

Moringa oleifera Seed Oil: Composition, Functional Applications and By-product Valorisation — A Review

Madhura Bhalerao^{1*}, Vijay Y. Karadbhaje¹

¹Department of Oil Technology, Laxminarayan Innovation Technological University (LITU), Nagpur 440033, India

Corresponding author: madhurabhalerao17@gmail.com; drvijaylit@gmail.com

Abstract

Moringa oleifera Lam. seed kernels contain 35–42% oil. *Moringa oleifera* oil (MOO) combines three features rarely found together in one vegetable oil: 72–80% oleic acid, 5–7% behenic acid, and less than 5% polyunsaturated fatty acids. The result is an oil with very high oxidative and frying stability, and virgin oil of good quality needs no refining. Despite this profile, MOO remains commercially marginal. This review is oil-specific rather than a whole-plant survey. It grades each health and application claim by evidence type (analytical, animal or human) and covers 2024–2026 composition, digestion and clinical-umbrella data. It synthesises evidence on MOO physicochemistry, fatty acid and triacylglycerol composition, minor bioactives, extraction, modification, stability, safety and applications in food, cosmetics and pharmaceuticals. It also identifies an overlooked valorisation route. Refining crude MOO generates a fatty acid distillate (MFAD) that, unlike palm fatty acid distillate, should be oleic-dominant, and its esterification could yield methyl oleate-rich esters for flavour-related uses. The main barriers to wider use are the absence of human trials using the oil itself, the lack of codified quality standards, and immature seed supply chains, particularly in India, the largest *Moringa* producer.

Keywords: *Moringa oleifera* oil; Oleic acid; Oxidative stability; Non-traditional oils; Fatty acid distillate; Methyl oleate; Valorisation

1. Introduction

Vegetable oils supply energy, essential fatty acids and fat-soluble vitamins, and underpin frying fats, spreads, emulsified cosmetics and oleochemicals [1]. Yet global supply rests on a handful of crops. Soybean, palm, rapeseed and sunflower dominate production, which exposes importing countries such as India to price volatility and supply risk. Partially hydrogenated fats, still common in South Asian diets, add a trans-fat burden. Both pressures have renewed interest in non-traditional oilseeds [2].

Moringa oleifera Lam., the drumstick tree native to the sub-Himalayan foothills of north-west India, is among the most credible candidates [3]. Its seed oil, historically called ben or behen oil, has an olive-like fatty acid profile and oxidative stability well above that of common polyunsaturated oils [2, 4].



Several recent reviews cover *M. oleifera* as a whole plant, and oil-specific findings are a small part of their scope [5–7]. The closest oil-specific review [2] predates the past decade of characterisation and processing work. This review differs in four respects: (i) it is restricted to the seed oil; (ii) it grades evidence by type (Section 2, Fig. 4); (iii) it incorporates 2024–2026 composition, digestion and clinical-umbrella data [8–10]; and (iv) it identifies the fatty acid distillate generated when MOO is refined as an unexplored feedstock for methyl oleate-rich esters (Section 8), extending established palm fatty acid distillate (PFAD) chemistry [11]. Commercialisation barriers are examined with particular reference to India.

2. Review Methodology

This is a structured critical narrative review, not a systematic review or meta-analysis. PubMed and publisher databases were searched: ScienceDirect, Wiley Online Library, SpringerLink, MDPI, Frontiers and the CSIC journal platform. The searches were supplemented by backward citation tracking and by regulatory and technical documents from the Food Safety and Standards Authority of India (FSSAI) and Tamil Nadu Agricultural University. Searches were last updated on 1 August 2026.

The core query “*Moringa oleifera*” AND (“seed oil” OR “ben oil” OR “behen oil”) was combined with terms covering composition (fatty acid, triacylglycerol, tocopherol, phytosterol), processing (cold press, solvent, aqueous enzymatic, supercritical CO₂, refining, fractionation, interesterification), stability (oxidative stability, frying, heating), applications (food, cosmetic), safety (toxicology, clinical) and trade (authentication, adulteration, India). Peer-reviewed English-language studies reporting data on *M. oleifera* seeds or seed oil were included. Leaf-, root-, bark- and pod-only studies were excluded from oil-specific conclusions but were retained to show where claims have been extrapolated from other plant parts. Conference abstracts, duplicates and untraceable numerical claims were excluded.

Studies differed in cultivar, origin, seed maturity, dehulling, extraction method and test conditions, so quantitative pooling was not appropriate. Evidence was therefore synthesised narratively. Each claim was classified as analytical/in vitro, animal or human, and was further marked as oil-specific or indirect (derived from extracts, other plant parts or the oleic-acid class generally). This improves transparency but does not replace the formal risk-of-bias assessment of a registered systematic review. The age profile of the cited literature is shown in **Fig. 1**.

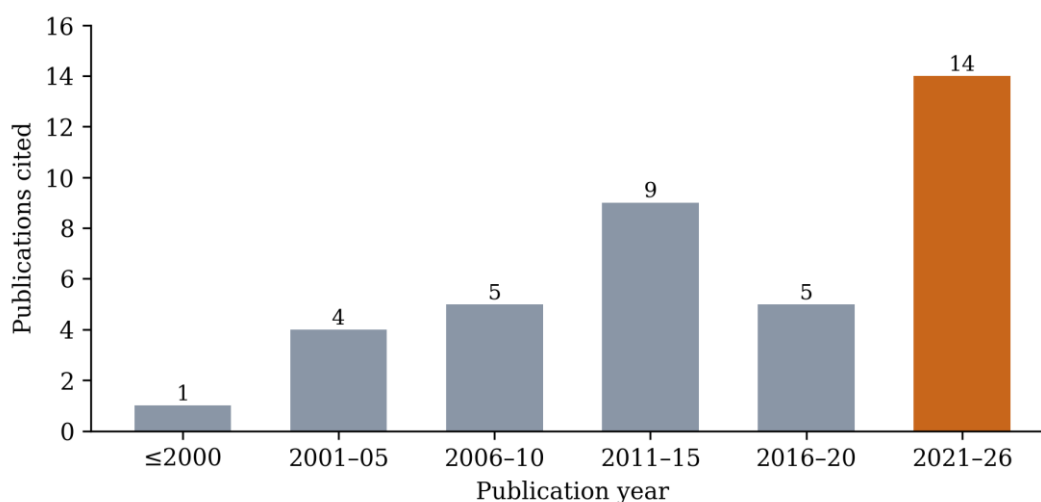


Fig. 1 Publication-year distribution of the literature cited in this review ($n = 38$), grouped in five-year bins. The figure shows the temporal spread of the evidence base, not a bibliometric census.

3. Botanical and Agronomic Profile

M. oleifera is the most widely cultivated of the 13 species in the monogeneric family Moringaceae. It grows rapidly and tolerates drought, saline soils and marginal land where conventional oilseeds fail [3]. Its triangular pods (30–60 cm) each hold 12–20 winged seeds. Dehulled kernels contain 35–42% oil and about 38% crude protein, so the press cake is a protein co-product rather than waste [2]. Yields of around 3,000 kg seed ha⁻¹ ($\approx$ 1,200 kg oil) are frequently cited [2], but they come from secondary sources and have not been validated in multi-location trials. Field data from Argentina's arid Chaco confirm that seed and oil yields hold up under drought [12].

India is the largest *Moringa* producer, with cultivation concentrated in Tamil Nadu, Andhra Pradesh, Karnataka and Maharashtra [13]. The frequently quoted national figure of 1.1–1.3 million tonnes refers to tender pods, not oil. Oil-specific production statistics do not exist, and nearly all output goes to pod and leaf markets. A domestic MOO industry would therefore build on an existing cultivation base but would need dedicated seed-to-oil infrastructure.

4. Physicochemical Characterisation

4.1 General properties

Virgin MOO is a clear, pale-yellow oil with a mild nutty aroma; electronic-nose profiling places it close to peanut [4]. Freshly pressed oil has low free fatty acids (FFA, 0.16–0.32%) and peroxide values ($\approx$ 0.24 meq O₂ kg⁻¹), so good-quality virgin oil can be used without refining [4, 8]. The defining parameter is the iodine value (65–80 g I₂ 100 g⁻¹), roughly half that of soybean ($\approx$ 134) or sunflower ($\approx$ 122) oil [2]. This reflects MOO's low number of double bonds and is the main reason for its oxidative stability (Table 1).

Table 1 Physicochemical properties of *M. oleifera* seed oil compared with major commercial vegetable oils

Parameter	MOO	Soybean	Canola	Sunflower	Palm	MOO source
Free fatty acids (%)	0.16–0.32	0.30–0.80	0.20–0.50	0.30–0.60	0.10–0.30	[4, 8]
Moisture (%)	0.10–0.20	≤0.20	≤0.20	≤0.20	≤0.20	[8]
Refractive index (40 °C)	1.452–1.465	1.466–1.470	1.465–1.468	1.467–1.473	1.453–1.456	[2, 4]
Saponification value (mg KOH g ⁻¹)	188–193	189–195	182–193	188–194	190–205	[8]
Iodine value (g I ₂ 100 g ⁻¹)	65–80	120–141	110–126	118–145	50–55	[2, 8]
Peroxide value, fresh oil (meq O ₂ kg ⁻¹)	0.24–1.12	1.0–3.0	0.8–2.5	1.2–3.5	0.2–1.0	[4, 8]
Unsaponifiable matter (%)	0.8–1.3	0.6–1.2	0.8–1.5	0.8–1.4	0.3–0.8	[2, 9]
Melting point (°C)	11–20	–18	–10	–17	33–39	[2, 9]
Oleic acid (%)	72–80	20–30	58–66	18–35 ^a	38–45	[2, 8, 9]
Behenic acid (%)	5–7	trace	trace	trace	trace	[2, 9]
Total tocopherols (mg kg ⁻¹)	220–280	900–1500	500–900	450–750	400–800	[2, 9]
Total phytosterols (mg kg ⁻¹)	2100–2200	1800–3000	7000–10000	3000–5000	600–1000	[9]

Values are representative ranges and vary with cultivar, origin, seed maturity and extraction method. Commercial-oil values are compiled from Codex Alimentarius standards and standard lipid references. ^a Conventional (high-linoleic) sunflower; high-oleic cultivars exceed 75%.

4.2 Fatty acid and triacylglycerol profile

Oleic acid (C18:1) makes up 72–80% of total fatty acids, which is comparable to olive oil and far above soybean, sunflower or palm oil (**Fig. 2**) [2, 8, 9]. Two further features set MOO apart. First, behenic acid (C22:0, 5–7%) is almost absent from common oils. It acts as a natural crystallisation and structuring agent, allowing firm fats to be made without partial hydrogenation [2]. Second, polyunsaturated fatty acids are scarce: linoleic acid is about 4% and α -linolenic acid is essentially absent. Because polyunsaturated fatty acids are the main targets of autoxidation, their scarcity underlies MOO's shelf life.

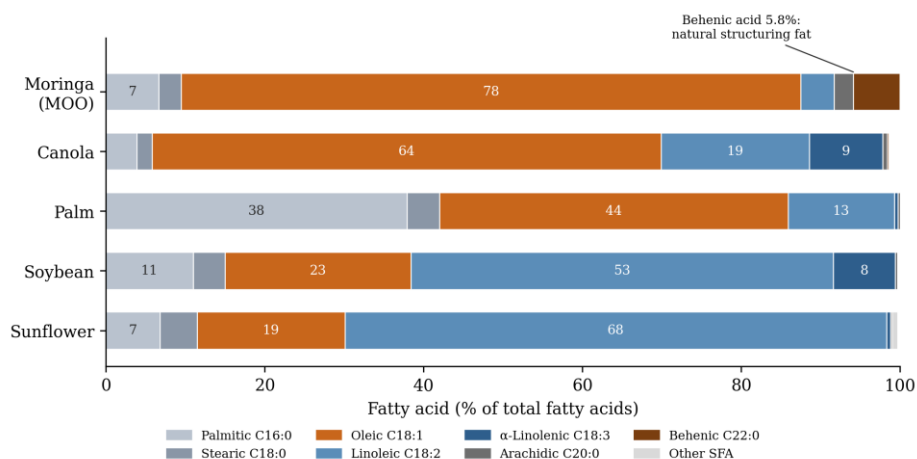


Fig. 2 Fatty acid composition of *M. oleifera* oil compared with four major commercial oils (% of total fatty acids). Values from the compilation in Nadeem and Imran [2]; individual values vary with cultivar and origin.

Triolein (OOO) is the dominant triacylglycerol ($\approx 37\text{--}41\%$), followed by palmitoyl-diolein (POO) and stearoyl-diolein (SOO), a pattern close to that of virgin olive oil [4, 9]. ^{13}C -NMR has also detected cis-vaccenic acid, and MOO has been described as an “oleic–vaccenic” oil [14]. An oleic-dominated triacylglycerol backbone keeps the oil liquid at room temperature and slow to oxidise.

4.3 Minor bioactive constituents

Total tocopherols in MOO are about 276 mg kg^{-1} (α 134, γ 94, δ 48 mg kg^{-1}) [2]. This is above virgin olive oil ($\sim 100\text{ mg kg}^{-1}$) but well below soybean, sunflower and canola oils (Table 1). MOO’s stability therefore comes mainly from its fatty acid profile, not from exceptional tocopherol levels. Phytosterols exceed $2,100\text{ mg kg}^{-1}$ and are dominated by β -sitosterol, stigmasterol and campesterol [2, 9]. The oil also carries phenolics, kaempferol and the cytokinin zeatin; 36 naturally occurring antioxidants have been reported, and total phenolics of 7.1% GAE [2]. These minor components explain MOO’s activity in DPPH and ABTS assays, and their physiological relevance is discussed in Section 9.

5. Extraction and Refining

The choice of extraction route determines yield, how much of the minor bioactives are retained, and whether the oil must be refined (Fig. 3).

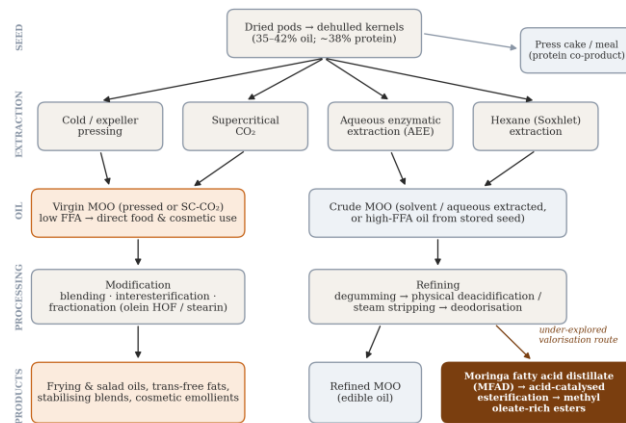


Fig. 3 Processing pathways for *M. oleifera* seed oil. Virgin oil is used directly or modified; crude oil is refined, generating a moringa fatty acid distillate (MFAD) that can be esterified to methyl oleate-rich esters (Section 8).

5.1 Mechanical pressing and solvent extraction

Cold or expeller pressing is the simplest route and yields food- and cosmetic-grade oil that retains tocopherols and flavour. Its weakness is recovery. From dehulled Indian seed, cold pressing gave 24.2% oil against 39.4% by hexane extraction, so only about 61% of the available oil was recovered [15]. Hexane extraction approaches total recovery but leaves residual-solvent concerns and requires full refining (degumming, neutralisation or physical deacidification, bleaching and deodorisation). Refining removes part of the bioactive fraction and generates the distillate stream discussed in Section 8.

5.2 Aqueous enzymatic and supercritical CO₂ extraction

Aqueous enzymatic extraction (AEE) uses cellulases, pectinases and proteases to break down the seed matrix. It recovers oil and protein together without organic solvents, and enzymes significantly raise oil recovery over purely aqueous processing [16]. Supercritical CO₂ extraction ($\approx 40\text{--}45\text{ }^{\circ}\text{C}$, 200–400 bar) has reached yields of up to 38.5%. It gives solvent-free oil that is richer in unsaponifiables, tocopherols, sterols and phenolics, and more strongly antioxidant, than hexane-extracted oil [17]. Its capital cost currently limits it to high-value cosmetic and nutraceutical grades.

6. Oil Modification

6.1 Blending

Blending MOO into sunflower, soybean or canola oil lowers the accumulation of primary and secondary oxidation products and lengthens the induction period of the blend [18]. In butter oil, MOO addition raised radical-scavenging activity from 5.2% to 31.7% and lowered cholesterol in proportion to the substitution level. MOO could therefore replace synthetic antioxidants such as BHA and BHT for ambient storage of butter oil in tropical markets [19].

6.2 Interesterification

Interesterification rearranges fatty acids within and between triacylglycerols, changing melting behaviour without creating trans isomers. Enzymatically and chemically interesterified blends of MOO with butter oil, palm olein, palm stearin and coconut oil have produced trans-free fats with the solid-fat profiles needed for margarine, vanaspati-type and bakery fats [20, 21]. French fries prepared in vanaspati containing 50% MOO were rated indistinguishable from the commercial product by a trained panel [2]. This is relevant in South Asia, where vanaspati remains widely consumed.

6.3 Fractionation

Slow cooling separates MOO into two fractions. The liquid olein, a high-oleic fraction (HOF), contains more than 80% oleic acid, melts at about 1 °C and resists accelerated oxidation (5 days at 63 °C) better than sunflower, canola or soybean oil [22]. It is therefore suitable as a salad oil or mayonnaise base. The solid stearin is enriched in behenic and arachidic acids and is a candidate hard stock for bakery fats. MOO also modifies the crystallisation behaviour of palm oil when blended with it [23].

7. Oxidative and Thermal Stability

Reported Rancimat induction periods for crude MOO (72.6 h; 42.6 h after degumming) exceed those reported for sunflower, canola and soybean oils (3.5–5.8 h) by an order of magnitude [2, 24]. These values come from different studies and test temperatures, so the ratio is indicative rather than exact. Frying trials confirm the direction of the difference. After six 6-h frying cycles, MOO showed the lowest total polar compounds, polymers, darkening and viscosity rise when compared with canola and soybean oils [25]. In deep-fried potatoes, MOO preserved vitamin E and carotenoids better than sunflower oil, and a sunflower/MOO blend has been proposed as a cost-effective compromise [26]. Cold-pressed Indian MOO also oxidised more slowly than groundnut oil during storage [15].

Heating route matters for minor components. Oven and microwave heating reduced MOO carotenoids by up to 96%, whereas oven heating increased measured total phenolics [27]. Frying performance should therefore not be taken as a proxy for bioactive retention.

8. By-product Valorisation: Moringa Fatty Acid Distillate

8.1 Origin of the distillate stream

Good virgin MOO needs no refining. However, solvent- or aqueous-extracted oil, oil from poorly stored seed, and oil destined for standardised bland food grades are refined. In physical refining, FFA and volatile minor components are steam-stripped under vacuum and condensed as a fatty acid distillate. In palm oil refining this stream (PFAD) amounts to about 4–5% of the oil processed. PFAD consists mainly of FFA (~82%) together with glycerides, squalene, tocopherols and sterols, and it is sold for oleochemicals, animal feed and biodiesel [11].

8.2 The PFAD precedent

Acid-catalysed esterification of PFAD with methanol to fatty acid methyl esters (FAME) is well established. In methanesulfonic acid-catalysed batch esterification at 60–75 °C with 400 rpm agitation, methanol was added in stages as guided by acid-value monitoring. FFA

conversion reached about 99% (final acid value $1.7 \text{ mg KOH g}^{-1}$), and the kinetics fitted a second-order model [11]. Because the reaction is reversible, both staged methanol addition and removal of water drive conversion.

8.3 The gap: an oleic-dominant distillate

A distillate inherits the fatty acid profile of its parent oil. PFAD is palmitic-rich, whereas a moringa fatty acid distillate (MFAD) should be dominated by oleic acid ($\approx 72\text{--}80\%$), with 5–7% behenic acid (Fig. 2). Esterifying MFAD should therefore yield a methyl oleate-rich ester fraction rather than a generic biodiesel-grade FAME. To our knowledge, the recovery, characterisation and esterification of MFAD have not been reported. The concept is distinct from converting whole MOO into methyl esters, because it uses a low-value by-product and leaves the edible oil for food use (Fig. 3).

8.4 Potential uses and constraints

Methyl oleate-rich esters may provide a value-added intermediate stream for flavour-related and oleochemical applications rather than serving directly as bakery-fat ingredients. Methyl oleate is included in the EU Union List of flavouring substances (FL No. 09.652), and its transesterification with ethanol provides ethyl oleate [28]. Ethyl oleate is recognised as a flavouring agent under JECFA No. 345 and FEMA No. 2450. [28]. Four constraints must be addressed:

- **Volume.** Low-FFA virgin oil yields little distillate, so MFAD economics depend on crude-oil FFA and refinery scale.
- **Regulation.** Methyl esters and residual methanol require specific clearance before any food-contact or flavour use.
- **Composition.** Methyl behenate is high-melting and may require winterisation.
- **Co-products.** Co-distilled tocopherols and sterols are a recovery opportunity, as they are for palm distillates [11].

Priority data include MFAD yield per tonne of crude MOO, its composition, esterification kinetics, ester purity by GC, residual methanol and sensory evaluation.

9. Health-related Properties

Fig. 4 maps the evidence behind each commonly cited benefit. Only one outcome, skin hydration, has human evidence using the oil itself. Most health claims rest on animal studies or on extracts of other plant parts.

	Analytical / in vitro	Animal	Human
Oxidative & frying stability	Oil-specific, replicated	n/a	n/a
Lipid profile / cardiovascular	Indirect only	Oil-specific, limited	Indirect only
Antioxidant activity	Oil-specific, replicated	Indirect only	None
Topical anti-inflammatory	Oil-specific, limited	Oil-specific, limited	None
Wound healing	None	Oil-specific, limited	None
Skin hydration (cosmetic)	Oil-specific, limited	n/a	Oil-specific, limited
Antidiabetic	None	Indirect only	Indirect only
Anticancer	Oil-specific, limited	None	None
Dietary safety / toxicity	n/a	Oil-specific, limited	None

Fig. 4 Evidence map for health and functional claims made for *M. oleifera* seed oil.

“Indirect” denotes evidence from leaf or seed extracts, whole-plant preparations or the oleic-acid class, not from the oil itself. Classification by the authors from the studies cited in Sections 7–10.

9.1 Cardiovascular and lipid effects

High-oleic diets can modestly reduce total and LDL cholesterol, particularly when high-oleic oils replace fats rich in saturated fatty acids, while HDL cholesterol is generally maintained. The U.S. FDA permits a qualified health claim for edible oils containing at least 70% oleic acid per serving when they replace fats and oils higher in saturated fat, based on supportive but not conclusive evidence for reduced coronary heart disease risk. [30]. MOO meets this compositional threshold, although the claim has not been evaluated for MOO specifically. Direct evidence is animal-based. Rats fed MOO-based diets for six weeks had lower LDL and higher HDL than soybean-oil controls [31]. The frequently cited lovastatin-comparison study in hypercholesterolaemic rabbits used *Moringa* fruit, not the oil, and is indirect evidence [32].

9.2 Antioxidant, anti-inflammatory and skin effects

Topical MOO inhibited acute (TPA- and phenol-induced) and chronic skin inflammation in mice through a glucocorticoid-receptor-dependent mechanism, without the adverse effects of dexamethasone. Oleic acid alone reproduced the acute effect but not the chronic one [33]. Topical MOO also accelerated wound closure by 2–4 days in healthy, immunosuppressed and diabetic mice, largely attributable to oleic acid [34]. A 2025 umbrella review of 26 systematic reviews found consistent benefits of *Moringa* in diabetes, obesity and hypertension, but the underlying trials used mainly leaf preparations and were of variable quality [10].

9.3 Antidiabetic and anticancer signals

The antidiabetic evidence comes almost entirely from leaf and seed extracts in animal models [35]. Seed-oil extracts inhibited cancer cell lines while sparing normal lymphocytes in vitro,

possibly through SIRT1/BCL2 modulation [36]. Both findings are hypotheses for testing, not established properties of the oil.

10. Safety

In a six-week feeding study, rats given MOO-based diets showed no differences from soybean-oil controls in haematological or renal markers (urea, creatinine). They also had better growth and a more favourable lipid profile [31]. FSSAI lists MOO as an edible vegetable oil. Long-term and human safety data are still lacking, and this is the most important unmet evidence need [5].

11. Applications

Table 2 summarises applications with direct oil-specific evidence. In food, MOO's value is as a frying and cooking oil, a stabilising blend component, a trans-free hard stock (via interesterification or the stearin fraction) and a premium salad oil (the HOF). In cosmetics, MOO is listed in the EU CosIng inventory (INCI: *Moringa Oleifera Seed Oil*). It has been valued since antiquity in perfumery for retaining fragrance and resisting rancidity, and it is now formulated in creams, serums, hair oils and soaps because it spreads well and leaves little greasy after-feel [2, 37]. Most MOO sold for Indian personal care is imported, which is a missed domestic value-addition opportunity. In pharmaceuticals, its oleic-acid content and skin-permeation behaviour make it a candidate vehicle for topical lipophilic drugs, supported by the anti-inflammatory and wound-healing data above.

Table 2 Applications of *M. oleifera* seed oil with direct oil-specific evidence

Sector	Application	Key evidence	Evidence type	Ref.
Food	Frying oil	Lowest polar compounds, polymers and darkening vs canola and soybean after 6 × 6-h frying cycles; better vitamin E and carotenoid retention in fried potatoes than sunflower oil	Analytical	[25, 26]
Food	Stabilising blend component	MOO addition extended induction period and lowered oxidation products of sunflower, soybean and canola oils	Analytical	[18]
Food	Butter-oil stabiliser	Radical scavenging raised from 5.2% to 31.7%; potential replacement for BHA/BHT	Analytical	[19]
Food	Trans-free structured fats	Interesterified blends with butter oil and palm fats gave margarine- and vanaspati-type fats with zero trans isomers	Analytical ; sensory	[20, 21]
Food	Salad oil / emulsion base	High-oleic olein (>80% oleic acid, m.p. ≈1 °C) more stable than sunflower, canola and soybean oils	Analytical	[22]
Cosmetic	Moisturising cream	Stable for 28 d at 4/30/45 °C and 6 heat-cool cycles; improved skin hydration in 32 volunteers; DPPH IC ₅₀ 121.9 mg mL ⁻¹	Analytical ; human	[38]
Cosmetic	Antioxidant body cream	Cream base with MOO showed antioxidant activity	Analytical	[39]

Pharmaceutical	Topical anti-inflammatory	Reduced acute and chronic skin inflammation in mice via glucocorticoid receptor, without steroid side-effects	Animal	[33]
Pharmaceutical	Chronic wound healing	Faster wound closure (2–4 d) in healthy, diabetic and immunosuppressed mice; increased collagen deposition	Animal	[34]

12. Challenges and Research Priorities

Each constraint to commercialisation points to a specific research or policy need:

- **Extraction at scale.** Cold pressing leaves about 40% of the oil in the cake [15]. Modular, energy-efficient pressing and AEE systems suited to rural enterprises, with protein co-product recovery, are needed, as is cheaper supercritical CO₂ extraction for high-value grades [16, 17].
- **Supply chain and agronomy.** No organised seed-to-oil chain exists at scale. Oil-enriched cultivars, region-specific cultivation protocols and validated per-hectare oil yields are needed.
- **Human evidence.** Randomised controlled trials of dietary MOO should use cardiovascular (LDL, HDL, triglycerides, CRP), inflammatory (IL-6, TNF- α) and glycaemic endpoints. Controlled cosmetic trials should build on the single human hydration study [38].
- **Standards and authentication.** Codified FSSAI/BIS grading limits for FFA, peroxide value, fatty acid profile and colour are needed. Rapid NIR, Raman or NMR methods should be developed that exploit behenic acid as an authenticity marker against adulteration.
- **By-product valorisation.** MFAD recovery and esterification (Section 8), and structured lipids built from the HOF and stearin fractions, should be quantified, including their regulatory status for food and flavour use.
- **Consumer awareness.** Clear labelling and familiar product formats are needed outside niche premium markets.

13. Conclusion

MOO's case rests on replicated analytical evidence. It has 72–80% oleic acid, a distinctive behenic acid fraction and very little polyunsaturated fat, which together give it frying and storage stability that most commodity oils lack. Its health case, by contrast, is still largely inferred from animal studies, extracts and the oleic-acid class, and human trials with the oil itself are the critical gap. Beyond the oil, refining by-products offer an unexamined opportunity. An oleic-dominant fatty acid distillate could be esterified to methyl oleate-rich esters, adding value to every tonne refined. India has the cultivation base to lead. Converting that base into an oil industry now requires processing technology, quality standards and clinical evidence more than new compositional data.

Abbreviations

ABTS – 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulphonic acid)

AEE – aqueous enzymatic extraction

BIS – Bureau of Indian Standards

CRP – C-reactive protein

DPPH – 2,2-diphenyl-1-picrylhydrazyl

FAME – fatty acid methyl ester(s)

FFA – free fatty acid(s)

FSSAI – Food Safety and Standards Authority of India

GAE – gallic acid equivalent

HDL – high-density lipoprotein

HOF – high-oleic fraction

LDL – low-density lipoprotein

MFAD – moringa fatty acid distillate

MOO – *Moringa oleifera* oil

NIR – near-infrared

PFAD – palm fatty acid distillate

SC-CO₂ – supercritical carbon dioxide

Funding

This research received no external funding.

Conflicts of interest

The authors declare no financial or personal conflicts of interest that could have influenced this work.

Ethics approval

Not applicable.

Consent to participate

Not applicable.

Consent for publication

Not applicable.

Data availability

Not applicable; no new data were generated in this review.

Code availability

Not applicable.

Author contributions

M.B. Conceptualisation, Writing – original draft. **V.Y.K.** Conceptualisation, Supervision, Resources, Writing – review & editing.

Acknowledgements

The authors thank the Department of Oil Technology, Laxminarayan Innovation Technological University (LITU), Nagpur, for infrastructure support. This work forms part of Madhura Bhalerao's doctoral thesis under the supervision of Dr V. Y. Karadbhajne.

References

1. Campbell-Platt, G. (Ed.). (2017). Food science and technology. John Wiley & Sons.
2. Nadeem, M., & Imran, M. (2016). Promising features of Moringa oleifera oil: recent updates and perspectives. *Lipids in Health and Disease*, 15(1), 212.
3. Anwar, F., Latif, S., Ashraf, M., & Gilani, A. H. (2007). Moringa oleifera: a food plant with multiple medicinal uses. *Phytotherapy Research: An International Journal Devoted to Pharmacological and Toxicological Evaluation of Natural Product Derivatives*, 21(1), 17-25.
4. Abdulkarim, S. M., Long, K., Lai, O. M., Muhammad, S. K. S., & Ghazali, H. M. (2005). Some physico-chemical properties of Moringa oleifera seed oil extracted using solvent and aqueous enzymatic methods. *Food chemistry*, 93(2), 253-263.
5. Pareek, A., Pant, M., Gupta, M. M., Kashania, P., Ratan, Y., Jain, V., ... & Chaturgoon, A. A. (2023). Moringa oleifera: an updated comprehensive review of its pharmacological activities, ethnomedicinal, phytopharmaceutical formulation, clinical, phytochemical, and toxicological aspects. *International journal of molecular sciences*, 24(3), 2098.
6. Bibi, N., Rahman, N., Ali, M. Q., Ahmad, N., & Sarwar, F. (2024). Nutritional value and therapeutic potential of Moringa oleifera: a short overview of current research. *Natural Product Research*, 38(23), 4261-4279.
7. Klimek-Szczykutowicz, M., Gawel-Beben, K., Rutka, A., Blicharska, E., Tatarczak-Michalewska, M., Kulik-Siarek, K., ... & Szopa, A. (2024). Moringa oleifera (drumstick tree)—nutraceutical, cosmetological and medicinal importance: a review. *Frontiers in Pharmacology*, 15, 1288382.
8. Cervera-Chiner, L., Pageo, S., Juan-Borrás, M., García-Mares, F. J., Castelló, M. L., & Ortolá, M. D. (2024). Fatty acid profile and physicochemical properties of Moringa oleifera seed oil extracted at different temperatures. *Foods*, 13(17), 2733.
9. Wang, Y., Xu, H., Wei, W., Yu, L., Meng, X., & Wang, X. (2025). Physicochemical characterization, bioactive compounds, and in vitro digestion characteristics of Moringa oleifera seed oil: a comprehensive investigation. *Journal of the Science of Food and Agriculture*, 105(7), 3572-3581.
10. da Silva Parente, T. S. J., Sarandy, M. M., de Araújo, E. R. D., Gonçalves, R. V., & Zucolotto, S. M. (2025). Effect of Moringa oleifera on inflammatory diseases: an umbrella review of 26 systematic reviews. *Frontiers in pharmacology*, 16, 1572337.
11. Charhate, P. S., Bhalerao, M., & Karadbhajne, V. Y. Optimisation of Reaction Time and Methanol Consumption for Esterification of Palm Fatty Acids and its Kinetic Study.
12. Ayerza, R. (2011). Seed yield components, oil content, and fatty acid composition of two cultivars of moringa (Moringa oleifera Lam.) growing in the Arid Chaco of Argentina. *Industrial Crops and Products*, 33(2), 389-394.
13. Rajangam, J., Azahakia Manavalan, R. S., Thangaraj, T., Vijayakumar, A., & Muthukrishnan, N. (2002). Status of production and utilisation of Moringa in Souther India.

14. Vlahov, G., Chepkwony, P. K., & Ndalut, P. K. (2002). ¹³C NMR characterization of triacylglycerols of *Moringa oleifera* seed oil: an “oleic-vaccenic acid” oil. *Journal of agricultural and food chemistry*, 50(5), 970-975.
15. Ogunsina, B. S., Indira, T. N., Bhatnagar, A. S., Radha, C., Debnath, S., & Gopala Krishna, A. G. (2014). Quality characteristics and stability of *Moringa oleifera* seed oil of Indian origin. *Journal of Food Science and Technology*, 51(3), 503-510.
16. Abdulkarim, S. M., Lai, O. M., Muhammad, S. K. S., Long, K., & Ghazali, H. M. (2006). Use of enzymes to enhance oil recovery during aqueous extraction of *Moringa oleifera* seed oil. *Journal of food lipids*, 13(2), 113-130.
17. Chen, X., Li, Z., Smith, S. A., Chen, M., Liu, H., Zhang, J., ... & Wu, X. (2022). Optimization of supercritical CO₂ extraction of *Moringa oleifera* seed oil using response surface methodological approach and its antioxidant activity. *Frontiers in nutrition*, 8, 829146.
18. Anwar, F., Hussain, A. I., Iqbal, S., & Bhanger, M. I. (2007). Enhancement of the oxidative stability of some vegetable oils by blending with *Moringa oleifera* oil. *Food Chemistry*, 103(4), 1181-1191.
19. Nadeem, M., Abdullah, M., & Hussain, I. (2014). Improvement of the oxidative stability of butter oil by blending with *Moringa oleifera* oil. *Journal of Food Processing and Preservation*, 38(4), 1491-1500.
20. Javid, A. (2012). Evaluation of functional fat from interesterified blends of butter oil and *Moringa oleifera* oil. *Pakistan Journal of Nutrition*.
21. Dollah, S., Abdulkarim, S. M., Ahmad, S. H., Khoramnia, A., & Ghazali, H. M. (2014). Physicochemical properties and potential food applications of *Moringa oleifera* seed oil blended with other vegetable oils. *Journal of oleo science*, 63(8), 811-822.
22. Rahman, F., Nadeem, M., Azeem, M. W., & Zahoor, Y. (2014). Comparison of chemical characteristics of high oleic acid fraction of *moringa oleifera* oil with some vegetable oils. *Pakistan Journal of Analytical & Environmental Chemistry*, 15(1), 80-83.
23. Marikkar, J. M. N., & Ghazali, H. M. (2011). Effect of *Moringa oleifera* oil blending on fractional crystallization behavior of palm oil. *International Journal of Food Properties*, 14(5), 1049-1059.
24. Tsaknis, J., Lallas, S., Gergis, V., & Spiliotis, V. (1998). A total characterisation of *Moringa oleifera* Malawi seed oil. *Rivista Italiana delle Sostanze Grasse*, 75, 21-28.
25. Abdulkarim, S. M., Long, K., Lai, O. M., Muhammad, S. K. S., & Ghazali, H. M. (2007). Frying quality and stability of high-oleic *Moringa oleifera* seed oil in comparison with other vegetable oils. *Food chemistry*, 105(4), 1382-1389.
26. Boukandoul, S., Zaidi, F., Santos, C. S., & Casal, S. (2023). *Moringa oleifera* Oil Nutritional and Safety Impact on Deep-Fried Potatoes. *Foods*, 12(24), 4416.
27. Ahmed, I. A. M., Özcan, M. M., Uslu, N., Karrar, E., & Al Juhaimi, F. (2026). *Moringa* (*Moringa oleifera* L.) seed: Heating, oil, physico-chemical and bioactive properties, phenolic compounds and fatty acid profiles. *South African Journal of Botany*, 190, 61-67.
28. Ogunjobi, J. K., Farmer, T. J., Clark, J. H., & McElroy, C. R. (2023). Synthesis, characterization, and physicochemical performance of nonionic surfactants via PEG modification of epoxides of alkyl oleate esters. *ACS sustainable chemistry & engineering*, 11(5), 1857-1866.
29. Lokuruka, M. N. (2007). Role of fatty acids of milk and dairy products in cardiovascular diseases: A review.
30. Huth, P. J., Fulgoni III, V. L., & Larson, B. T. (2015). A systematic review of high-oleic vegetable oil substitutions for other fats and oils on cardiovascular disease risk factors: implications for novel high-oleic soybean oils. *Advances in Nutrition*, 6(6), 674-693.

31. Bolanle, A. O., Olufunmilayo, A., Olorunfemi, O., & Temitayo, O. (2014). The effect of Moringa oleifera oil-based diet on growth performance, haematological parameters and plasma lipid profile in albino rats.
32. Mehta, K., Balaraman, R., Amin, A. H., Bafna, P. A., & Gulati, O. (2003). Effect of fruits of Moringa oleifera on the lipid profile of normal and hypercholesterolaemic rabbits. *Journal of ethnopharmacology*, 86(2-3), 191-195.
33. Cretella, A. B. M., da Silva Soley, B., Pawloski, P. L., Ruziska, R. M., Scharf, D. R., Ascari, J., ... & Otuki, M. F. (2020). Expanding the anti-inflammatory potential of Moringa oleifera: topical effect of seed oil on skin inflammation and hyperproliferation. *Journal of ethnopharmacology*, 254, 112708.
34. Ventura, A. C. S. S. B., de Paula, T., Gonçalves, J. P., da Silva Soley, B., Cretella, A. B. M., Otuki, M. F., & Cabrini, D. A. (2021). The oil from Moringa oleifera seeds accelerates chronic skin wound healing. *Phytomedicine plus*, 1(3), 100099.
35. Mthiyane, F. T., Dlodla, P. V., Ziqubu, K., Mthembu, S. X., Muvhulawa, N., Hlengwa, N., ... & Mazibuko-Mbeje, S. E. (2022). A review on the antidiabetic properties of Moringa oleifera extracts: focusing on oxidative stress and inflammation as main therapeutic targets. *Frontiers in Pharmacology*, 13, 940572.
36. Shahbaz, M., Naeem, H., Batool, M., Imran, M., Hussain, M., Mujtaba, A., ... & Al Jbawi, E. (2024). Antioxidant, anticancer, and anti-inflammatory potential of Moringa seed and Moringa seed oil: A comprehensive approach. *Food Science & Nutrition*, 12(9), 6157-6173.37.
37. Garg, P., Pundir, S., Ali, A., Panja, S., Chellappan, D. K., Dua, K., ... & Negi, P. (2024). Exploring the potential of Moringa oleifera Lam in skin disorders and cosmetics: nutritional analysis, phytochemistry, geographical distribution, ethnomedicinal uses, dermatological studies and cosmetic formulations. *Naunyn-Schmiedeberg's Archives of Pharmacology*, 397(6), 3635-3662.38.
38. Athikomkulchai, S., Tunit, P., Tadtong, S., Jantrawut, P., Sommano, S. R., & Chittasupho, C. (2020). Moringa oleifera seed oil formulation physical stability and chemical constituents for enhancing skin hydration and antioxidant activity. *Cosmetics*, 8(1), 2.
39. Ojiako, E. N., & Okeke, C. C. (2011). Determination of antioxidant of Moringa oleifera seed oil and its use in the production of a body cream. *Asian Journal of Plant Science & Research*.