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Sesame: A high value oilseed for sustainable agricultural development: A comprehensive review

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Abstract
Sesame (*Sesamum indicum* L.) is an ancient oilseed crop of significant nutritional, medicinal, and industrial value, distinguished particularly by its rich content of the bioactive lignans sesamin and sesamolin. These lignans are central to sesame's renowned antioxidant capacity, oxidative stability, and diverse health-promoting properties. Sesamin exhibits potent lipid-lowering, antihypertensive, hepatoprotective, and anti-inflammatory effects, while sesamolin contributes to thermal stability and converts to sesamol under heat, an exceptionally strong antioxidant that enhances the shelf life and flavor of sesame oil. Together, these compounds underpin sesame's status as a functional food with broad nutraceutical potential. The lignan composition of sesame seeds is significantly influenced by genotype, seed coat color, and processing methods, with black sesame consistently exhibiting the highest concentrations of bioactive lignans. Beyond its phytochemical richness, sesame remains a vital global crop used in traditional foods, value-added products, therapeutics, and Ayurveda. Its by-products further support animal nutrition, environmental remediation, and industrial applications. Overall, the prominence of sesamin and sesamolin reinforces sesame's unique role as both a nutrient-dense oilseed and a powerful bioactive resource with expanding significance in health and industry.

Keywords: Sesame, *Sesamum indicum*, Phytochemical composition, Nutritional Value, Sesamin, Antioxidants

1. Introduction
Sesame (*Sesamum indicum* L.) is one of the earliest oilseed crops to be domesticated which has been cultivated in the Indian subcontinent since 3500-3050 BCE (Bedigian 2015; Nagar *et al.* 2022) [10, 40]. It is a member of the Pedaliaceae family. The name "sesame" comes from Greek sesamon and Latin sesamum. These roots led to words with the broad meaning "oil, liquid fat". It is prized for its outstanding oil quality, nutritional value, and cultural importance.

Sesame seeds contain approximately 50% oil, 25% protein, and 15% carbohydrates, making them an important raw material for the baking, confectionery, and food-processing industries. The oil is characterized by a high proportion of oleic acid (36-54%) and linoleic acid (38-49%), along with natural antioxidants such as sesamol, sesamin, and sesamolin, which impart remarkable oxidative stability and extended shelf life (Dossou *et al.* 2023; Wan *et al.* 2023) [16, 58]. Owing to this superior oil quality, sesame is frequently referred to as the "Queen of Oils" and, more broadly, the "Queen of Oilseeds" because its oil concentration can reach up to 63%, surpassing that of groundnut, sunflower, rapeseed, and soybean (Teklu *et al.* 2021; Ma *et al.* 2022) [55, 34]. Sesame oil has widespread applications in cooking, salad preparations, margarine, traditional medicine, cosmetics, soaps, pharmaceuticals, and insecticides (Wang *et al.* 2022) [59]. Additionally, sesame meal, containing about 40% high-quality protein, serves as an excellent nutritional component in poultry and livestock feed. (Sanni *et al*. 2024) [49]

From a nutritional standpoint, sesame seeds constitute a concentrated source of energy and are enriched with a spectrum of vitamins particularly vitamin E, vitamin A, and B-complex vitamins as well as essential minerals including calcium, phosphorus, iron, copper, magnesium, zinc, and potassium. Their substantial levels of amino acids, most notably methionine and tryptophan, further elevate their dietary significance. Owing to their remarkable resilience, long-standing medicinal relevance, and deep cultural integration, sesame seeds have historically been revered as the "seed of immortality" (Bedigian *et al.* 2015) [10]. Contemporary research underscores the presence of bioactive lignans that confer

potent antioxidant, antihypertensive, anticancer, anti-aging, and cholesterol-modulating effects, thereby reinforcing the therapeutic value attributed to sesame (Majdalawieh & Mansour 2019; Mili *et al.* 2021) [35, 38].

Global sesame seed production has surpassed 7 million tonnes, establishing it as a crop of significant agricultural and economic importance. Africa and Asia collectively contribute over 95% of the world's sesame supply, serving as the primary hubs for both cultivation and international trade. Among the leading producers in 2025, Sudan ranks first with an annual output of approximately 1.37 million tonnes, and India, the second-largest producer with about 802,100 tonnes per year, primarily cultivates sesame in Gujarat, Rajasthan, and Uttar Pradesh, supplying premium-quality seeds to markets in China, Europe, and the Middle East. Sesame also holds deep cultural and culinary significance across India. (Anonymous, 2025) [8]

Recent advancements in sesame research have deepened scientific understanding of its phytochemical profile, bioactive constituents, protein characteristics, and diverse industrial applications. Sesame flour and protein exhibit considerable potential for incorporation into value-added and functional food products; however, their broader utilization is constrained by issues such as poor solubility and limited emulsifying capacity (Abbas *et al.* 2022) [1]. Moreover, sesame protein hydrolysates possess notable immunomodulatory, antimicrobial, antihypertensive, antithrombotic, and antioxidant activities, underscoring their relevance in nutraceutical and therapeutic applications (Chen *et al*. 2022) [13].

2. Nutritional Value of Sesame

The literature of Ayurveda mentions "Sarvesham taila jaathanaam tila taila prasasyathe Balarthe snehane" highlights Sesame Oil or "Tila Taila" as the king of all oils, for strengthening and nourishing the skin. These small seeds also possess quantifiable levels of oxalic acid, dietary fiber, antioxidants, and minerals including iron, magnesium, and zinc. (Ujjainkar, 2025) [56] The fatty acid profile of sesame seeds is mainly composed of unsaturated fatty acids, such as oleic and linoleic acids, alongside lesser quantities of saturated fatty acids, including palmitic and stearic acids. (Wei *et al*.. 2022) [61]. Sesame seeds are rich in nutrients and have the reputation of being an "all-purpose nutrient bank" and the "crown of eight grains" (Haixia and lu, 2015) [22].

2.1 Protein

Sesame meal, a major by-product of processing contains nearly 50% protein (Vangaveti *et al.*, (2016) [57]. A genome-wide association study by Cui *et al.*, reported that seed protein content increases with darker seed coat color, with black sesame generally having higher protein levels than white sesame. Sesame seeds contain four main protein fractions: albumins, globulins (α and β), prolamins, and glutelins Hegde (2012) [26], all identified across various seed types.

2.2 Fatty Acids

Linoleic and linolenic acids are essential unsaturated fatty acids that cannot be synthesized by the human body and must be acquired through diet. Linoleic acid, in particular, supports cholesterol metabolism, enhances vascular epithelial integrity, and plays an important role in growth and development.

2.3 Vitamins

Sesame seeds contain several vitamins, with vitamin E being the most abundant Mili *et al.*, 2021 [38]. Black sesame, in particular, can contain up to 50.4 mg/100 g of vitamin E. Studies indicate that α-tocopherol is the predominant form of vitamin E in sesame seeds, whereas γ-tocopherol is present in comparatively lower amounts.

2.4 Carbohydrates

The hull of sesame seeds, a major by-product of oil extraction, is primarily composed of 70-80% carbohydrate polymers Liu *et al.* 2021 [32].

2.5 MineralElements

Sesame seeds are a rich source of essential minerals, containing notable levels of K (525.9 mg/100 g), P (516 mg/100 g), Mg (349.9 mg/100 g), Na (15.28 mg/100 g), Fe (11.39 mg/100 g), Zn (8.87 mg/100 g), and Mn (3.46 mg/100 g) Elleuch *et al.* (2007) [17].

3. Phytochemistry

Sesame seeds are rich in bioactive lignans, including sesamin, sesamolin, sesamol, sesaminol, and sesamolin phenol Pathak *et al.* 2014 [46], which contribute to their strong antioxidant activity and the oxidative stability of sesame oil (Andargie, 2021, Dar *et al.*, 2015) [7, 14]. The content of these components varies with extraction methods—hot-pressed oils contain higher levels of sesamol, sesamin, and total lignans than cold-pressed or refined oils (Khuimshukhieo and Khaengkhan, 2018) [30] and is influenced by genotype, strain, seed coat color, growing location, and cultivation practices such as irrigation, fertilization, and harvest timing. Notably, black sesame seeds exhibit the highest lignan content, while white seeds contain comparatively lower levels of sesamin and total lignans. (Ayoub & Wani, 2025) [9]

Sesamin, one of the major lignans in sesame seeds, exhibits strong physiological activity, including antioxidant, cholesterol-lowering, lipid-regulating, antihypertensive, and anti-tumor effects (Majdalawieh *et al.* 2017) [36]. In the human body, it is primarily metabolized through the cytochrome P-450 pathway.

Sesamolin, the second most abundant sesame lignan, exhibits relatively weak antioxidant activity due to the absence of phenolic hydroxyl groups. However, under heat, it can convert into sesamol, a potent antioxidant. This conversion makes sesamolin valuable for enhancing the oxidative stability of oils and fats during heating (Mili *et al.* 2021) [38].

Sesamol, though present in low amounts among sesame lignans, is the key flavor and stability component of sesame oil, possessing strong antioxidant and antimicrobial properties. It remains stable under sunlight and is compatible with food additives containing Zn^{2+} and Mg^{2+}, but should not be used alongside strong oxidants (Jayaraj *et al.* 2020) [27].

Sesaminol, a fat-soluble lignan present at low levels in sesame seeds, exhibits strong antioxidant activity and thermal stability. It can be readily formed from sesamolin under acidic conditions (Katayama *et al.* 2016) [29].

4. Sesame-Based Foods and Functional Products

4.1 Traditional and Processed Foods

Sesame is a versatile ingredient widely used in traditional foods, including sesame oil, paste, candies, cakes, and filled dumplings, with China recognized for its innovation in diverse sesame-based products. Sesame is also incorporated with beans, grains, nuts, fruits, and vegetables to create nutrient-enriched beverages and foods. Sesame protein isolates enhance the nutritional quality of bakery products, serving as thickeners, binders, and protein enhancers (Dossa *et al.* 2017) [15]. Blending sesame oil with other vegetable oils, such as chia or kiwi oil, optimizes the omega-3/omega-6 ratio, improves antioxidant properties, and is suitable for margarine and trans-fat-free ghee (Rodriguez *et al.* 2020, Sivakanthan *et al.* 2019) [47, 52]. Sesame lignans provide cholesterol regulation, liver protection, antioxidant, hypotensive, and anti-aging effects, making them valuable in functional foods (Ji *et al.* 2019, Tai *et al.* 2019) [28, 54].

4.2 Sesame Oil

Sesame oil, extracted from seeds, is rich in linoleic (~47%) and oleic acids (~37%), essential fatty acids that must be obtained through diet, as well as bioactive compounds like lignans, vitamin E (predominantly γ-tocopherol, 90.5%), and phytosterols (Hama J. R. 2017, Gharby *et al.* 2017) [24, 21]. Cold-pressed oil retains higher nutritional quality and flavor, with an unsaturated fatty acid content (~75%) comparable to olive oil, but with greater aroma and cost-effectiveness (Ma and Fang 2019). Modern extraction methods include supercritical CO_2, microwave-assisted, hydro-enzymatic, and alkaline techniques. Sesame oil demonstrates anti-inflammatory, emollient, and skin-repairing properties.

4.3 Sesame Meal

Sesame meal, the defatted by-product of oil extraction, is rich in protein, dietary fiber, and bioactive lignans (e.g., sesamin triglucoside and diglucoside) (Melo *et al.* 2021) [37]. Its high fiber content acts as a prebiotic, supporting gut microbiota, digestive health, and satiety, potentially contributing to weight management (Fuller *et al.* 2016, Stephen *et al.* 2017) [20, 53].

4.4 Antioxidant Properties

The antioxidant content of sesame oil is enhanced during roasting, where thermal decomposition of sesamolin forms sesamol, a potent antioxidant, increasing flavor and shelf life (Ji *et al.* 2019) [28]. Sesame-derived extracts can also be added to other oils to improve oxidative stability, e.g., sunflower oil (El-Roby *et al.* 2020) [18].

5. Industrial, Pharmaceutical, and Environmental Applications of Sesame

5.1 Pharmacological and Therapeutic Uses

Sesame seeds and oil confer health benefits for the liver, kidneys, spleen, and stomach, while aiding intestinal lubrication and organ nourishment (Adebisi *et al.* 2017) [2]. Sesame oil promotes burn healing, acts as a solvent and carrier for medications, serves as a skin softener and natural UV protector, and exhibits analgesic effects, such as reducing pain in chemotherapy-induced phlebitis and traumatic limb injuries (Nasiri and Farsi, 2017, Shamloo *et al.* 2019, Pathak *et al.* 2014) [46, 50].

5.2 Animal Nutrition

Sesame meal contains >45% crude protein and essential amino acids, serving as a cost-effective protein source for livestock (Capellini *et al.* 2019) [11]. Anti-nutritional factors like oxalates and phytates require microbial fermentation before use (Hajimohammeadi *et al.* 2020) [23]. Fermented sesame meal can partially replace soybean meal in broiler and lactating ewe diets, enhancing nutritional value, digestibility, milk production, and reducing feed costs (Okoro *et al.* 2017) [45].

5.3 Biofuels

Historically, sesame stalks served as fuel. Modern methods utilize sesame oil and waste flour for biodiesel production. Transesterification with methanol yields up to 92% biodiesel, performing comparably to mineral diesel in efficiency, power, and consumption (Adewuyi and Pereira 2017) [4].

5.4 Pest and Insect Control

Sesamin exhibits fungicidal and insecticidal properties, acting synergistically with pyrethroids. Sesame oil is used to prevent lice infestations and as a wood protection agent against termites (Fatima *et al.* 2021) [19].

5.5 Environmental Remediation

Activated carbon derived from sesame cake effectively removes hexavalent chromium from wastewater, supporting environmental protection (Nagashanmugam 2018) [41].

5.6 Genetic and Bioengineering Applications

Overexpression of SiDGAT1 from sesame in soybean increases seed oil content and modifies protein and sugar composition, demonstrating potential for crop improvement (Wang *et al.* 2019) [60].

5.7 Other Industrial Uses

Sesame oil can be used in copy paper and high-grade ink production, and the plant serves in lubricating soap manufacture. Defatted sesame powder stabilizes oil-in-water emulsions, improving droplet size, emulsion stability, and gel formation (He *et al.* 2020) [25]. Sesame oil is approved for cosmetic use and serves as a base for ointments, moisturizers, lipsticks, and eye shadow creams. Active components from sesame stems and flowers are used in perfumes, and myristic acid from seeds is a common cosmetic ingredient (Haixia and Lu 2015) [22].

5.8 Sesamum Oil in Ayurveda

Sesame oil, or “Tila Taila” in Ayurveda, is regarded as one of the most important herbal oils due to its heating (ushna) and unctuous (snigdha) qualities, which help maintain the balance of Vata and Kapha doshas. Traditionally, it has been widely used in Ayurvedic massage (Abhyanga), where it improves blood circulation, promotes joint flexibility, while providing analgesic, anti-inflammatory, and rejuvenating effects on muscles and connective tissues. Sesame oil plays a vital role in wound healing and burn recovery, nourishing the skin and accelerating repair. Its lipid-soluble nature also allows it to act as an effective carrier for herbal drugs, enhancing the transdermal absorption of therapeutic compounds, which has contributed to its longstanding prominence in Ayurvedic medicine.

Conclusion

In summary, sesame (*Sesamum indicum* L.) stands as a nutritionally dense, economically significant, and culturally valued oilseed crop whose relevance spans ancient tradition to modern innovation. Its exceptional oil quality, rich protein profile, abundant minerals, vitamins, and potent bioactive lignans collectively underpin its reputation as a "Queen of Oilseeds" and a functional "nutrient bank." Advances in phytochemical characterization, food processing, biotechnology, and health research continue to reveal the extensive therapeutic, nutritional, and industrial potential of sesame, from cardiovascular and antioxidant benefits to applications in pharmaceuticals, cosmetics, agriculture, and environmental sustainability. Moreover, its integral role in Ayurveda and other traditional systems of medicine highlights a long-standing legacy that complements contemporary scientific validation. Altogether, sesame remains a vital global crop whose multifaceted value ensures its enduring prominence in food security, health promotion, and diverse industrial sectors.

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