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SEA BUCKTHORN (HIPPOPHAE RHAMNOIDES) OIL: PHYTOCHEMISTRY, FRACTIONATION, AND DERMAL-MUCOSAL BIOACTIVITY A NARRATIVE REVIEW

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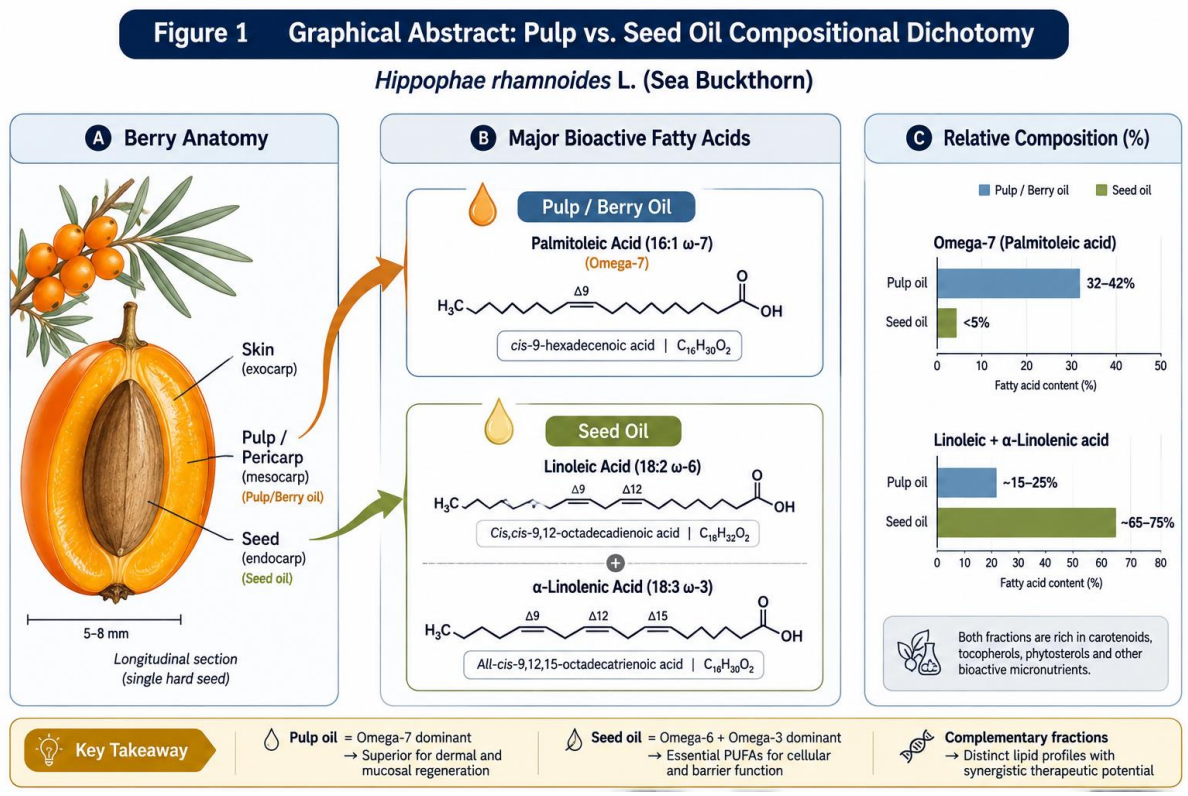
ABSTRACT

Sea buckthorn (*Hippophae rhamnoides* L., Elaeagnaceae), a trans-Himalayan and Eurasian shrub, has a documented medicinal history in Sowa-Rigpa (Tibetan/Amchi) medicine dating to the 8th-century *rGyud-bZhi*, and an increasing role in contemporary Indian formulation science, cosmeceuticals, and nutraceuticals.[5], [6] This narrative review synthesises 33 sources 32 peer-reviewed studies and reviews plus 1 classical/secondary Ayurvedic reference across phytochemistry, dermatological and mucosal pharmacology, transdermal permeation, safety, and traditional use. **Phytochemical analysis** distinguishes pulp/berry oil, dominated by palmitoleic acid (16:1 ω-7, "Omega-7"; 32–42%, occasionally higher)[3],[4], from seed oil, dominated instead by the essential polyunsaturated pair linoleic and α-linolenic acid in a near 1:1 ratio comprising roughly two-thirds to three-quarters of seed fatty acids.[1], [2] Both fractions carry a dense antioxidant micronutrient load of carotenoids, tocopherols, and phytosterols.[17], [18] **Mechanistic review** identifies convergent dermal and mucosal bioactivities: accelerated wound and burn re-epithelialisation, corroborated by a randomised triple-blind clinical trial against silver sulfadiazine[7] and controlled burn-model studies[8], [9]; Nrf2-linked antioxidant protection of UV-irradiated keratinocytes and fibroblasts[12]; anti-inflammatory Th1/Th2 rebalancing in an atopic-dermatitis model[15]; and gastroprotective activity across multiple experimental gastric-ulcer models.[21], [22] **Transdermal permeation relevance** is more equivocal than for lauric-acid-rich carriers: a direct comparative ex-vivo study found sea buckthorn pulp oil did not significantly enhance skin distribution of a model co-permeant, unlike olive or soybean oil[13], positioning the oil primarily as a bioactive antioxidant/regenerative ingredient rather than a classical penetration enhancer. Sea buckthorn's classical textual lineage lies in Sowa-Rigpa rather than the Sanskrit Ayurvedic Samhitas. The review identifies six standardisation and evidence gaps - chiefly pulp-versus-seed-oil conflation.

KEYWORDS: Sea buckthorn; *Hippophae rhamnoides*; Palmitoleic acid; Omega-7; Carotenoids; Tocopherols; Sowa-Rigpa; Wound healing; Transdermal permeation; Gastroprotection; Elaeagnaceae.



1. INTRODUCTION

Sea buckthorn (*Hippophae rhamnoides* L.), family Elaeagnaceae, is a thorny, nitrogen-fixing, dioecious shrub native to the cold-arid and sub-alpine belt stretching from Western Europe through Central Asia, Mongolia, and China into the Trans-Himalaya, where it grows wild between roughly 1,200 and 4,300 metres of elevation.[5] In India it is concentrated in Ladakh, Himachal Pradesh, Uttarakhand, Sikkim, and Arunachal Pradesh, with Ladakh accounting for the majority of the country's cultivated area.[5] The berry, seed, pulp, leaf, and bark are all used medicinally in the regions where the plant grows wild, but the oils expressed from the seed and from the fleshy pulp/peel are the forms of principal pharmaceutical and cosmeceutical interest, owing to their distinct and complementary lipid and micronutrient profiles.[1], [2]

The plant's best-documented classical medicinal lineage is not the pan-Indian Sanskrit Ayurvedic corpus but Sowa-Rigpa (Tibetan/Trans-Himalayan medicine), where its therapeutic use is recorded in the 8th-century *rGyud-bZhi* ("Four Tantras"), the foundational text of Amchi medical practice, and in over a hundred formulations across subsequent Sowa-Rigpa pharmacopoeias.[5] Parallel traditional use is documented in classical Chinese and Mongolian medicine, chiefly for splenic-gastric, respiratory, and circulatory indications, with the Chinese Pharmacopoeia formally listing sea buckthorn berry as a recognised medicinal material.[6] Its incorporation into contemporary pan-Indian Ayurvedic and nutraceutical formulation is comparatively recent and reflects modern scientific and commercial interest converging with a genuine but geographically distinct classical precedent, a distinction this review treats explicitly rather than assumes (**Section 9**).

Phytochemically, sea buckthorn oil occupies a very different chemical space from the medium-chain-fatty-acid carrier oils, such as coconut, more commonly discussed as penetration-enhancing.[1] Its pulp/berry oil is unusually rich in palmitoleic acid (16:1 ω-7, colloquially "Omega-7"), a monounsaturated fatty acid that is also a major constituent of human sebum, alongside a carotenoid and tocopherol density that gives the oil its characteristic deep orange-red colour and confers substantial intrinsic antioxidant capacity.[3], [17] Its seed oil instead carries a near-equal ratio of the two essential polyunsaturated fatty acids, linoleic and α-linolenic acid.[4] This compositional duality - a sebum-mimetic MUFA-rich pulp fraction and an essential-PUFA-rich seed fraction - underlies most of the plant's documented dermatological and mucosal bioactivity (Section 6).

This review synthesises the phytochemical, mechanistic, transdermal-permeation, safety, and traditional-use literature on sea buckthorn oil. It follows a formulation-relevant structure: botanical source and production (Section 3), phytochemical composition with attention to pulp/seed differentiation (Section 4), oil extraction technologies (Section 5) and industrial fractionation and processing (Section 6), antioxidant micronutrient profile (Section 7), mechanistic dermatological and mucosal pharmacology (Section 8), traditional and ethnomedical context (**Section 9**), safety and tolerability (**Section 10**), and standardisation and quality-control considerations

(**Section 11**), closing with identified evidence gaps and recommendations (**Section 12**).

2. METHODS

This review adopts a narrative-synthesis methodology, consistent with the integrative, application-oriented aim of evaluating a single ingredient across heterogeneous literatures (phytochemistry, dermatology, gastroenterology, and ethnobotany) rather than pooling a homogeneous outcome measure as in a systematic review or meta-analysis.

Literature was retrieved through structured searching of PubMed, ScienceDirect, Frontiers, MDPI, Springer Nature, and Wiley Online Library, using combinations of the search terms "sea buckthorn," "Hippophae rhamnoides," "palmitoleic acid," "Omega-7," "seed oil," "pulp oil," "transdermal," "skin penetration," "wound healing," "gastric ulcer," "tocopherol," "carotenoid," "supercritical CO2 extraction," "cold pressing," "fractionation," and "Sowa-Rigpa." Only sources with verifiable authorship, journal/publisher indexing, or clear institutional provenance were retained; promotional, unreferenced, or non-attributable web content was excluded from the formal reference list, consistent with the verification standard applied across this formulation programme.

3. Botanical Source, Distribution, and Production

H. rhamnoides is a winter-hardy, deciduous, actinorhizal (nitrogen-fixing) shrub tolerant of extreme temperature ranges, drought, and poor soils, characteristics that make it ecologically valuable for slope stabilisation and soil restoration in fragile Himalayan terrain in addition to its medicinal value.[5] The female plant bears small, orange-to-yellow berries typically hand-harvested by comb or careful pruning owing to the plant's dense thorns and the fragility of the ripe fruit. Oil is expressed separately from the seed (a small, hard kernel within the berry) and from the pulp/peel (the soft outer flesh); a minority of preparations use whole-berry oil, which combines both fractions in ratios that vary by processing method.[1] China is the dominant global producer, followed by Russia, Mongolia, and Northern Europe; within India, cultivation is concentrated in Ladakh, supported by government and research-institution programmes given the plant's dual medicinal and land-restoration value.[5]

Taxonomically, the genus *Hippophae* currently comprises seven recognised species, all but the widely distributed *H. rhamnoides* itself centred on the Qinghai–Tibet Plateau and adjacent high-altitude Asia.[30] *H. rhamnoides* is further divided into eight to nine recognised subspecies - carpatica, caucasica, fluviatilis, mongolica, rhamnoides, sinensis, turkestanica, wolongensis, and yunnanensis - distinguished by leaf morphology, stellate-hair density, and geographic distribution.[30] Trans-Himalayan and Central Asian material, including Ladakh-cultivated stock, is drawn chiefly from ssp. turkestanica and ssp. mongolica, while ssp. sinensis dominates commercial cultivation in China.[5],[30] This subspecies-level distinction is formulation-relevant rather than academic: comparative analysis of ssp. sinensis and ssp. mongolica sources under matched analytical conditions has found measurable differences in vitamin and phytonutrient content between the two, sufficient to support molecular-marker-based subspecies authentication as a safeguard against economically motivated substitution.[31] In-house specification should therefore record subspecies, not only species, wherever the supply chain permits.

Fruit oil content varies markedly by plant part and is a key driver of extraction economics: seed kernels typically yield 7–11% oil by weight, while the pulp/soft tissue yields a considerably lower 2.8–8%.[1] Harvesting remains labour-intensive and is the principal cost driver in sea buckthorn oil production; because ripe berries bruise and exude juice readily and the shrub is densely thorned, hand-stripping, comb-harvesting, and the more destructive branch-cutting-and-freezing method (in which whole fruiting branches are removed, frozen, and mechanically shaken to detach berries) are all used commercially, with mechanised harvesting adopted at scale chiefly in China and Russia.[5] Post-harvest, berries are typically washed, sorted, and either processed fresh or frozen for later processing, since fresh material deteriorates rapidly and freezing is the dominant commercial preservation method pending juice/oil extraction.[1]

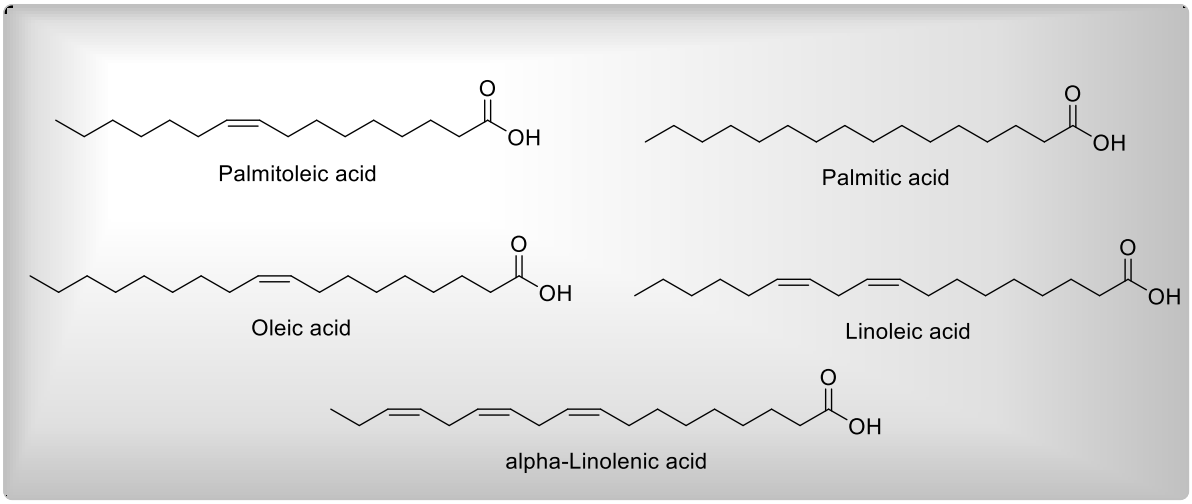
4. Phytochemical Composition: Pulp Oil versus Seed Oil

The single most formulation-relevant fact about sea buckthorn oil is that "sea buckthorn oil" is not compositionally uniform: pulp/berry oil and seed oil differ substantially in fatty-acid profile and are typically standardised and sourced separately for pharmaceutical use.[1], [4]

4.1 Fatty Acid Backbone - Pulp MUFA versus Seed PUFA

Table 1: Fatty-acid backbone of sea buckthorn pulp/berry oil versus seed oil. References: Fatty Acid Composition of Developing Sea Buckthorn Berry, PLOS ONE, 2012[3]; Fatty acid composition of lipids in sea buckthorn berries of different origins, PubMed.[4]

Fatty Acid	Pulp / Berry Oil (%)	Seed Oil (%)	Primary Relevance
Palmitoleic acid (16:1 ω-7, "Omega-7")	32–42 (up to ~49 in some cultivars)	Trace / absent	Dominant MUFA of pulp oil; structural analogue of skin sebum lipid
Palmitic acid (16:0)	Moderate	Moderate	Saturated backbone component
Oleic acid (18:1 ω-9)	Present, variable	Present, variable	General emollient MUFA
Linoleic acid (18:2 ω-6)	Low–moderate	33–42	Essential PUFA; barrier-lipid precursor
α-Linolenic acid (18:3 ω-3)	Low–moderate	30–39	Essential PUFA; anti-inflammatory eicosanoid precursor



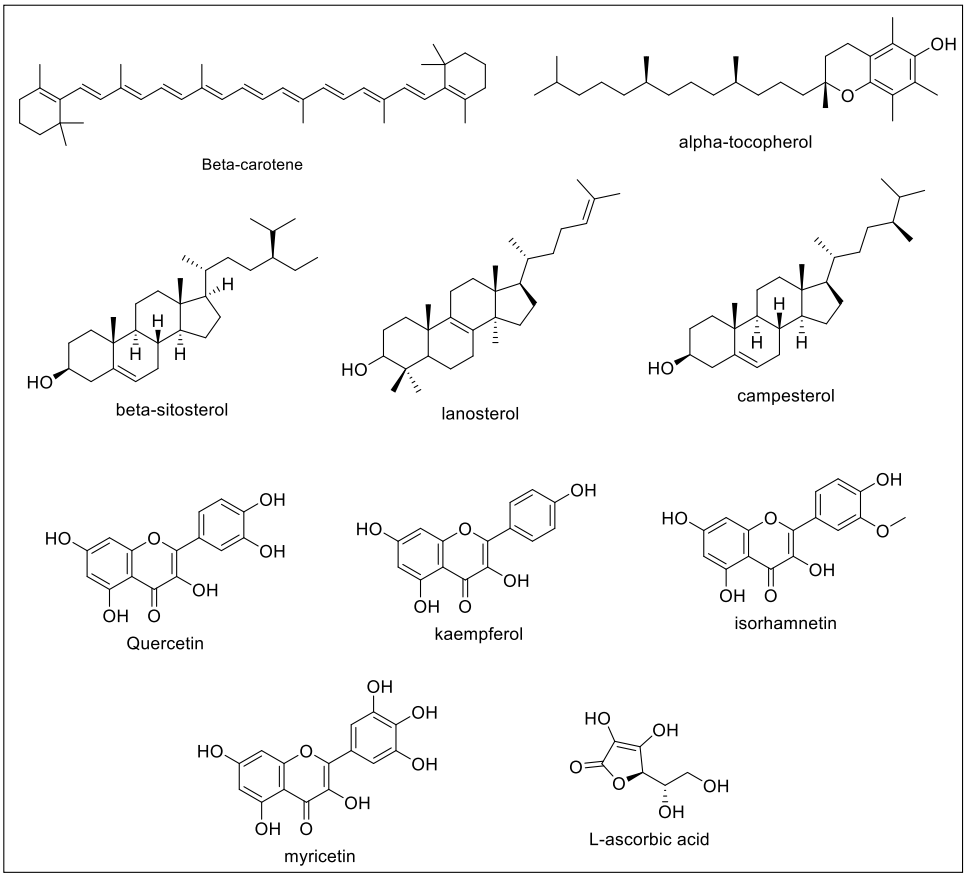
Pulp/berry oil is characterised by a high monounsaturated palmitoleic acid content, commonly cited in the 32–42% range and reported as high as ~49% in some cultivar and subspecies studies[3], a fatty acid of particular dermatological interest because it is also a major constituent of native human sebum.[9] Seed oil, in contrast, is essentially devoid of palmitoleic acid and is instead dominated by the two essential polyunsaturated fatty acids linoleic (18:2 ω-6) and α-linolenic (18:3 ω-3) acid, which together commonly account for roughly two-thirds to three-quarters of seed-oil fatty acids in a ratio close to 1:1 - a profile substantially different from the polyunsaturated fatty acid balance of most major vegetable oils.[4] Subspecies, growing origin, and ripening stage produce measurable variation in these ranges[4], underscoring the need for batch-level fatty-acid verification (**Section 11**) rather than reliance on literature averages alone.

4.2 Non-Fatty-Acid Constituents

Beyond its fatty-acid backbone, sea buckthorn oil - particularly the pulp fraction - carries an unusually dense antioxidant micronutrient load spanning carotenoids, tocopherols/tocotrienols, phytosterols, and phenolic compounds, summarised with reported concentration ranges in Table 2. Carotenoids (predominantly β-carotene, zeaxanthin, and lycopene) are reported in the broad range of roughly 300–2,800 mg/kg depending on cultivar, subspecies, and extraction method, and are responsible for the oil's characteristic deep orange-red colour[17],[18]; comparative Mongolian cultivar screening has reported carotenoid content as low as ~1.8 mg/100 g and as high as ~49 mg/100 g fresh weight, underscoring the scale of batch-to-batch variation that in-house specification must accommodate.[39] Tocopherols and tocotrienols, with α-tocopherol typically the dominant vitamin E congener, are reported in the broad range of 100–1,600 mg/kg across pulp and seed oils and extraction methods.[18],[19] Phytosterols, chiefly β-sitosterol, are commonly reported at 1.0–2.9% of total oil by conventional extraction, rising to as much as 1.6–1.8% (approximately 16.4 mg/g oil total sterols) under optimised supercritical-CO2 extraction, which recovers this sterol fraction more efficiently than cold pressing or hexane extraction.[2],[35],[40] Flavonoids (quercetin, kaempferol, isorhamnetin, myricetin) and proanthocyanidins are present at lower concentrations, largely in the aqueous/juice rather than oil fraction[4],[20], but are relevant to the whole-berry ethnopharmacological picture.

Table 2: Non-fatty-acid micronutrient and phytosterol composition of sea buckthorn oil, by principal fraction. References: carotenoid and tocopherol content[17],[18],[19],[39]; phytosterol content[2],[35],[40]; aqueous-phase flavonoids and ascorbic acid.[4],[20],[39]

Constituent Class	Principal Compounds	Reported Range	Primary Fraction	Ref.
Carotenoids	β-carotene, zeaxanthin, lycopene	~300–2,800 mg/kg (cultivar/method-dependent)	Predominantly pulp	[17],[18],[39]
Tocopherols / tocotrienols	α-, β-, γ-tocopherol (α dominant)	~100–1,600 mg/kg	Pulp and seed	[18],[19]
Phytosterols	β-sitosterol (dominant), campesterol, lanosterol, others	~1.0–2.9% of total oil (up to 1.6–1.8% by SC-CO2)	Predominantly seed	[2],[35],[40]
Flavonoids / proanthocyanidins	Quercetin, kaempferol, isorhamnetin, myricetin	Trace in oil; concentrated in juice/aqueous fraction	Aqueous/juice, not oil	[4],[20]
Ascorbic acid (Vitamin C)	L-ascorbic acid	~70–373 mg/100 g fresh fruit; not oil-soluble	Juice/pulp aqueous phase	[39]



5. Oil Extraction Process

Extraction technology materially determines the composition, potency, and stability of the sea buckthorn oil ultimately delivered to formulation, and should therefore be treated as a specified process parameter rather than a supplier-discretionary detail. Four extraction technologies dominate current commercial and research practice - mechanical (cold) pressing, organic-solvent extraction, supercritical carbon dioxide (SC-CO2) extraction, and newer ultrasonic-/enzyme-assisted and aqueous methods - whose comparative principles, yields, and effects on heat- and oxidation-sensitive actives are summarised in Table 3.[32],[33]

Cold (mechanical/screw) pressing is the most widely used method for commercial-grade pulp and seed oil and, by convention, must not exceed approximately 49°C during expression to retain the "cold-pressed" designation. It is solvent-free and comparatively low-cost, but yields are lower than solvent- or CO2-based methods, and the mechanical heat and pressure generated can degrade a portion of the oil's heat-labile carotenoid load.[33] Solvent extraction (typically hexane or petroleum ether) achieves higher oil yields by exhaustively partitioning lipophilic material from dried pomace or seed meal, but requires a subsequent desolventisation step and carries a residual-solvent quality-control burden; comparative studies have found petroleum-ether-extracted sea buckthorn oil comparable

to other methods in principal fatty-acid content but generally lower in recovered tocopherol, carotenoid, and sterol content than supercritical-CO2 extraction.[32]

Supercritical CO2 extraction operates at low temperature (typically below 40°C) using pressurised carbon dioxide as a tunable, residue-free solvent, and is consistently reported across independent studies as the method best preserving heat- and oxidation-sensitive carotenoids, tocopherols, and phytosterols, in some comparisons yielding markedly higher total-sterol recovery than cold pressing or hexane extraction.[33],[35] Response-surface optimisation of SC-CO2 parameters (pressure, temperature, CO2 flow rate, and extraction time) has been used to maximise simultaneous oil, vitamin E, and carotenoid yield, with reported optimal conditions in the region of ~28 MPa and ~35°C for whole-berry oil.[34] A secondary application of SC-CO2 to sea buckthorn pomace (the pressed cake remaining after primary juice/oil extraction) allows recovery of a second, carotenoid-enriched oleoresin fraction, reported at carotenoid concentrations several-fold higher than conventional cold-pressed pulp oil, illustrating the formulation value of pomace valorisation in a well-run industrial process.[36] Ultrasonic-assisted, enzyme-assisted, and aqueous extraction methods are more recent additions to the processing literature, generally reported as improving yield or reducing solvent burden relative to classical methods, though they remain less established at commercial scale than pressing, solvent extraction, or SC-CO2.[33],[39]

Table 3: Comparison of sea buckthorn oil extraction technologies. References: extraction-technique review, Trends in Food Science & Technology, 2025[33]; pilot-scale extraction comparison, Canadian Biosystems Engineering[32]; SC-CO2 response-surface optimisation, LWT-Food Science and Technology, 2008[34]; β-sitosterol SC-CO2 extraction study.[35]

Method	Typical Conditions	Reported Yield / Recovery	Solvent Residue	Ref.
Cold (mechanical/screw) pressing	≤~49°C, no solvent	Moderate; lower than solvent or SC-CO2 methods; some carotenoid loss from process heat	None	[33]
Solvent extraction (hexane / petroleum ether)	Ambient–moderate temperature; requires desolventisation	High oil recovery; lower tocopherol/sterol/carotenoid retention than SC-CO2	Requires QC testing	[32],[35]
Supercritical CO2 (SC-CO2)	~15–60 MPa, <40°C	High; tunable via pressure/temperature; best-preserved carotenoid, tocopherol, and phytosterol retention	None	[34],[35],[36]
Ultrasonic-/enzyme-assisted extraction	Aqueous or solvent-assisted, with ultrasound or enzymatic pre-treatment	Improved yield vs. classical methods in several studies; milder processing	Method-dependent	[33],[39]
Aqueous extraction	Water-based, no organic solvent	Generally lower yield than solvent/SC-CO2 methods; limited commercial adoption	None	[32]

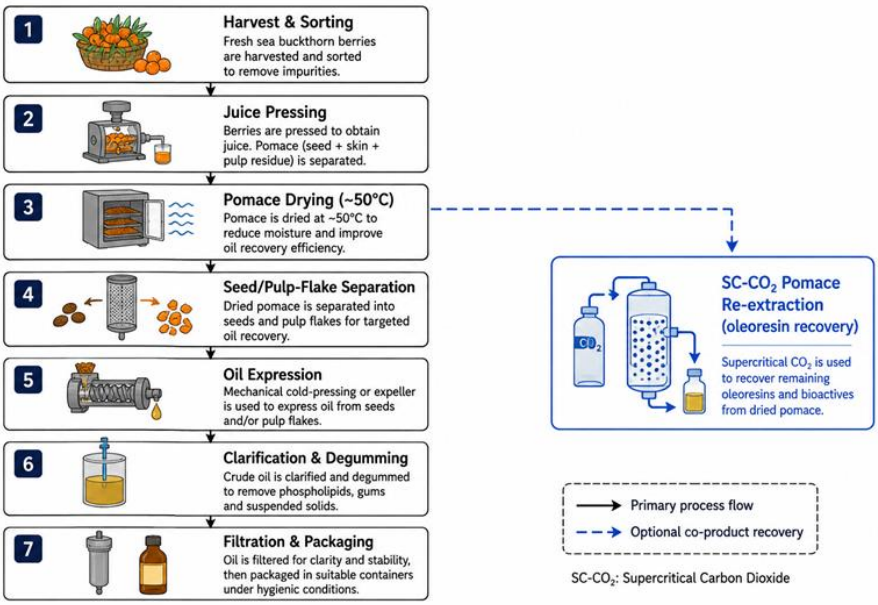


Figure 1: Extraction and Industrial Fractionation Process of Sea Buckthorn Oil.

6. Industrial Fractionation and Processing

Because pulp and seed oils are compositionally distinct (Section 4.1) and are typically marketed as separate ingredients, industrial-scale sea buckthorn processing is built around a fractionation sequence that physically separates seed from pulp/peel material before oil is expressed from each, rather than pressing whole berries and accepting a blended output. A representative pilot-to-industrial-scale sequence, consistent across several independent process studies, is summarised in Table 4.[32],[39]

Table 4: Representative industrial fractionation and processing sequence for sea buckthorn pulp and seed oil. References: pilot-scale seed/pulp oil quality study, Canadian Biosystems Engineering[32]; SC-CO2 pomace oleoresin recovery study[36]; enzymatic extraction and biochemical analysis, Mongolian Journal of Chemistry.[39]

Stage	Process Description	Purpose / Notes
1. Harvest & sorting	Hand-stripped, combed, or branch-cut-and-frozen berries are washed and sorted; damaged or immature fruit removed	Minimises microbial load and oxidative pre-damage entering the process
2. Juice pressing	Sound berries are pressed (bladder or belt press) to separate juice from wet pomace (skin, pulp residue, and seeds)	Juice is typically diverted to nutraceutical/beverage use; pomace carries the oil-bearing fractions
3. Pomace drying	Wet pomace is dried at controlled low temperature (commonly ~50°C, forced-convection) to a stable moisture content	Low-temperature drying limits thermal degradation of carotenoids and tocopherols
4. Seed/pulp-flake separation	Dried pomace is passed through a vibratory screen or aspirator/screen separator to separate hard seeds from lighter pulp-flake material	Enables independent, fraction-specific oil extraction and specification
5. Oil expression (per fraction)	Seed and pulp-flake fractions are separately processed by screw pressing, solvent extraction, or SC-CO2 (Section 5)	Fraction-specific extraction preserves the compositional distinction essential to formulation specification
6. Clarification & degumming	Crude oil is centrifugally clarified and degummed to remove residual solids, phospholipids, and mucilaginous material	Improves clarity, oxidative stability, and shelf handling
7. Filtration & packaging	Clarified oil is filtered and packaged under light- and oxygen-protective conditions (amber/opaque containers, nitrogen headspace where available)	Sea buckthorn oil's intense carotenoid pigmentation and high unsaturated-fatty-acid content make it particularly prone to photo-oxidative degradation if unprotected

A newer industrial variant bypasses full pomace drying: fresh pulp is separated from seed shortly after pressing, and oil is recovered directly from the moist pulp fraction by centrifugal (decanter) separation, avoiding the thermal exposure of a drying step and reportedly better preserving heat-labile carotenoid content, though at the cost of a shorter processing window before microbial spoilage of the wet material.[36],[39] Secondary valorisation of the spent pomace by supercritical-CO2 re-extraction, described in Section 5, is increasingly used to recover a second, carotenoid-enriched oleoresin fraction from material that would otherwise be discarded as processing waste.[36]

7. Antioxidant and Micronutrient Profile: Formulation Relevance

The combination of a MUFA-dominant pulp oil with a dense, co-located carotenoid and tocopherol load is mechanistically significant for topical formulation: lipophilic antioxidants such as carotenoids and tocopherols are more efficiently absorbed and stabilised in the presence of dietary or topical fat[24], meaning the fatty-acid matrix of the oil itself likely improves the bioavailability of its own antioxidant cargo rather than acting as an inert carrier. This self-contained lipid–antioxidant pairing distinguishes sea buckthorn oil from carrier oils whose penetration-enhancing value depends on co-administered actives, and supports its candidacy as both a standalone bioactive and a co-carrier within a multi-ingredient formulation.

8. Mechanistic Review: Dermatological and Mucosal Bioactivity

8.1 Wound Healing and Re-epithelialisation

The strongest and most clinically advanced evidence base for sea buckthorn oil concerns burn and wound healing. A randomised, triple-blind clinical trial in fifty-five patients with second-degree burns found that sea buckthorn dressings produced a shorter healing period than 1% silver sulfadiazine, the standard-of-care comparator.[7] A separate controlled study comparing sea buckthorn oil, olive oil, and their mixture against silver sulfadiazine and normal-saline controls on full-thickness burn wounds found faster wound contraction and better-controlled exudate volume in the sea buckthorn-treated groups, with histopathology showing more mature granulation tissue than the silver-sulfadiazine group.[8] In a large-animal (ovine) grafted-burn and donor-site model, Omega-7 (palmitoleic acid) isolated from sea buckthorn oil increased keratinocyte proliferation and migration in vitro and improved epithelialisation rate and shortened epithelialisation time relative to controls in vivo.[9] Mechanistic work links these effects to promotion of keratinocyte and fibroblast proliferation, collagen deposition, and angiogenesis, with supercritical-CO2-extracted seed oil additionally shown to up-regulate

matrix metalloproteinases (MMP-2, MMP-9) and type-III collagen in burn-wound models.[10]

8.2 Antioxidant and UV-Protective Activity

In human skin cell (keratinocyte and fibroblast) culture exposed to UV irradiation, sea buckthorn seed oil partially prevented UV-induced reactive-oxygen-species generation and enhanced non-enzymatic antioxidant defences (glutathione, thioredoxin, vitamins E and A), while stimulating Nrf2 transcription-factor activity and its downstream antioxidant enzyme response; treated cells showed reduced lipid-peroxidation markers (4-hydroxynonenal, 8-isoprostaglandin) relative to untreated UV-exposed controls.[12] This Nrf2-linked antioxidant mechanism is consistent with the oil's dense endogenous tocopherol and carotenoid content (Section 4.2), and provides a plausible basis for photoprotective and anti-ageing formulation claims, though direct human photoprotection endpoints remain limited.

8.3 Anti-inflammatory and Barrier-Modulating Activity

In a murine model of DNCB-induced atopic dermatitis, sea buckthorn oil reduced dermatitis severity scores, ear thickness, and mast-cell infiltration, and shifted the Th1/Th2 cytokine balance by reducing IL-4, IFN-γ, TNF-α, and TSLP expression in ear tissue and serum IgE, alongside inhibition of Langerhans-cell migration to draining lymph nodes[15] - a mechanistically coherent anti-inflammatory and immunomodulatory signature relevant to eczematous and barrier-compromised skin conditions. Separately, controlled human/animal hydration studies found that creams containing 40% sea buckthorn oil produced a statistically significant increase in skin hydration compared with creams using a synthetic emollient (isopropyl myristate) at equivalent concentration, without altering skin surface pH[14], consistent with a genuine barrier-supportive rather than purely occlusive emollient effect.

8.4 Antimicrobial Activity

Sea buckthorn seed oil has demonstrated antimicrobial activity against skin-relevant organisms including *Escherichia coli*, *Staphylococcus aureus*, and *Propionibacterium (Cutibacterium) acnes* in laboratory testing[1], [11], supporting a plausible adjunctive role in acneiform or minor cutaneous infection contexts, though clinical antimicrobial efficacy data in humans remain sparse and this activity should be regarded as supportive rather than primary.

8.5 Gastroprotective and Mucosal Activity

Independent of its dermatological profile, sea buckthorn seed and pulp oils have repeatedly demonstrated gastroprotective activity across multiple experimental ulcer models. CO2-extracted seed and pulp oils significantly reduced ulcer formation in water-immersion and reserpine-induced gastric-ulcer models in rats, reduced the pylorus-ligation ulcer index, and accelerated healing in an acetic-acid-induced ulcer model.[21] In a comparative veterinary trial in dogs with dexamethasone-induced gastric ulceration and erosion, orally administered seabuckthorn seed oil performed alongside standard anti-ulcer agents (lansoprazole, sucralfate, misoprostol, famotidine) as active comparators, indicating a genuine - not merely traditional - gastroprotective effect.[22]

8.6 Immunomodulatory and Immune-Supportive Activity

Sea buckthorn is frequently described in the broader phytochemical literature as an immunomodulatory botanical, a property most often attributed collectively to its vitamin C, vitamin E, carotenoid, and flavonoid content.[41]

Within that constraint, oral (not topical) sea buckthorn preparations have shown reproducible immunomodulatory activity in rodent models. An in vitro and in vivo study of leaf-extract feeding found it reduced chromium-induced reactive-oxygen-species generation and preserved lymphocyte size and viability under oxidative challenge[42]; a related study in chromium(VI)-immunosuppressed rats found the same leaf extract partially restored antibody titres and delayed-type hypersensitivity responses, alongside normalisation of IL-2, IL-4, and IFN-γ levels.[43] Most directly relevant to the oil fraction specifically, oral gavage of sea buckthorn oil (rather than leaf extract) protected against chronic-stress-induced suppression of natural killer (NK) cell activity in rats, restoring NK cell numbers, cytotoxicity, and perforin/granzyme B expression via normalisation of the neuroendocrine–immune axis - reduced serum cortisol, ACTH, IL-1β, and TNF-α alongside increased serotonin and IFN-γ.[44]

Table 5: Summary of documented pharmacological actions of sea buckthorn oil relevant to dermal and mucosal formulation. References as cited in Sections 8.1–8.6.

Pharmacological Action	Model / Evidence Level	Key Finding	Ref.
Wound / burn healing	Human RCT (n=55) vs. silver sulfadiazine; controlled burn models; ovine graft model	Shorter healing time than standard-of-care comparator; improved epithelialisation and granulation-tissue maturity	[7],[8],[9]
Antioxidant / UV-protective	Human keratinocyte/fibroblast culture, UV-irradiated	Reduced ROS and lipid-peroxidation markers; Nrf2 pathway activation	[12]
Anti-inflammatory / barrier-modulating	Murine DNCB atopic-dermatitis model; human/animal hydration study	Reduced dermatitis severity and Th1/Th2 rebalancing; increased skin hydration without pH change	[14],[15]

Pharmacological Action	Model / Evidence Level	Key Finding	Ref.
Immunomodulatory (oral, not topical)	Rat chromium-immunosuppression and chronic-stress NK-cell models (oral leaf extract / oral oil gavage)	Restored antibody/DTH responses and NK-cell cytotoxicity; not tested via topical.	[42],[43],[44]
Antimicrobial	In vitro (E. coli, S. aureus, C. acnes)	Demonstrated inhibitory activity against skin-relevant organisms	[1],[11]
Gastroprotective	Rat ulcer models (water-immersion, reserpine, pylorus-ligation, acetic-acid); canine dexamethasone-ulcer trial	Reduced ulcer index; comparable performance to standard anti-ulcer comparators	[21],[22]
Lipid-metabolic	Rodent models	Improved lipid-metabolism markers and gut-microbiota modulation	[25],[27]

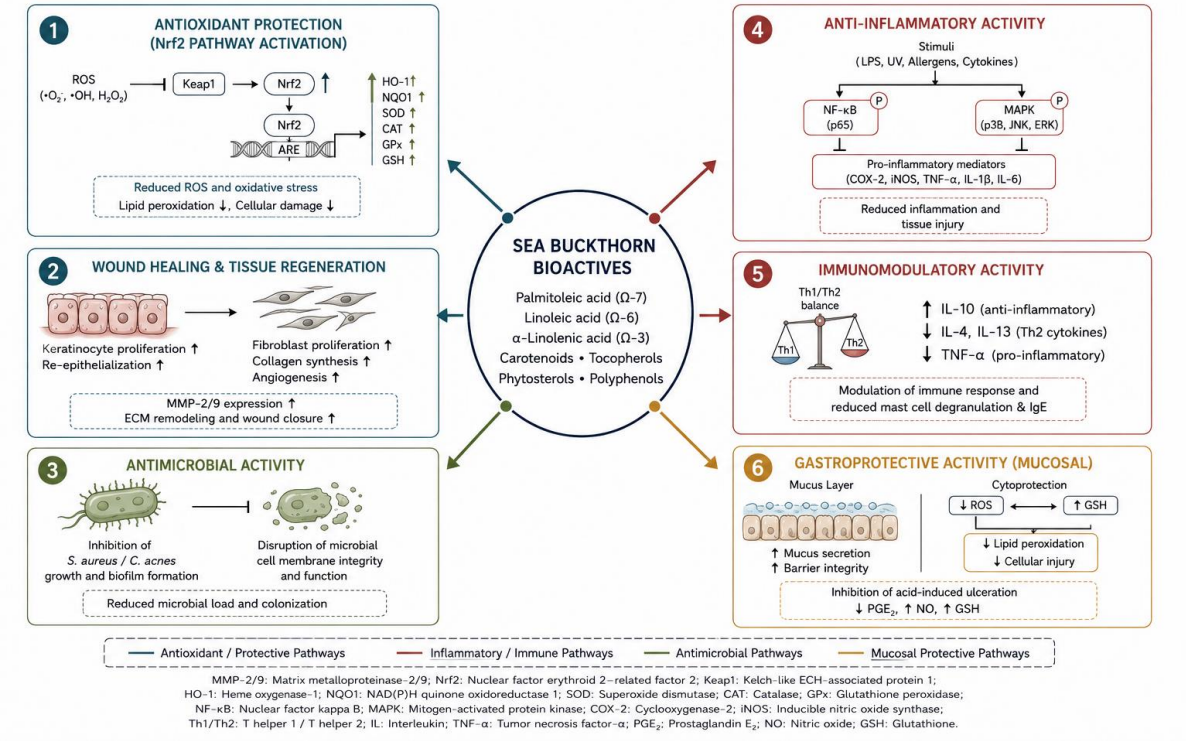


Figure 1: Mechanistic Summary.

9. Traditional and Ethnomedical Context

Unlike coconut oil (Narikela Taila) or sesame oil (Tila Taila), sea buckthorn does not appear as a named *dravya* in the classical Sanskrit Ayurvedic compendia (Charaka Samhita, Sushruta Samhita, Ashtanga Hridaya); its principal, well-documented classical textual lineage is Sowa-Rigpa (Tibetan/Trans-Himalayan medicine), where it is recorded in the 8th-century *rGyud-bZhi* and features in over a hundred formulations across subsequent Sowa-Rigpa pharmacopoeias, used historically for burns, respiratory ailments, and digestive complaints.[5] In Ladakh, the region of India where the plant is both wild-harvested and cultivated, it is used within the local Amchi (Sowa-Rigpa-derived) medical tradition and in domestic use.[5] Parallel traditional use is documented in classical Chinese and Mongolian medicine, chiefly for splenic-gastric, respiratory, and circulatory indications, with the Chinese Pharmacopoeia formally listing sea buckthorn berry as a recognised medicinal material.[6]

Within Sowa-Rigpa nosology, sea buckthorn (Tibetan: *Star bu*) is classified among the more extensively employed single medicinal substances, appearing not as an isolated remedy but as a component across more than a hundred classical polyherbal formulations addressing respiratory, digestive, circulatory, and dermatological conditions - consistent with the rasayana-adjacent (restorative/rejuvenative) role attributed to nutrient-dense fruits across several Trans-Himalayan medical systems.[5],[6] Contemporary Sowa-Rigpa and Trans-Himalayan Amchi practice continues to use sea buckthorn preparations, including oil, for topical wound and burn care and for digestive complaints, a continuity of indication that is consistent with - though not proof of - the modern pharmacological findings summarised in Section 8.[5]

Its presence in contemporary Indian Ayurvedic and nutraceutical formulation reflects a more recent convergence of this genuine Trans-Himalayan classical precedent with modern scientific interest and government-supported cultivation programmes, rather

than continuous use within the pan-Indian Sanskrit textual tradition. This distinction does not diminish the plant's legitimacy as a formulation ingredient - the Sowa-Rigpa classical record is well documented and independently corroborated by modern pharmacological findings - but it should be represented accurately rather than conflated with classical Ayurvedic *dravya* status, consistent with the evidence-transparency standard applied throughout this formulation programme.

10. Safety, Tolerability, and Contraindications

Topical tolerability data are reassuring within the limits of available testing. A controlled emulsion study using Draize-type dermal irritation testing on rabbit skin, alongside human skin pH and hydration testing, found no significant change in skin pH and no erythema or oedema-type irritation at 2, 24, 48, 72 hours, or 7 days after application of a sea buckthorn oil emulsion, alongside a significant increase in skin hydration.[16] General clinical summaries nonetheless recommend routine patch testing before broader topical use, particularly on sensitive or reactive skin, consistent with standard practice for any concentrated botanical oil.

Systemic and oral-route safety considerations are also relevant. Sea buckthorn oil has documented mild anticoagulant activity and blood-pressure-lowering effects in some reports, raising a theoretical caution around concurrent use with anticoagulant or antihypertensive medication, and around perioperative use given possible interaction with bleeding risk and anaesthesia. Gastrointestinal upset (cramping, diarrhoea, nausea) is reported at higher oral doses, and allergic reactions - ranging from mild dermatological and gastrointestinal symptoms to rare severe reactions - are documented in individuals with sensitivity to the plant or the broader Elaeagnaceae family. Paediatric- and pregnancy-specific safety data are limited and should be treated as a knowledge gap requiring dedicated evidence rather than assumed favourable on the strength of general adult tolerability data, mirroring the evidentiary caution applied to paediatric claims in the companion coconut oil review of this series.

Parameter	Proposed In-House Quality Specifications for Sea Buckthorn Oil
Acid Value	≤ 2.0 mg KOH/g oil
Peroxide Value	≤ 10.0 meq O_2/kg oil
Palmitoleic Acid Content (Pulp Oil)	32–42% of total fatty acids (GC-FID)
Linoleic + α-Linolenic Acid Content (Seed Oil)	~65–75% of total fatty acids (near 1:1 ratio; GC-FID)
Total Carotenoids	≥ 150 mg/kg oil (as β-carotene equivalents) (UV–Vis)
Total Tocopherols	≥ 200 mg/kg oil (as α-tocopherol equivalents) (HPLC)
Phytosterols (Total)	≥ 800 mg/kg oil (GC-FID)

11. Standardisation and Quality-Control Considerations

Four standardisation issues are of particular formulation relevance, building on the process detail established in Sections 5–6. First, pulp/berry oil and seed oil are compositionally distinct (Section 4.1) and are not interchangeable; a formulation specification should state explicitly which fraction, or what blend ratio of the two, is intended, and should specify verification by gas chromatography fatty-acid profiling rather than relying on a generic "sea buckthorn oil" designation. Second, extraction method (cold-pressed, supercritical CO2, or solvent-based; Section 5) measurably affects tocopherol, carotenoid, and phytosterol retention[18],[19],[32],[35], and should be documented and, where feasible, held constant across production batches. Third, the industrial fractionation sequence itself (Section 6) - drying temperature, separation method, degumming, and filtration - introduces further batch-to-batch variability that in-house supplier qualification should audit rather than assume standardised. Fourth, the oil's intense natural pigmentation (from its carotenoid load) and lipophilic, viscous character make it liable to visible discolouration and oxidative degradation over time if not adequately stabilised; peroxide value and acid value monitoring, consistent with the physicochemical characterisation approaches reported in the literature[1],[37], is

recommended as a routine batch-release check alongside fatty-acid and marker-carotenoid quantification.

No sea buckthorn oil monograph currently exists in the United States Pharmacopoeia, European Pharmacopoeia, or Indian Pharmacopoeia; the most substantial pharmacopoeial recognition is the Chinese Pharmacopoeia's listing of the berry as a medicinal material.[6] In the absence of a harmonised international monograph, Table 6 consolidates physicochemical and marker-compound benchmarks drawn from the peer-reviewed literature reviewed in this paper.

Table 6: Physicochemical and marker-compound quality parameters for sea buckthorn oil (pulp/berry and seed fractions). References: whole-berry oil physicochemical study[1]; cold-pressed oil oxidative-quality study, Applied Sciences, 2024[37]; seed oil oxidative-stress/quality baseline[38]; carotenoid, tocopherol, and phytosterol literature (Section 4.2).[2],[17],[18],[19],[35],[39],[40]

Parameter	Pulp / Berry Oil (Literature Range)	Seed Oil (Literature Range)
Appearance	Deep orange to orange-red viscous liquid	Pale yellow to golden-yellow oily liquid
Refractive index (20–25°C)	1.469–1.476 (whole-berry/pulp-dominant studies)[1]	Not separately characterised in literature reviewed
Acid value (mg KOH/g)	4.0–16.2 (species/cultivar-dependent)[1]	~1.9 (≈0.97% FFA, fresh commercial oil) [38]
Peroxide value (meq O2/kg)	1.3–18.3 (species/storage-dependent)[1]; Codex Alimentarius ceiling for cold-pressed non-typical oils ≤15[37]	~0.9 (fresh, low)[38]
Iodine value (g I2/100 g)	~124–155[1]	Not separately quantified in literature reviewed (seed oil is PUFA-dominant; expected higher)
Total carotenoids	~300–2,800 mg/kg (cultivar/method-dependent) [17],[18],[39]	Substantially lower than pulp; not separately quantified in literature reviewed
Total tocopherols/tocotrienols	~100–1,600 mg/kg.[18],[19]	~100–1,600 mg/kg (overlapping range reported)[18],[19]
Palmitoleic acid (16:1 ω-7, GC-FAME)	32–42% (up to ~49% in some cultivars)[3]	Trace / absent.[4]
Linoleic + α-linolenic acid (combined, GC-FAME)	Low–moderate	~65–75% combined, ~1:1 ratio.[4]
Total phytosterols (β-sitosterol dominant)	1.0–2.9% of total oil[2],[40]; up to 1.6–1.8% by SC-CO2.[35]	1.2–2.3% w/w (varies by extraction method).[35]
Heavy metals (ppm, total)	Not addressed in literature reviewed	Not addressed in literature reviewed
Microbial limits	Not addressed in literature reviewed	Not addressed in literature reviewed

As with the fatty-acid backbone (Section 4.1), several of the marker parameters in Table 6 are populated only for the fraction in which they have been directly reported in the literature reviewed; rows marked "not addressed" or "not separately characterised" should be treated as explicit targets for in-house baseline generation rather than assumed acceptable by extrapolation from the other fraction, consistent with the evidence-transparency standard applied throughout this formulation programme.

12. CONCLUSION

Sea buckthorn oil offers a phytochemically distinct and mechanistically well-supported case for use in dermatological and mucosal Ayurvedic oil formulation, grounded in a genuine - if geographically and textually distinct - classical precedent in Sowa-Rigpa medicine and corroborated by a comparatively mature modern evidence base for wound healing, antioxidant, anti-inflammatory, and gastroprotective activity. Its formulation rationale differs meaningfully from that of medium-chain-fatty-acid carrier oils: it is better characterised as a bioactive antioxidant and regenerative ingredient than as a stratum-corneum penetration enhancer, and its two principal oil fractions - pulp and seed - require separate specification rather than being treated as a single interchangeable ingredient. Addressing the identified paediatric/pregnancy and fraction-specific evidence gaps would materially strengthen the basis for formulation-specific claims beyond the currently well-supported general dermatological and gastroprotective indications.

Extraction and industrial fractionation choices (Sections 5–6) are not incidental supplier detail but directly determine the antioxidant marker-compound potency delivered to the finished formulation, and should be specified and audited accordingly through the quality-control framework proposed in **Section 11.**

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