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Pharmacognostic, Therapeutic, and Formulation Insights into *Sesamum indicum*: From Traditional Uses to Advanced Drug Delivery Systems

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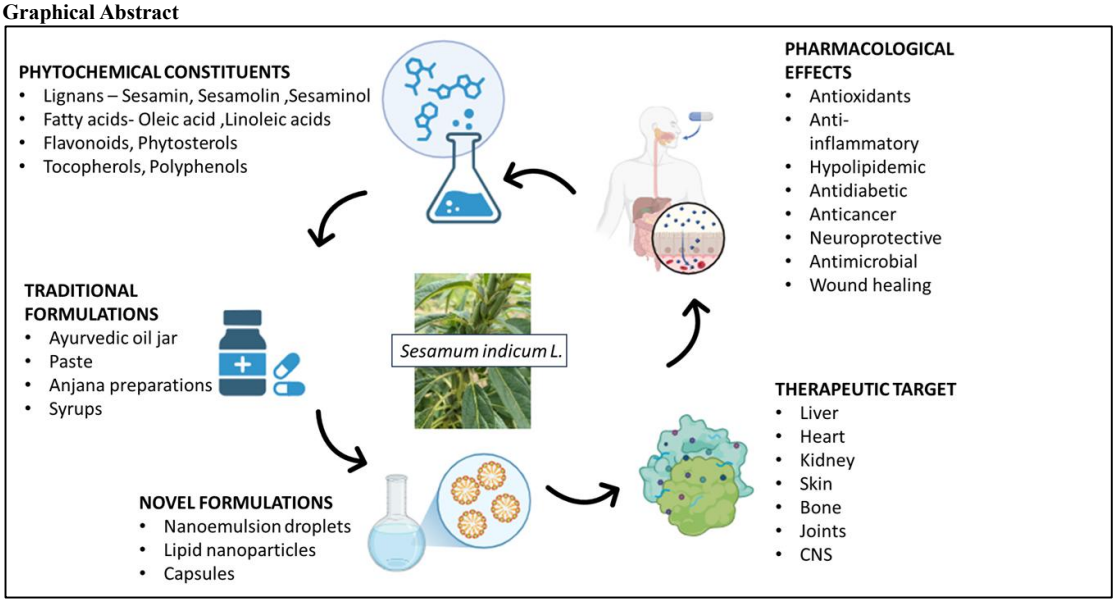
Abstract:
Purpose: The present article aims to compile current information on Sesamum indicum, including its pharmacological and nutritional importance, historic uses, main bioactive components, and new developments in formulation techniques. Through better delivery methods, the review seeks to show how old usage relates to contemporary therapeutic breakthroughs. **Method:** Information from published pharmacognostic studies, ethnomedical records, phytochemical investigations, and current pharmaceutical formulation research is gathered and examined in this review. To comprehend the evolution of sesame-derived actives from traditional applications to modern therapeutic use, a comparative analysis of traditional preparations and contemporary delivery systems was carried out. **Outcomes**: Unsaturated fatty acids, tocopherols, phytosterols, as well as lignans like sesamin, sesamolin, and sesamol are abundant in S. indicum seeds and oil, according to findings from the reviewed literature. These components have significant hepatoprotective, lipid-lowering, anti-inflammatory, and antioxidant properties. Sesame lignans regulate oxidative stress, inflammatory mediators, and lipid metabolic pathways, according to mechanistic research. Clinical research shows moderate but positive impact on cardiovascular and metabolic parameters. The stability, bioavailability, and controlled release of sesame actives are improved by developments in formulation science, such as nanoemulsions, microcapsules, solid lipid nanoparticles, and co-delivery systems. **Conclusion:** Sesamum indicum has significant nutritional and medicinal benefits that are backed by both conventional use and current pharmacological research. Its physiological advantages and varied phytochemical profile support ongoing investigation into its therapeutic potential. By resolving stability and bioavailability issues, emerging delivery technologies expand their usefulness and connect traditional methods with cutting-edge treatment approaches.

Keywords- *Sesamum indicum*, lignans, pharmacological properties, novel drug delivery system, phytochemical profile

Graphical Abstract



1.Introduction

Sesamum indicum L. (family Pedaliaceae) is among the most ancient oilseed crops domesticated, appreciated for its superior-quality vegetable oil, nutritional value, and multipurpose medicinal use. Records of its cultivation go as far back as ancient cultures in the Indian subcontinent, Mesopotamia, and East Asia, where sesame oil was a symbol of vitality and longevity. Through centuries, this heritage crop has maintained significance as both a food ingredient and a source of therapeutic compounds in Ayurvedic, Chinese, and other traditional medical practices [1]. Botanically, S. indicum (Pedaliaceae family) is a terrestrial annual herb with simple opposite leaflets, tubular bilabiate flowers, and unique elongated capsule fruits (dehiscent pods) with 2–6 small, flat seeds. Phenotypic diversity in landraces and breeding lines (seed colour, capsule dehiscence, plant height) has been extensively described because these characters affect oil yield and processing behaviour; contemporary morpho-biochemical profiling continues to guide breeding for quality and phytochemical composition [2].

Sesame, also called as Benne, is an upright, annual plant, according to Encyclopedia Britannica. Sim-sim (Sudanese), till (Hindi), hu ma (Chinese), sesame (French), goma (Japanese), and gergelim (Portuguese) are the names given to sesame (Sesamum Indicum L)[3,4]. Sudan produces roughly 350 kg of seeds per hectare on average. It is among the most significant cash crops. The top producers of sesame, accounting for 68% of global production, are Sudan (38.2%), India, Myanmar, and China [5]. Contemporary pharmacognostic studies have established sesame seeds and oil as excellent sources of unsaturated fatty acids, tocopherols, phytosterols, and phenolic lignans, primarily sesamin, sesamolin and sesamol, that are collectively responsible for nutritional and pharmacological attributes. These compositional properties explain sesame's antioxidant, anti-inflammatory, lipid-modulatory and hepatoprotective activity described in preclinical and clinical research. Preclinical mechanistic studies have demonstrated that sesame lignans regulate oxidative stress pathways, inflammatory signaling and lipid metabolism, but small clinical trials and meta-analyses infer modest therapeutic effects on lipid profiles, markers of oxidative stress and metabolic variables [1,6].

Nutritionally, sesame seeds stand out due to their well-balanced content of proteins, unsaturated triglyceride vitamins, minerals, and an original pattern of lignans and phenolic compounds responsible for good antioxidant capacity. Contemporary analytical studies verify that sesamin, sesamolin, and sesamol are primarily accountable for radical-scavenging activity as well as lipid-stabilising action to differentiate sesame oil from the other edible oils [7]. The pharmacological significance of sesame has been backed by recent pharmacological data. Extracts and purified fractions display anti-inflammatory, antihypertensive, hepatoprotective, neuroprotective, and antidiabetic activities in experimental models, offering molecular rationales for its ancient uses.

From a formulation point of view, the lipophilicity of sesame oil and its bioactive components offers both benefits and challenges to pharmaceutical development. Traditional preparations (oils, pastes, decoctions) optimise lipophilic extraction but can be hampered by stability, standardization and bioavailability constraints. Modern formulation science has thus investigated nano- and micro-encapsulation, nanoemulsions, solid lipid nanoparticles and other drug delivery platforms to achieve stability enhancement, controlled release, target delivery and oral bioavailability enhancement of sesame bioactives and co-loaded drugs. Recent research illustrates the feasibility of sesame oil–based nanoemulsions and nanoparticle encapsulation to shield antioxidant compounds, extend release and enhance functional performance in vitro and in vivo, weighing the viable approaches to bridge ethnopharmacology and modern therapeutics [8]. This review provides a summary of the numerous reports and bioactives having pharmacological activity. Furthermore, conventional formulations and novel carrier systems of Sesamum indicum.

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Fig.1 Black sesame seeds

Fig.2 White sesame seeds

Fig.3 Roots and stem of Sesamum indicum

2. Phytochemical and Therapeutic Characterisation of Sesamum indicum

Different parts of *Sesamum indicum* L. have different phytochemical compositions and pharmacological properties. Among them, the seeds are the most deeply studied component and classified as oilseeds rich in lignans, especially sesamin, sesamolin, and sesamol, but also containing γ-tocopherol, oleic acid, linoleic acid, and phytosterols [9,10]. These elements have been reported to hold strong antioxidant, anti-inflammatory, hepatoprotective, hypolipidemic, and cardioprotective activities. The most significant lignans are sesamin and sesamol, which act as free radical scavengers, modulate lipid metabolism, and offer protection against oxidative stress-induced tissue injury. Unsaturated triglycerides enhance the stability of membranes and reduce LDL cholesterol, whereas phytosterols support cholesterol metabolism and offer liver protection[11].

It is also determined that sesame seeds exert natural antibacterial activity against ordinary skin microbe, likely as Staphylococcus and Streptococcus spp., besides other antifungal, anti-viral and anti-inflammatory activities. Earlier studies have shown that sesame seeds include flavonoids and other phenolic compounds with antioxidant activity [12]. Reduce bone mass and bone formation, Anti-rheumatoid activity, anticancer, protect the femoral head from osteonecrosis, growth and development of mammary gland tissue, antibacterial [13] .Oil and paste obtained from seeds are used in the treatment of burns and wounds topically [14]. The seeds can be utilised for decorating bread and cookies, and in manufacturing candies, while the paste obtained from sesame seeds are added to various dishes[15]. Other traditional uses of the seeds in other areas of the world encompass treatment for cholera, scorpion poison, respiratory illness, tinnitus, diarrhoea, dysentery, sores, amenorrhea, dysmenorrhea, obstipation, anaemia, bleeding piles, vertigo, and as a memory enhancer [16].

The fixed oil from the seed, which belongs to the oleaginous group, is mostly composed of unsaturated fatty acids, lignans, especially sesamin and sesamolin, sesamol, tocopherols, forms of vitamin E, and phytosterols, including β-sitosterol, campesterol, and stigmasterol. This lipid composition contributes to excellent oxidative stability and assures therapeutic benefits like antioxidant, anti-arthritic, antihypertensive, and wound-healing activities [8,17].

The liver, kidney, spleen, and stomach are particularly benefited from sesame seeds. Its high oil content feeds all of the internal viscera and lubricates the intestines. Additionally, it has been known to turn hair black, particularly black sesame. As a result, it is used to treat white hair, persistent constipation, and inadequate lactation. Furthermore, intestinal worms like tapeworm and ascaris can be treated with sesame oil [18]. Numerous medicinal properties of sesame oil include antioxidant, antibacterial, cardiotonic, and anti-diabetic properties [19]. low cholesterol [20], anti-inflammatory [24], anti-tumour [21, 22], and anti-ulcer [23].

Sesamum indicum leaves are rich in flavonoids and phenolic compounds; metabolomic and phytochemical analyses reveal a complex profile that includes tannins, quercetin, kaempferol and its glycosides, caffeic and chlorogenic acids, and a variety of other polyphenols and minor alkaloids. According to targeted metabolomics, leaves have higher concentrations of certain polyphenols than other tissues, and young leaves are especially rich in phenolic acids and flavonoid glycosides[25].

Antioxidant action due to high total phenolic and flavonoid contents, Disinfectant activity of leaf extracts against Gram-positive and Gram-negative bacteria and some fungi, and anti-inflammatory and wound-healing potential [26]. The leaves' decoction can be utilised to cure eye pain, catarrh, and damaged or inflamed skin. Inflamed oral membranes can be gargled with an infusion of warm water leaves. It has been discovered that the decoction of both leaves and roots works well as a hair shampoo and as an antiviral against measles and chicken pox [27]. The sesame plant's leaves and roots are used to cure piles, chicken pox, ulcers, migraines, hypertension, and constipation [28, 29]. Sesamol, sesaminol, sesamin, polyphenol, naphthoquinone hydroxysesamone, alkaloids, saponins, 2,3-epoxysesamone, and anthrasesamones are among the roots of sesame [30]. Five unique anthraquinones (Anthrasesamones A, B, C, D, and E) with C6 side chains at C-2 in the anthraquinone ring were produced by indicum [31]. However, little is known about the components of the roots, an unused portion of sesame [32]. Therapeutically, roots have antifungal activities against Cladosporium fulvum, as well as anti-malarial properties [33]. The roots have activity to cure asthma and cough, encourage hair growth, and stop premature grey hair [34].Cerebrosides, Latifonin, Aurantiamide Acetate, Benzyl Alcohol Glycosides, Sterols, D-galactitol, alkaloids, flavonoids, coumarins, anthraquinones, phlobatannins, and leucoanthocyanins are just a few of the unique active ingredients and bioactives found in Sesamum indicum (sesame) blossoms. Alopecia (hair loss), frostbite, constipation, and superficial skin problems, including verruca vulgaris and verruca plana/warts, have all been successfully treated with dry sesame flowers. The combination of polyphenols, flavonoids, and alkaloids has antibacterial, anti-inflammatory, and antioxidant properties [34,35]. Sesame flower extract has the ability to prevent tumour growth [36].Alkaloids, flavonoids, proteins, carbohydrates, phytosterols, phenols, tannins, saponins, and glycosides are among the classes of phytochemicals found in S. indicum stems. Potential wound healing, antimicrobial activity, anti-inflammatory benefits, antioxidant qualities, and skin protection [37].Traditionally, sesame fruits have been used as a poultice, laxative, and cough remedy [38].

3. Botanical and Pharmacognostic Overview of *Sesamum indicum*

3.1 Botanical overview: Sesame (*Sesamum indicum L.*), a participant of the Pedaliaceae family and genus *Sesamum,* is traditionally divided into three varieties: white, black, and yellow. White and black sesame are the most widely grown and produced forms. It is once a year herbaceous plant that grows upright and usually reaches a height of 60 to 150 cm. The stem can have white pith inside of it or be hollow. Simple leaves typically have an ovate or rectangular form and measure 3–10 cm in length and 2.5–4 cm in breadth. The fruit is a rectangular capsule with a diameter of 6–12 mm and a length of 2–3 cm [39,40,41]. Its worldwide producers include China, Tanzania, Sudan, Myanmar, and India. North Africa and Central Asia are two of its main producing regions [42]. Sesame seeds, seed oils, and other plant organs have yielded over 180 distinct phytochemical compounds. Lignans, polyphenols, anthraquinones, phytosterols, phenols, cerebrosides, fatty acids, vitamins, proteins, essential amino acids, and carbohydrates are some of these[43]. Morphological characteristics of Sesamum indicum are described in table 1.

Table1: Key Morphological and Diagnostic Features of Sesamum indicum[1,2]

Family	Pedaliaceae
Plant type	Annual herb
Height	60-150cm
Flower	Tubular, white to pinkish
Leaves	Ovate- lanceolate, opposite and hairy
Stem	Hollow or filled with white pith
Fruits	Rectangular capsule with many seeds

3.2 Pharmacognostic overview

3.2.1 Macroscopic Pharmacognostic characters : *Sesamum indicum* is an annual herb characterised by a green, hairy, quadrangular stem that has visible internodes and nodes, a fibrous fracture, and a pale pith; the opposite leaves are ovate lanceolate, clearly veined, and can range from whole to serrate. The plant produces tubular, 2.5–3 cm white to pale pink blooms with a superior, hairy ovary and four stamens. The fruit is a tiny, rectangular capsule with fine surface hairs and longitudinal ribs. When it reaches maturity, it splits open to release a large number of tiny, smooth, oily seeds (2–3 × 1–1.5 mm) that are flat, oval, white or black, and have longitudinal ridging. The seeds have an oily, bitter taste but no distinctive smell [39, 44, 45, 46]

3.2.2 Microscopic pharmacognostic characters : The *Sesamum indicum* stem's T.S. reveals a quadrangular transverse region made up of three separate layers: a cortex of parenchymatous cells with mucilage and pigments, an epidermis with a mucilaginous coating and numerous trichomes, and vascular tissues with collateral bundles arranged in a ring divided by multiseriate medullary rays, encasing a sizable parenchymatous pith. Cells containing oil globules, fibres, pitted vessels, spiral-thickened tracheids, and crystal inclusions such as calcium oxalate are visible under powder microscopy. Large polygonal epidermal cells, palisade, and

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isodiametric parenchyma cells packed with protein bodies and oil globules are seen under a microscope; thick-walled epidermal cells rich in protein and oil granules with mucilage and sporadic calcium oxalate crystals are found in seed coverings. Four to eight locules make up the capsule fruit, which has a strong endocarp of fibres and a mesocarp of soft parenchyma. The thickness of each locule can be determined either longitudinally or transversely [45,47,48].

4 Novel formulations

4.1 Spray-dried encapsulated sesame oil powders: Sesame oil nanoemulsions are transformed into stable, free-flowing powders using gum arabic or maltodextrin to create spray-dried encapsulated sesame oil powders. This method guarantees high encapsulation efficiency, prolongs shelf life, permits controlled release, and shields sesamol and sesamin from oxidation, making the formulation appropriate for oral capsule and tablet manufacturing in the nutraceutical industry [49].

4.2 Intra-articular sesamin formulations (injection): Sesamum indicum intra-articular sesamin formulations, which have localised anti-inflammatory and chondroprotective properties, have great promise for treating osteoarthritis. Sesamin reduces oxidative stress and cartilage degradation by inhibiting pro-inflammatory mediators (TNF-α, IL-1β, nitric oxide synthase) and downregulating the NF-κB and MAPK pathways. Additionally, it promotes the synthesis of collagen II and aggrecan while suppressing MMP-3 and MMP-13. Sesamin injections are a promising localised treatment for osteoarthritis with less systemic adverse effects, according to preclinical research showing increased cartilage thickness, decreased inflammation, and pain alleviation[50].

4.3 Gel formulation of *Sesamum indicum* : A mixture of Sesamum indicum root extract designed to combat oral candidiasis caused by the fungus Candida albicans [51].

4.4 Sesamol / Sesamin nanosystems combined with conventional drugs (combo formulations / co-delivery) Sesamol or sesamin are combined with traditional chemotherapy medications in combination nanosystems, which are intended to enhance anticancer activity and lower systemic toxicity. By co-encapsulating natural lignans and chemotherapeutic drugs, these formulations—such as lipid nanoparticles, polymeric nanocarriers, or nanoemulsions—ensure synchronized release and targeted tumor delivery. The capacity of sesamol and sesamin to regulate reactive oxygen species (ROS) levels results in a synergistic action that increases the death of cancer cells while minimizing oxidative damage to normal cells. Furthermore, these substances block important signaling pathways as MAPK, PI3K/Akt, and NF-κB. Sesamol or sesamin co-delivery systems improve antioxidant defense and apoptotic markers while reducing tumor development and toxicity, according to preclinical research on hepatic and breast malignancies[52].

4.5 Sesamin capsule : Includes 50–200 mg of sesamin daily as a standardized capsule supplement. It primarily works by suppressing NF-κB-mediated swelling and triggering the Nrf2 antioxidant pathway, which lowers oxidative stress and inflammatory cytokines containing TNF-α and IL-6. Additionally, sesamin controls hepatic lipid metabolism by blocking SREBP-1 and HMG-CoA reductase, which lowers the production of triglycerides and cholesterol. maintains the equilibrium between Th1 and Th2 responses, affects the cytotoxic activity of NK cells, and affects cellular and humoral immunity. Clinical studies have shown that supplementing with sesamin improves lipid profiles, decreases LDL and triglycerides, raises HDL, and boosts insulin sensitivity. Research on individuals with rheumatoid arthritis and metabolic syndrome revealed decreased joint pain and inflammation. Sesamin capsules are regarded as a safe and beneficial supplement for the treatment of inflammatory and metabolic diseases [53, 54].

4.6 Sesamol-loaded Nanostructured Lipid Carriers (NLCs) Second-generation lipid carriers include NLC. The diameter is between 10 and 1000 nm. NLC offers improved defense against drug deterioration and prevents drug leakage during storage [55]. Sesamol is administered topically using nanostructured lipid carriers (NLCs), an innovative delivery technology that improves the drug's stability, skin penetration, and antioxidant activity[56].Oxidation is caused by sesamol, a lignan component and strong antioxidant from *Sesamum indicum* [57].Its high volatility and oxidation susceptibility limit its usage in dermal preparations. Sesamol was added to NLCs made of solid and liquid lipids using a high-pressure homogenization technique in order to overcome these restrictions. This produced nanoparticles with a consistent size distribution (about 180 nm), high encapsulation efficiency, and good physical stability over time [56].

4.7 sesame ointment-(topical therapeutic delivery systems) Contains 0.258 mg/g of sasamol, an active ingredient that promotes balanced synthesis and the breakdown of collagen types I and III to improve wound healing outcomes. Additionally, it is seen that the active formulations of the ointment have anti-inflammatory effects in the treated wounds, such as decreased infiltration of inflammatory cells. However, additional components including lignans and oil matrix minor chemicals, produce a synergistic impact [58].

4.8 Sesame-oil nanoemulsions/microemulsions: The pharmacological uses of cold-pressed sesame oil, which is naturally enriched with lignans, are limited by its limited water solubility and susceptibility to oxidative destruction. In order to get around these restrictions, scientists have created nanoemulsion and microemulsion systems in which sesame oil is distributed as lipid droplets that are nanosized and stabilised by surfactants and co-surfactants. These droplets are usually 20–200 nm in diameter. These nanocarriers shield lipophilic chemicals from environmental deterioration while greatly improving their solubility, physical stability, and bioavailability. When paired with therapeutic adjuvants or anticancer drugs, sesame oil-based nanoemulsions show increased cytotoxic effects in vitro [59]. Sesame oil nanoemulsions' nanosized droplets and lipid compatibility improve skin absorption and bioavailability of active ingredients when applied topically, allowing for improved stratum corneum penetration and more potent anti-inflammatory and antioxidant effects [60].

5 Traditional formulations

5.1 Tila –Taila: One of the greatest medications for vatashamana is sesame oil. Sesame oil serves as a basis for the majority of oils used in Ayurvedic treatments [61]. In Panchkarma therapy, Tila oil can be utilised as Abhyanga Shirodhara, Nasya, Basti. It can be used both inside and externally. While sesame oil is also good for skin, its internal application is excellent for raising iron levels, lowering cholesterol, and managing cardiac conditions. Sesame oil acts as a purgative. Constipation is cured by it. It is among the greatest oils for treating Vata Vyadhis like rheumatism, arthritis, and swollen joints.

5.2 Tila lepa (sesame paste) Chakradatta describes Tiladi Lepa, a traditional Lepa preparation. To make a paste, toasted sesame seeds are mashed with oil in a mixer. Tila, Madhuka, Nimba patra, and Madhu are its four constituents. These medications all have the ability to heal wounds and contain antioxidant properties that aid in this process. Only discomfort, itching, discharge, and tenderness can be treated with lepa as an immediate remedy [62,63].

5.3 Anjana (eye collyrium) preparations using sesame oil: Aanjana Kriya (collyrium) is one of the kriyakalpa recommended for treating and preventing a number of eye conditions. A local remedy for eye conditions is called anjana. Applying medication in the form of Gutika, Raskriya, or Churna (powder) to the inner side of the lower lid using Anjana shalaka or the fingertip is known as Anjana [64].

5.4 Ellukai Thol Uppu (ETU) siddha formulation: ETU is a Siddha formulation with antibacterial and wound-healing properties that is derived from the pericarp of Sesamum indicum using a traditional Siddha process. ETU is available as a dusting powder for use as an external medication for excision wounds (Pun). Standardized preparation and quality control techniques make it safe and efficient. The medicine ETU has no adverse effects and is devoid of microbial contamination, according to the study's findings[65].

5.5 Sesame syrup: Sesamum indicum aqueous extract is utilized to make syrup. Sesame syrup was standardized based on its total phenolic content for possible therapeutic use. In letrozole-induced polycystic ovarian syndrome (PCOS), treatment with sesame syrup improved hormone levels such as serum LH, testosterone, estrogen, and progesterone, decreased cystic follicles, and ovarian function [66].

5.6 Emulsion : Oil and protein separated from sesame (Sesamum indicum) and deionised water were used to create oil-in-water emulsions with protein concentrations of 1.5%, 2.5%, and oil10%, 20%. Sesame oil was then added to a pH 11 water-protein sesame (Sesamum indicum) solution to create emulsions, which have food applications [67].

Table 2: Pharmacological properties and therapeutic use of *Sesamum indicum*

Pharmacological Properties	Therapeutic use	Reference
Anti oxidant	Sesame seed/leaf extracts constituents such as lignans) show free-radical scavenging, reduction of lipid-peroxidation	2
Anti inflammatory	Sesamin has been demonstrated to act similarly as non-steroidal anti-inflammatory medications and opioids. Sesamin's anti-inflammatory actions were found to be enhanced by a diet supplemented with sesamin, resulting in a larger reduction in the expression of TNFα and IL-6.	68
Anti depressant	Sesamum indicum seeds have a strong antidepressant-like effect. The reduction in the period of immobility in the TST and FST tests indicates this.	69
Laxative,emollient ,demulcent	Sesame seeds and oil are used as mild Laxative, emollient and demulcent agent.	22
Anti-hypertensive and Vascular Properties	Acteoside and Pedaliin constituent of Sesame leaves are responsible for the inhibitory and antihypertensive effects	70
Anti-ageing / skin /hair protection	Sesamin extract from sesame seeds is used to treat genetic hair loss, canities, and grey hair. Sesame oil can be used as a natural sunscreen to shield the skin from UV rays, prevent sunburns, and decrease the effects of ageing caused by sun exposure.	71,72,73
Viral infections	Sesamin is utilized as an organic antiviral drug to combat the H1N1 virus, which causes swine flu.	74

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Lipidemia	Sesamum's effect on PPAR, which controls lipoprotein metabolism, which probably drops serum cholesterol levels and boost fatty acid oxidation. Sesame oil's unsaturated fatty acids enhance lipid profiles by raising HDL-C and decreasing LDL-C and lipid oxidation.	75,76,77
Hepatoprotective	Sesamin is used as a therapy for management and treatment of hepatic disorders.Sesamin given orally (40–160 mg/kg for 7 weeks) significantly reduced IL-6 and TNF-α levels and in invivo showed strong hepatoprotective effects in BALB/c mice with LPS/D-GalN-induced liver failure	78
cancer	Sesame has a preventive effect against the growth of prostate cancer tumors caused by LPS.	79
Digestive disorders	Sesame have protective effects on digestive Disorders such as ulcerative colitis, inflammatory disease.	80
Bone and Joint disorders	Sesamin has anti-inflammatory properties that may help treat a variety of bone and joint conditions. Sesamin's anti-inflammatory and anti-catabolic effects on LPS-induced intervertebral disk (IVD) degeneration were investigated in an in vitro and ex vivo investigation employing nucleus pulposus (NP) cells and IVD organ culture from Sprague-Dawley rats.	81
Kidney disorders	sesame plant have activity against LPS-induced acute kidney injury (AKI) and inflammation-induced chronic kidney disease that develops with age	82,83
Diabetes	Sesame supplements decreased hemoglobin A1c (HbA1c) and fasting blood sugar (FBS), revealing possible advantages for glycemic control in people with type 2 diabe	84,85

6. Conclusion: Sesamum indicum L. remains a scientifically and therapeutically valuable plant whose traditional importance is strongly supported by modern pharmacological evidence. This is underlined by the rich profile of lignans, unsaturated fatty acids, tocopherols, and phenolic compounds responsible for its broad spectrum of biological activities, mainly exerting antioxidant, anti-inflammatory, lipid-modulatory, and hepatoprotective effects. The long-standing ethnomedicinal relevance is underlined by traditional preparations such as oils and pastes, while recent advances in formulation science, including nanoemulsions, microcapsules, and lipid-based carriers, significantly improve the stability, bioavailability, and targeted delivery of sesame bioactives. Despite encouraging mechanistic and preclinical findings, clinical data remain scant and heterogenous, calling for well-designed trials to substantiate therapeutic claims. In toto, sesame provides a promising bridge between traditional medicine and contemporary pharmaceutical innovation in functional foods, nutraceuticals, and novel drug-delivery systems.

7. Future prospective : Sesamum indicum L. has great potential for future therapeutic development. Large, controlled clinical trials are required to confirm the cardiometabolic, hepatoprotective, neuroprotective, and anti-inflammatory benefits. Approaches from genomics, metabolomics, and lipidomics will help support the breeding of high-lignan chemotypes that possess an elite bioactive profile. Its lipophilic compounds show great promise for modern delivery systems in improving stability and bioavailability, like nanoemulsions, liposomes, and polymeric nanoparticles. Sesamin and sesamol can be considered lead molecules for novel drug development, while sesame oil is gaining increased interest in cosmeceuticals and wound-healing formulations. The efficient use of seed by-products for further nutraceutical applications is very promising. Traditional knowledge combined with advanced formulation technology will contribute to the development of standardized clinically relevant sesame-based therapies.

Conflict of interest: The authors declare that they have no conflict of interest related to this publication.

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Ethical approval and consent to participate : Not applicable

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Availability of data and materials : All data generated or analysed during this study are included in this article.

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