative stress, inflammation, and insulin resistance. In another human study, the effects of phenol-rich sea buckthorn powder were investigated. The authors conducted an NMR analysis of plasma samples after meals and reported that supplementation with this powder decelerated postprandial lipids compared with that in a control group without supplementation, and also restrained increases in 3-hydroxybutanoic acid and N-acetyl glycoproteins.[15] In one study, researchers investigated the effects of sea buckthorn puree on plasma metabolome and gut microbiota in patients with hypercholesterolemia. After 45 days of intervention, increased blood glucose, lactate, and lipids counteracted potential positive effects on sugar and lipid metabolism, which may be due to added sugars in the puree having a negative effect on those with high cholesterol.[15] However, at 90 days, glucose and lactate had decreased below baseline while lipids normalized, perhaps due to bioactive phenolics in the puree. In a randomized, single-blind, three-way crossover trial, sea buckthorn was shown to increase blood glucose 44.7% relative to controls ($p < 0.01$), decreasing plasma insulin 39.6% at 30 minutes ($p < 0.01$) and 16.5% at 45 minutes ($p < 0.05$) post-intervention.[15] In another randomized, double-blind, two-way crossover trial, 5 weeks of sea buckthorn puree slightly decreased fasting blood glucose in patients with impaired glucose regulation.[15] Nonmodified sea buckthorn oil and a version enriched with trans-palmitoleic acid (16:1n-7t) were evaluated and both were found to moderately increase serum phospholipid fatty acid levels in healthy adults. Due to the association of 16:1n-7t with a lower risk of type 2 diabetes, it is suggested that the potential for diabetes prevention exists. Daily administration of 0.75 mL of sea buckthorn seed oil lowered dyslipidemia, cardiovascular risks, and hypertension in human subjects. The authors attribute this effect to the ω-3, -6, and -9 fatty acids, as well as to increased antioxidants from β-carotene and vitamin E. Consumption of sea buckthorn puree did not change total cholesterol, LDL-C, or triglycerides. HDL-C initially increased and then decreased. It reduced diastolic blood pressure and showed a downward trend in hsCRP, indicating long-term anti-inflammatory response and benefits on blood pressure in the hypercholesterolemia patients.[15]

Table1: The therapeutic effect of sea buckthorn on hyperlipidemia and obesity.

Sea buckthorn seed	Subjects	Dosage	Duration	Observed effects
Erolemia	Patients with hypercholesterolemia	90 g/day	90 days	Effectively controlled energy metabolism and intestinal microbiome composition
Sea buckthorn berry	18 normal-weight subjects	150 g/day	1 day and 2 days apart	Pronounced effect on postprandial insulin concentration, causing decreased and delayed insulin response
Sea buckthorn fruit puree	38 subjects with impaired glucose regulation (IGR)	90 ml/day	5 weeks	Downward trend in fasting plasma glucose in IGR subjects[16]
Sea buckthorn oil [14]	13 Participants (7 women,6 men ;age 48±16 years BMI 30.4±3.7)	380,760,1520 mg/day	3 weeks, with 4-week washout between supplements	Increased phospholipid fatty acid concentrations in metabolically healthy adults
Sea buckthorn seed oil	32 normal and 74 hypertensive and hypercholesterolemic subjects	0.75 ml/day	30 days	Lowered dyslipidemia and hypertension in male subjects

Sensory perception of sea buckthorn: Sea buckthorn berries and their juices have a distinct sensory profile dominated by the sensations of sourness, bitterness, and astringency, whereas sweetness is normally low. These taste characteristics often make the raw berries unattractive for immediate consumption. The dominating sour and bitter flavors in sea buckthorn products originate mainly from organic acids, flavonol glycosides, proanthocyanidins, and especially a special compound, ethyl β-D-glucopyranoside (EG). EG, present in amounts of 0.6-19.8 g/L, is responsible for bitterness, acting via bitter taste receptors. The dominance of acidity and tannin-like compounds on flavor is also reflected by the fact that sourness and astringency are dominating in the taste, even when sugar is added. Bitterness tends to increase in overripe berries due to increased levels of EG, which, in turn, has a bitterness threshold of about 1.0 g/L in water and may be perceived as strongly bitter at higher concentrations. Aroma of sea buckthorn is distinct, fruity, but less noticeable compared to strong taste sensations. The overall flavor varies depending on plant variety, ripeness, growing conditions, and climate. Overall, the sensory experience caused by the berries is more dependent on the ratio than on the absolute amount of different compounds such as proanthocyanidin dimers and trimers, quercetin glycosides, etc. Processing methods, such as juice extraction or the preparation of tea, may alter the bitterness and astringency; however the exact effects on flavor chemistry are currently not well understood.

Effect on glycation and browning: Extracts of *Hippophae rhamnoides L.*, especially its leaves and berries, exhibit a strong inhibitory activity towards the formation of advanced glycation end-products and protein crosslinking-both crucial steps in glycation implicated in the development of diabetic complications.[17] These manifestations result from bioactive polyphenols, including flavonoids and phenolic acids, which interfere with the Maillard reaction between reducing sugars and proteins, decreasing non-enzymatic browning in food systems and pathological glycation in vivo.[17] The active principles in sea buckthorn scavenge reactive carbonyl species and quench free radicals, thereby reducing oxidative stress that fuels AGE accumulation.[17]

Mechanisms of inhibition: Sea buckthorn leaf extracts are more active against the formation of AGE than the berry extracts. Ultra-performance liquid chromatography has determined the main active inhibitors in the form of quercetin derivatives up to 30% of total phenolics. This activity was consistent with the dose-dependent decrease in browning intensity in model reactions, maintaining protein functionality and color stability in processed foods. Animal and cell studies further reveal that the extracts modulate glucose metabolism enzymes, thus indirectly curbing glycation substrates like hyperglycemia.[17]

Applications and implications: Sea buckthorn incorporation in food could reduce the Maillard browning and off-flavor in high-sugar-content processed foods, enhancing their shelf life without the use of artificial additives. Therapeutically, anti-glycation activity supports its use in age-related disease management as it helps reduce tissue damage caused by AGEs, although clinical trials are still limited.

PRODUCTS DERIVED FROM SEA BUCKTHORN BERRIES, PULP, LEAVES, OIL AND POWDER:

Tulasi drops

Turmeric oil

Nourishing oil

CTC tea

Weight loss kit

Dry berry powder

Immunity booster

Diabetic care kit

Thyroid care kit

SEA BUCKTHORN FRUIT: PHYTOCHEMISTRY AND GENERAL PHARMACOLOGY

Sea buckthorn berries contain high levels of vitamin C, vitamin E, carotenoids (including beta-carotene and lycopene), flavonoids (quercetin, kaempferol, isorhamnetin), proanthocyanidins, fatty acids (palmitoleic, linoleic, α-linolenic) and phytosterols.These constituents underpin potent antioxidant, anti-inflammatory, immunomodulatory, cardioprotective, antimicrobial and tissue-protective effects observed in various experimental models. [19]The fruit, seeds and leaves have been formulated as juices, oils, extracts and nutraceutical preparations, with reported benefits in metabolic, cardiovascular, hepatic, dermatologic and gastrointestinal conditions. Standardisation of preparations remains a major challenge, and differences in cultivar, growing conditions and extraction methods significantly influence phytochemical profiles and bioactivity.

Carcinogenic / anticancer activity :
Current literature predominantly describes anticancer and chemopreventive effects of sea buckthorn rather than intrinsic carcinogenicity. Extracts from berries, seeds and leaves exhibit antiproliferative, pro-apoptotic and anti-metastatic activities against a range of cancer cell lines, including colon, liver, lung, cervical, ovarian and breast cancer cells.[20]

Mechanistically, flavonoids, proanthocyanidins and other phenolics modulate oxidative stress, inflammatory signalling (e.g. NF-κB, cytokines), cell cycle regulators and apoptotic pathways, thereby inhibiting tumour cell growth and enhancing susceptibility to radiotherapy or chemotherapy in experimental systems. Animal studies suggest sea buckthorn preparations may reduce carcinogen-induced DNA damage and tumour burden, although doses and formulations vary widely. With respect to carcinogenicity, acute, subchronic, genotoxicity and teratogenicity studies on sea buckthorn berry or seed oil generally show a favourable safety profile, with no clear mutagenic or teratogenic signal at tested doses. Nonetheless, the absence of strong carcinogenic signals in preclinical tests does not equate to definitive long-term safety in humans, and high-dose or chronic supplementation should be approached cautiously until large, well-designed clinical studies are available. [21]

Hepatoprotective activity:
Sea buckthorn demonstrates consistent hepatoprotective effects in multiple experimental models of liver injury, including toxic, metabolic and drug-induced hepatotoxicity. Phenolic-rich fractions from leaves and ethanolic extracts of berries attenuate carbon tetrachloride- or acetaminophen-induced hepatic damage in rodents, reducing serum transaminases, lipid peroxidation markers and histological necrosis while enhancing antioxidant enzymes such as superoxide dismutase and glutathione peroxidase.[21] Berry seed oil has shown protection against cyclophosphamide-induced liver injury, which is attributed to its antioxidant and membrane-stabilising properties mediated by tocopherols, carotenoids and unsaturated fatty acids.[22] Sea buckthorn leaf extract supplementation has also improved liver enzyme profiles and oxidative stress markers in diabetic animal models, suggesting potential benefits in chronic metabolic hepatopathies such as non-alcoholic fatty liver disease. [22]Limited human data indicate improvements in liver enzymes and lipid parameters with sea buckthorn preparations in dyslipidaemic or obese subjects, but sample sizes are small and study durations short.[22] Consequently, sea buckthorn should presently be regarded as a promising adjunctive hepatoprotective agent rather than an established therapy, pending more rigorous clinical validation.

Anti-atherogenic and cardiometabolic effects:
Sea buckthorn fruit and seed oils exert notable effects on lipid metabolism and vascular function, supporting an anti-atherogenic profile.[23][24] Animal studies reveal that seed oil reduces total cholesterol, low-density lipoprotein cholesterol and triglycerides while increasing high-density lipoprotein cholesterol, accompanied by decreased aortic lipid deposition and improved endothelial status.[25][26] These cardioprotective effects are linked to unsaturated fatty acids, phytosterols, tocopherols and flavonoids, which collectively modulate oxidative stress, inflammatory mediators, platelet aggregation and endothelial nitric oxide bioavailability.[27] Early human studies suggest modest improvements in dyslipidaemia, blood pressure and markers of oxidative stress with sea buckthorn supplementation, though heterogeneity in products and study design currently precludes firm clinical recommendations. Importantly, "atherogenic effects"[28] in the conventional sense (promotion of atherosclerosis) have not been demonstrated; instead, the evidence points towards anti-atherogenic and cardioprotective activity when sea buckthorn is used in appropriate doses as part of a balanced diet. However, caution is advised in patients on lipid-lowering, antiplatelet or anticoagulant therapies due to potential additive effects, underscoring the need for controlled interaction studies.

Antidiabetic effect :
Sea buckthorn possesses notable antidiabetic effects, primarily due to its ability to reduce blood glucose levels. Regular intake of sea buckthorn has been reported to lower both fasting and post-prandial glucose levels, thereby supporting better overall glycemic control (Christaki2012). Evidence from cell studies, animal research, and limited clinical trials suggest that sea buckthorn play a beneficial role in managing diabetes.Antidiabetic activity was evaluated using an alpha-glucosidase inhibition assay. different concentrations of the samples (0.0625-0.50 mg/ml) were combined with PNPG and phosphate buffer, then incubated at 37 degrees Celsius.[29] The reaction was initiated by adding the enzyme and allowed to run for 15 minutes. It was stopped using Na2CO3 after which the absorbance of the produced P-nitrophenol was recorded at 400nm. The percentage of enzyme inhibition was calculated, and the IC50 value was identified as the concentration that inhibited 50% of the enzyme activity.Sea buckthorn has shown potential in managing diabetes due to its rich content of bioactive substance, such as flavonoids, peptides, and dietary fibers, which can reduce blood sugar by

blocking enzymes that break down carbohydrates. [30]While laboratory and animals studies report encouraging results, evidence from human trails remains limited, highlighting the need for standardized formulations and further research to confirm its effectiveness and safety.

Antibacterial activity:

Sea buckthorn has been extensively studied for its bacterial effect, with many investigations evaluating both aqueous and hydroethanolic fruit extracts against various pathogenic bacteria. Several reports indicate that the extract inhibit gram-negative species such as Escherichia coli and Salmonella enterica (Korekar etal., 2011; Chawla et al.,2012), as well as gram-positive pathogens including Listeria monocytogenes and staphylococcus aureus[31] (Upadhayay et al., 2010; zeb, 2016), Most studies utilise agar diffusion - based assays, where sea buckthorn extracts consistently produce inhibition zones, confirming their antibacterial potential (Gornas et al.,2014).evidence also suggest that ethanol enriched extracts generally shows stronger activity than water extracts, likely due to enhanced extraction of phenolic and flavonoid compounds (Olas, 2018; Zakaria et al., 2019). [32]

Mechanism of action of antibacterial agents:

Many antibacterial agents target the bacterial peptidoglycan layer, as weakening this structure disrupts cell stabilising and division. Beta lactam block kay wall- forming enzymes, while Fts Z interfere with formation of the division ring. Natural phenolics like sophora flavanone B also hinder peptidoglycan synthesis.[33]

Anti -inflammatory effect:

Sea buckthorn exhibits significant anti-inflammatory effect attributed to its bioactive compounds such as flavonoids, carotenoids, and phenolics. Studies show its extract can reduce pro-inflammatory cytokines and oxidative stress by modulating pathway like NF-KB and metabolic inflammation.[34] while preclinical data are promising, limited human studies highlight the need for further research to confirm its efficacy and safety.A 2034 invitro study also demonstrated that sea buckthorn pulp oil significantly supress response in human dermal fibroblast-reducing UV-B-induced inflammation and collagen degradation, which support its potential as an anti-inflammatory/ anti-aging agent in dermatological applications.[34]

Antihypertensive activity:

Sea buckthorn, is increasingly recognised as a potential natural intervention for hypertension, owing to its rich in profile of bioactive constituents, including flavonoids, phenolic acids, unsaturated fatty acids, and vitamins.[35]Experimental studies indicate that sea buckthorn S may influence blood pressure through various pathways, such as antioxidant effects.Sea buckthorn, has gained attention for its potential role in managing hypertension and promoting health. preclinical studies and small clinical trials have reported modest reductions in diastolic blood pressure and improvements in endothelial function, although effects on systolic pressure are less consistent.[36] Variations in study design, populations, and the form and dosage of sea buckthorn limits the generalizability of these findings. Overall, while sea buckthorn shows promise as a complementary intervention for hypertension, further large-scale, well- designed trails are needed to established its efficacy and safety.The same extraction procedure was used for all tests, following the method of Nowicka et al. The antioxidant activities (ABTS, FRAP, and ORAC) were measured using methods described earlier by Re et al., Benzie and Strain, and Ou et al.[37]

IN VITRO ANTIOXIDANT ACTIVITY ASSESSMENT OF SEA BUCKTHORN EXTRACTS :

ABTS Test (2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid)

The ABTS•⁺ test measures how much the color of the solution fades, which decreases as antioxidant levels increase.An ABTS•⁺ solution with an absorbance of 0.700 ± 0.02 at 734 nm was prepared. Sea buckthorn extracts were mixed with this solution, and after 6 minutes the absorbance was measured. Distilled water was used as a blank. Results were calculated using a Trolox standard curve (R^2 = 0.9950) for concentrations between 0.100 and 0.900 mM.

FRAP Test (Ferric Reducing Antioxidant Power)

The FRAP test measures the ability of antioxidants to reduce Fe^{3+} to blue-colored Fe^{2+}. Extracts were mixed with water, and after adding the FRAP reagent (acetate buffer, TPTZ in HCl, and $FeCl_3 \cdot 6H_2O$ in a 10:1:1 ratio), the absorbance was measured at 593 nm after 10 minutes. Results were calculated using a Trolox curve (R^2 = 0.9899) for 0.050–0.900 mM.

ORAC Test (Oxygen Radical Absorbance Capacity)
The ORAC method measures how antioxidants prevent the loss of fluorescence caused by free radicals. Extracts, phosphate buffer, and fluorescein were incubated at 37 °C. After adding AAPH (a free-radical generator), fluorescence was measured every 5 minutes at 493 nm (excitation) and 515 nm (emission). The blank was phosphate buffer. Antioxidant activity was calculated by comparing the area under the curve with Trolox standards (12.5–75 μM).

Results for ABTS, FRAP, and ORAC were expressed as mmol Trolox equivalents per 100 g sample.

Anti-Enzyme Activity Tests:
Anti-α-amylase, anti-α-glucosidase, and anti-lipase activities were measured based on methods by Nowicka et al. and Podsędek et al.

α-Amylase Inhibition:
This test measures how much starch remains after enzymatic breakdown. Sea buckthorn extract, starch, and α-amylase were incubated at 37 °C. The reaction was stopped with HCl, then iodine–potassium iodide was added. Absorbance was measured at 600 nm. Acarbose was used as a positive control.

α-Glucosidase Inhibition :
When the enzyme reacts with its substrate, a yellow color is produced. Extracts and enzyme were incubated, the substrate was added, and absorbance was measured at 405 nm. Buffer was used for blanks, and acarbose was the positive control.

Lipase Inhibition :
This test measures p-nitrophenol formed from p-nitrophenyl acetate. Extracts, buffer, and lipase were incubated for 5 minutes, the substrate was added, and incubation continued for 15 minutes. Absorbance was measured at 400 nm. Orlistat was used as a positive control.Results for all the above enzyme-inhibitory tests were expressed as IC_{50} (mg/mL)—the amount of extract needed to inhibit 50% of enzyme activity.[38]

PROCESS INVOLVED IN ANTI-VIRAL EFFECT :
Plant collection:
Fresh aerial parts of sea buckthorn (Hippophae rhamnoides L.) were collected from the Karakoram-Indus valley, Pheh, Ladakh (3180 m altitude) in July 2018. The plant was first identified by a local Amchi herbal practitioner in Leh and later confirmed by Dr. Tariq Husain from the National Botanical Research Institute, Lucknow.

Extraction and Fractionation:
The dried aerial parts of sea buckthorn (410 g) were powdered and extracted with 90% ethanol (3 × 250 ml) at room temperature using continuous shaking until all components were removed. The combined extracts were filtered and concentrated at 40°C using a rotary evaporator. The resulting dried ethanol extract (198.7 g) was dissolved in water and then fractionated using chloroform (4.12 g), ethyl acetate (2.1 g), and n-butanol (62.9 g), leaving behind an aqueous fraction (122.4 g). All solvent fractions were evaporated to complete dryness and stored at 4°C for further analysis.

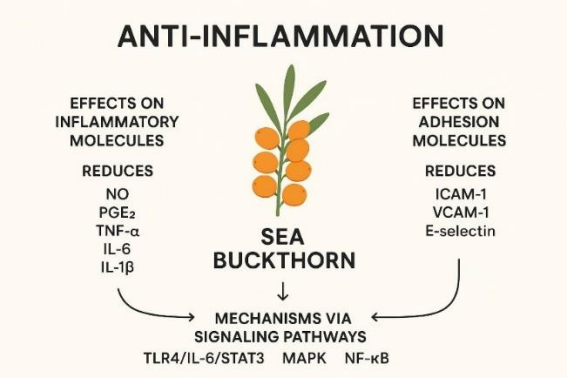
Anti-HBV Activities :
Sea buckthorn fractions (SB-Eac, SB-But, SB-Aqu) significantly reduced HBV surface antigen (HBsAg) and e antigen (HBeAg) in infected liver cells.SB-Eac showed the strongest antiviral effect among the fractions.The flavonoids quercetin and kaempferol showed high inhibition of both HBsAg and HBeAg (around 60–67%).Isorhamnetin showed mild antiviral activity (~30%).The antiviral effect was dose-dependent and time-dependent. Standard drug lamivudine had the highest suppression (80–87%), used as a control.Overall, quercetin and kaempferol are the main contributors to sea buckthorn's anti-HBV activity. Anti-Inflammatory Effects of Sea Buckthorn :Inflammation plays a key role in the development of cardiovascular diseases (CVD). Sea buckthorn helps prevent and slow down CVD by reducing inflammation.[39]

CARDIOVASCULAR EFFECT OF SEA BUCKTHORN FRUIT :
Effects on inflammatory molecules:
Sea buckthorn flavonoids reduce the production of NO, PGE2, TNF-α, IL-6, and IL-1β at both protein and mRNA levels.1,5-Dimethyl citrate from sea buckthorn reduces inflammation in mouse macrophages.In rats with exercise-related heart injury, sea buckthorn flavonoids lowered MDA, IL-1β, IL-6, and TNF-α, and increased antioxidant enzymes SOD and GSH-Px.Isorhamnetin, a sea buckthorn component, inhibits IL-6, TNF-α, and MCP-1 release in immune cells.

Mechanisms via signaling pathways:
Sea buckthorn flavonoids reduce inflammation through TLR4/IL-6/STAT3, MAPK (SAPK/JNK and p38), and NF-κB pathways.Isorhamnetin decreases foam cell formation in macrophages and modulates the TLR-4/IκBα/NF-κB pathway in mice, reducing inflammation in blood vessels.

Effects on adhesion molecules:
Sea buckthorn reduces expression of ICAM-1, VCAM-1, and E-selectin in endothelial cells, preventing inflammation and cell apoptosis.Sea buckthorn inhibits the release of pro-inflammatory

factors and works through multiple pathways (TLR4/IL-6/STAT3, MAPK, NF-κB) and adhesion molecules (ICAM-1, VCAM-1), offering strong anti-inflammatory
Effect for cardiovascular protection.



CONCLUSION AND FUTURE PERSPECTIVES:[40]

Collectively, sea buckthorn fruit represents a multifunctional medicinal and nutritional resource with antioxidant, anticancer, hepatoprotective and anti-atherogenic properties supported by a growing body of preclinical evidence. Nevertheless, issues such as standardisation of preparations, clarification of long-term safety (including carcinogenic risk), dose–response relationships and robust human clinical trials remain critical gaps before routine clinical or high-dose nutraceutical use can be recommended.

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