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RESEARCH ARTICLE

The Impact of Sesame Seeds on Human Health

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ABSTRACT

Sesame seeds, scientifically known as Sesamum indicum L., have been farmed for millennia and are highly regarded for their wide range of uses in cooking. In addition to their pleasant nutty taste and crispy consistency, sesame seeds have also been acknowledged for their extraordinary nutritional advantages. This article offers a comprehensive analysis of the various ways in which sesame seeds contribute to general health and wellness. Sesame seeds contain a variety of phytochemicals, such as lignans derivatives, tocopherol isomers, phytosterols, and phytates. These compounds have been linked to several health advantages, including the protection of cardiovascular health and the prevention of cancer, neurodegenerative disorders, and brain dysfunction. These chemicals have also been confirmed for their effectiveness in managing cholesterol. Their capacity as a natural reservoir of advantageous botanical chemicals is thoroughly elucidated. The article delves deeper into the beneficial effects of sesame seeds in lowering the likelihood of chronic diseases due to their abundant polyunsaturated fatty acids. However, it is important to recognise the importance of keeping a diverse diet in order to attain the appropriate equilibrium of n-3 and n-6 polyunsaturated fatty acids, which is deficient in sesame seed oil. The text explores the importance of bioactive polypeptides extracted from sesame seeds, highlighting their potential uses as nutritional supplements, nutraceuticals, and functional components. This review examines the impact of processing procedures on sesame seeds and how they can affect the presence and activity of bioactive chemicals. Roasting the seeds improves the antioxidant qualities of the oil extract, however some processing methods may decrease phenolic components.

INTRODUCTION

Sesame (*Sesamum indicum L.)* is an ancient oil crop in the Pedaliaceae family, along with rape, soybean, and peanuts [1]. It is considered one of China's four main oil crops. Sesame, a well-established cultivated crop, was initially found in ancient sites in Pakistan [2]. It is dispersed throughout nations such as India, China, and Malaysia. Sesame seeds have been utilised by the Chinese for over 5000 years [1,3]. India, Sudan, Myanmar, China, and Tanzania are the primary global producers of sesame. Over the past several years, African countries have experienced a rise in sesame seed output, with Tanzania surpassing India to become the top producer of sesame seeds. The Food and Agriculture Organisation of the United Nations reported that the worldwide sesame production in 2017 amounted to 5.899 million tonnes. Out of this, Tanzania contributed 806,000 tonnes while China produced 733,000 tonnes [4]. Sesame is extensively cultivated and favoured for its strongly fragrant perfume and smooth taste. Sesame seeds are commonly utilised in people's lives to produce a diverse range of food items, including sesame oil, sesame paste, and as a garnish for other dishes. In 2002, sesame seeds were officially recognized for their scientific nutritional worth and included in the list of medicinal and dietary ingredients published by the previous Chinese Ministry of Health. Out of all the articles on sesame, only one comprehensive review on the phytochemistry and ethno-pharmacology of sesame has been published in recent years [5]. Additional reviews focus on the specific chemical composition found in sesame seeds [6], the pharmacological effects of sesame [7], or the technical aspects of its manufacture [8]. This review will examine the phytochemical and pharmacological features of sesame, as well as its economic-phytological and nutritional importance.

Morphology of Sesame

Sesame is a tall, upright, annual herb that reaches a height of 60-150 cm. The stem is either hollow or has a white pith. The dimensions of the sesame leave range from 3 to 10 cm in length and 2.5 to 4 cm in width. They have a rectangular or ovate form with a slightly hairy surface. They are produced individually or in groups of 2–3 on the leaf axils. The calyx lobes of sesame are elongated, measuring 5–8 mm in length and 1.6–3.5 mm in width. They have a lanceolate form and a hairy appearance. The corolla of sesame measures 2.5–3 cm in length and has a cylindrical shape with a diameter of approximately 1–1.5 cm. The colour of the object is predominantly white, occasionally accompanied with a purplish-red or yellow halo. The flower conceals four stamens, while the ovary is positioned above, has four chambers, and is covered with fine hairs on the outside. The blossoming period takes place in the later part of summer and early part of fall. The sesame capsule has a rectangular shape, about 2–3 cm in length and 6–12 mm in diameter. It is characterised by longitudinal ribs on its surface and microscopic hairs on the epidermis. Sesame seeds exist in two colour variations: black and white. The black variety is referred to as black sesame, while the white kind is known as white sesame [9, 10, 11].

Classification of Sesame

Sesame, a genus of the plant Sesamum, belongs to the Pedaliaceae family. Sesame can be categorised into white sesame, black sesame, and yellow sesame based on variations in germplasm colour. Among these, black and white sesame are the more prevalent and extensively cultivated species. Black sesame exhibits robust growth, resistance to lodging, and resilience to drought, whereas white sesame possesses a high oil content and excellent quality. Additionally, white sesame boasts the largest cultivation area and widest spread. Regarding other variegated varieties like yellow sesame, their plants exhibit predominantly branching growth. Typically, as the colour of the germplasm becomes darker, the oil content drops steadily [9].

Nutritional Components

Sesame seeds are abundant in lipids, proteins, minerals, vitamins, and dietary fibre. Sesame oil, derived from conventional oil production techniques, is abundant in unsaturated fatty acids, fat-soluble vitamins, amino acids, and other nutrients. Research has indicated that sesame seeds have a protein content of 21.9% and a fat content of 61.7%. Additionally, they are abundant in minerals such as iron (Fe) and calcium (Ca) [12]. Sesame seeds are highly nutritious and are known for their reputation as a versatile source of nutrients, often referred to as the "all-purpose nutrient bank" and the "crown of eight grains [13].

Protein

Sesame protein is a complete protein with a ratio of necessary amino acid content that closely resembles that of the human body [14] . Sesame protein is diverse, consisting primarily of globulin, clear protein, alcoholic protein, and glutenin. Among these, globulin has the largest concentration, while alcoholic protein has the lowest [15,16] . Sesame meal, a residual substance resulting from the processing of sesame, also possesses around 50% protein content. The in vitro protein digestibility of sesame protein isolation was determined using the pepsin pancreatin enzyme systems. The results indicated that the sesame protein isolate had a digestibility rate of 89.57% [17]. The significant in vitro protein digestibility of sesame protein isolate indicates its potential as a valuable enrichment and supplement in many food systems, particularly in developing nations where protein insufficiency poses a significant health concern for children. Peptides have a crucial role in the control and well-being of organisms, as demonstrated by significant research. They are not only utilised by growth-promoting nutrients, but also contribute to overall health and development. The health advantages of black sesame seeds are regarded as superior to those of white sesame seeds in Asian countries due to the variations in the seed coat colour [18] . In a study conducted by Cui et al., a genome-wide association analysis was performed to investigate the relationship between sesame seed coat colour and protein content. The findings revealed that as the colour of the seed coat became darker, there was a corresponding rise in the protein content of the sesame seeds [19] . Black sesame seeds have a higher protein content compared to white sesame seeds, which is a more easily understandable characteristic. Four proteins identified in sesame include albumin, globulin (α and β), prolamin, and glutelin fractions [20] . These proteins were found in sesame seeds and are listed in Table 2. A total of nineteen essential amino acids have been extracted and identified from the roots, seeds, flowers, stems, and leaves. The following amino acids are included: alanine, arginine, aspartic acid, cysteine, glutamic acid, glycine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, serine, threonine, tyrosine, valine, tryptophane, proline, and γ-aminobutyric acid [21].

Lipids

The lipids in sesame are primarily concentrated in the seeds and serve as a crucial constituent of the plant. Sesame possesses the greatest oil content compared to other significant oil crops, ranging from 45% to 57%. This is the reason why it has been historically referred to as the "Queen of Oil" [22]. According to reports, sesame oil is composed of 80% unsaturated fatty acids and a tiny quantity of saturated fatty acids [23]. Linoleic acid and linolenic acid are unsaturated fatty acids that are classified as essential since they cannot be produced by the body and must be acquired from dietary sources. Linoleic acid plays a role in cholesterol metabolism, enhances the resilience of vascular epithelial cells, and supports growth and development. Linolenic acid has the ability to enhance the differentiation and proliferation of lymphatic B-cells, as well as boost the acquired external immunity [24]. Sesame oil, derived from sesame, is a significant source of major unsaturated fatty acids, including oleic (18:1) and linoleic (18:2) acids, which make up 26.60% to 54.85% of its composition. Minor unsaturated fatty acids account for a range of 0.13% to 0.89%. The concentration of saturated fatty acids ranges from 0 to 10.58%, making it a valuable addition to essential fatty acids [24] . reported on the correlation between the oil content and protein content of sesame seeds. The examination of the relationship between the amount of oil and protein in sesame seeds, using 112 different genetic markers, showed a clear and strong inverse link. Both the oil content and protein content were strongly affected by the specific genetic makeup and the environmental factors, such as the year and location of cultivation.

The lipid known as latifonin was discovered and identified in sesame flowers [25] . The following acids are included: oleic acid, linoleic acid, palmitic acid, stearic acid, arachidic acid, linolenic acid, palmitoleic acid, lignoceric acid, caproic acid, behenic acid, myristic acid, and margaric acid [9].

Vitamins

Sesame contains several vitamins, with vitamin E being the most abundant. Specifically, black sesame seeds can contain vitamin E in quantities of up to 50.4 mg/100 g. Research has indicated that γ-tocopherol is the predominant variant of vitamin E found in sesame seeds, but α-tocopherol is present in less quantities. Research conducted in laboratory settings has demonstrated that γ-tocopherol exhibits a greater potential for antioxidation compared to α-tocopherol. However, when considering the overall functional activity, vitamin E as a whole demonstrates a larger effect. All twelve vitamins, including Vitamin A, thiamine, riboflavin, niacin, pantothenic acid, folic acid, ascorbic acid, α-tocopherol, β-tocopherol, γ-tocopherol, δ-tocopherol, and tocotrienol, have been found in sesame seeds [26].

Carbohydrates

The primary by-product of extracting sesame seed oil is the sesame seed hull. The composition of this substance is mostly made up of carbohydrate polymers, specifically hemicelluloses, cellulose, and pectic polysaccharides, which account for 70-80% of its composition.The seeds contain seven types of carbohydrates: D-glucose, D-galactose, D-fructose, raffinose, stachyose, planteose, and sesamose [27]

Mineral Elements:

Sesame seeds are rich in several minerals, including potassium (525.9 mg/100 g), phosphorus (516 mg/100 g), magnesium (349.9 mg/100 g), sodium (15.28 mg/100 g), iron (11.39 mg/100 g), zinc (8.87 mg/100 g), and manganese (3.46 mg/100 g) [28].

Chemical Compounds

Sesame is not only abundant in nutrients, but it also includes several significant functional components, including sesamin, sesamolin, sesamol, sesaminol, sesamolin phenol, and other lignan-like active compounds [29]. The composition of each constituent in sesame differs based on the technique of extraction and the environmental circumstances in which it is grown. For instance, hot-pressed sesame oil has larger amounts of sesamol, sesamin, and total lignans compared to cold-pressed and refined sesame oil [51]. Several factors, including strain, genotype, growing location (soil and weather), and growth circumstances (irrigation, fertilisation, and harvest time), can influence the lignan concentration in sesame [30].

Lignans

Sesame lignans, found in sesame seeds, are the primary active components and have potent antioxidant properties. Research in the field of epidemiology has demonstrated that sesame lignans has advantageous properties in the regulation of blood lipids and enhancement of liver function. The oxidative stability of sesame oil is similarly influenced by these qualities. Sesamin comprises around 50% of the sesame lignans, whereas sesamolin, sesamol, and sesaminol make up a tiny fraction of the overall weight. The average concentrations of sesamin and sesamolin are 2.48 mg/g (with a range of 1.11–9.41 mg/g) and 1.72 mg/g (with a range of 0.20–3.35 mg/g) respectively. During the pressing process, sesame seeds undergo denaturing changes, converting sesamin and sesamolin into unsaturated low polymeric structural compounds as sesamol, sesaminol, and sesamolin phenol. Research has demonstrated a considerable correlation between the lignan levels in sesame seeds and their seed coat colour. Black sesame seeds have the greatest concentrations of sesamin, sesamol, and total lignans, whereas white sesame seeds have comparatively low levels of sesamin. The total lignin concentration in yellow, black, brown, and white sesame seeds ranged from 2.52 to 5.94 mg/g, 3.56 to 12.76 mg/g, 2.66 to 6.68 mg/g, and 2.83 to 5.66 mg/g, respectively [30,31].

Sesamin

Sesamin is a highly prevalent lignan found in sesame seeds and possesses significant physiological action. Research has demonstrated that sesamin possesses favourable antioxidant characteristics, aids in reducing cholesterol levels, regulates lipid metabolism, stabilises blood pressure, and exhibits anti-tumor actions [3]. The primary metabolic pathway of sesamin in the body is through the enzymatic activity of cytochrome P-450. The bodily fluids and tissues mostly include glucosinolates and sulfate-conjugated forms as the metabolites of sesamin. Sesamin is excreted by bile, urine, and faeces, and its removal is primarily accomplished through metabolism. The variability in sesamin concentration, a lignan that is soluble in oil, may be attributed to differences in sesame varieties, local climate, and soil type. The sesamin content ranges from 60.14 to 69.10 mg per 100 g. By subjecting the unroasted and pressed sesame oil to decolorization using acidic white clay, a portion of the sesamin underwent isomerization to generate the stereoisomer episesamin, resulting in a level of around 0.28% [33].

Sesamolin

Sesamolin is the second most prevalent lignan found in sesame. Due to the absence of phenolic hydroxyl groups, sesamolin has a significantly lower antioxidant impact in the body compared to sesamol. Nevertheless, when exposed to specific heating conditions, sesamolin can undergo a slow conversion into sesamol. By using this conversion property, the inclusion of sesamolin amplifies the antioxidant characteristics of oils and fats during the process of heating [5].

Sesamol

Sesamol is found in little quantities in sesame lignin, but it serves as the primary flavour compound and quality preserver in sesame oil, with notable antibacterial and antioxidant characteristics. Research has demonstrated that sesamol remains unchanged when exposed to sunlight and may be used in conjunction with dietary additives. However, it is not compatible with powerful oxidising agents [34].

Sesaminol

Sesaminol is a significant lignan that dissolves in fat. Sesame seeds contain a very little amount of it, but it has strong antioxidant capabilities and is stable under high temperatures. Sesamolin may be easily transformed into sesaminol when exposed to acidic environments [35].

Processing Technology of Sesame

Various processing processes have been discovered to yield different impacts on the bioactive chemicals present in sesame seeds. Research has demonstrated that the process of roasting the seeds enhances the amount of oil obtained and enhances the antioxidant qualities of the oil extract [36] . Nevertheless, it has been noted that the process of roasting and dehulling seeds might decrease the levels of lignan and phenolic components in sesame extracts, which are crucial for their antioxidant properties [38] . However, several processing methods such as soaking, cooking, germination, fermentation, and microwave heating have been discovered to decrease the levels of phenolic compounds and tannins in oilseeds, including sesame seeds [39] . In general, the processing processes employed for sesame seeds can have both advantageous and disadvantageous impacts on the bioactive components. To enhance the preservation of these beneficial compounds, additional investigation is required to optimise the processing methods. The traditional method of processing sesame mainly includes mechanical pressing, aqueous extraction, and solvent techniques. Additionally, advanced methods for processing and extracting sesame include supercritical (subcritical) CO_2 extraction, microwave-assisted extraction, and water enzyme extraction [40,41]. Proteins' biochemical properties can be modified by employing different food processing methods, such as high pressure, heat, radiation treatments, and ultrasound. These processes can result in alterations to the physical arrangement of molecules, such as clumping together, unfolding, and the breakdown of specific molecular structures. Additionally, various types of bonds can be formed or broken, and chemical events like glycation (Maillard reactions) can occur [42].

Heating Method

Multiple heating methods, including blanching, boiling, autoclaving, roasting, and frying, are commonly used in the production of sesame-based culinary products. Applying heat to proteins causes different changes in their structure, such as breaking apart and rearranging protein clusters, altering disulfide links, and reacting chemically with other components like carbohydrates and lipids. The aforementioned modifications result in changes to the epitopes of sesame, which can either reduce or enhance its allergenicity [43] . Research findings indicate that boiling sesame seeds at a temperature of 100 °C for 5 minutes increased their antigenicity. However, subsequent boiling did not result in any additional rise in antigenicity. The study discovered that exposing sesame seeds to dry roasting at a temperature of 150 °C for a duration of 7.5 minutes resulted in an increase in antigenicity. Moreover, a more pronounced augmentation in antigenicity was noted when the duration of roasting was prolonged to 15 minutes. Utilising microwave heating at a power of 1000 W for a duration of 3 minutes led to a notable decrease in the antigenicity of sesame seeds. Nevertheless, there were no notable changes in antigenicity when microwave heating was applied for a duration of 1 minute. Research has indicated that changes in the antigenicity of sesame seeds are linked to the specific heating method used, as well as the time and temperature of the process [44] . This aligns with the results obtained from studies on the thermal processing of soybeans. After being subjected to heat treatment, the protein composition of different sesame proteins undergoes specific changes [45]. Additional research is necessary to comprehend the mechanism responsible for changes in antigenicity. The heat treatment method has the ability to create advanced glycation end products, which can increase the capacity of IgE binding. It is crucial to take into account the impact of other components on the allergenicity of sesame [46].

Mechanical Pressing

The mechanical pressing technique is a widely used method for extracting oil from seeds that have a high oil concentration, resulting in the production of high-quality oil. This approach is distinguished by its simplicity, safety, and cost-effectiveness [47]. Martínez et al. [48] utilised Box-Behnken designs to optimise the screw-pressing procedure for extracting sesame oil, leading to a peak oil recovery rate of 71.1%. The ideal circumstances were attained by using a seed moisture content of 12.3%, a 4 mm restriction die, and a pressing speed of 20 r/min. The research conducted by Yin etal.[49] found that the volatile components of sesame oil obtained through mechanical pressing had higher concentrations of sulphur heterocyclic compounds compared to those recovered using water-based methods.

Aqueous Extraction

The aqueous extraction method can simultaneously extract both protein and oil. The ideal parameters for extracting sesame oil, which include a solid-to-water ratio of 0.8 g/mL (V/m), a temperature of 70 °C, and a pH of 5.0. As a result of the aforementioned variables, the extraction efficiency is at 82.49%. Fasuan et al. [50] successfully enhanced the process, leading to higher oil and protein recoveries of 73.60% and 75.12%, respectively. The desired outcome was obtained by employing a solid-to-solvent ratio of 1:3 (mass/volume), a pH of 11, an extraction temperature of 47 °C, and a surfactant concentration of 0.1 mol/L sodium chloride (NaCl).

Aqueous Enzymatic Extraction

Liu et al. [51] have demonstrated that enzymatic extraction can yield a high quantity of oil with excellent quality. The ideal parameters for the process were a liquid-to-material ratio of 7:1 (mL/g), a microwave power of 400 W, a treatment duration of 4 min, the addition of alkaline protease at a concentration of 0.1% (black sesame powder), a pH of 8.0, an enzymatic hydrolysis temperature of 50 °C, and a hydrolysis period of 2 h. In addition, de Aquino et al. [52] showed that the addition of a specific quantity of water, along with an appropriate temperature and enzyme dosage, can significantly enhance oil output.

Microwave/Ultrasonic-Assisted Extraction

Microwave-assisted extraction is a method that use electromagnetic waves to extract chemicals from cells. With rising temperature, the solvent molecules within the cell undergo rapid evaporation, leading to an increase in pressure and ultimately the rupture of the cell wall. This results in the rapid discharge of cellular contents. Lertbuaban and Muangrat [53] employed microwave-assisted extraction to isolate sesamin from black sesame seeds. The researchers determined that the most favourable circumstances for the extraction process were as follows: using 90% ethanol as the extractant, maintaining a solid-liquid ratio of 1:8 (g/L), applying a microwave power of 700 W for a duration of 9 minutes, resulting in a yield of 55.48 mg of sesamin. Conversely, Sarma et al. [54] examined the impacts of using solvents and microwave-assisted extraction to extract phenolic components from sesame. The researchers discovered that the maximum amount of total phenolic content was 206.14 mg GAE/100 g. These studies indicate that the efficiency of microwave-assisted extraction varies based on the specific material being targeted and the parameters of the extraction process.

Irradiation

Many research investigations have examined the antigenicity of sesame seeds and protein solutions, specifically focusing on the impact of γ-irradiation and high hydrostatic pressure. The study conducted by Zoumpoulakis et al. [55] found that there were no significant changes in the antigenicity of sesame proteins when white sesame seeds were exposed to radiation at doses of 2.5, 5.0, and 10.0 kGy. This result was statistically significant, with a p-value of less than 0.05. The permissible threshold of irradiation for food items generally remains below 10 kGy[56]. Therefore, the irradiation process should focus on the protein solution of sesame rather than its seeds in order to reduce its allergenic qualities. Higher levels of γ-irradiation result in reduced antigenicity in solutions that contain Ara h 2 and Ara h 6 [57].

High Hydrostatic Pressure

High hydrostatic pressure is an innovative technical method that affects non-covalent connections, including hydrophobic, hydrogen, ionic bonds, and salt bridges, rather than covalent ones. As a consequence, proteins undergo denaturation, which causes structural changes that ultimately result in the hiding or destruction of epitopes and a reduction in allergenicity. Achouri and Boye [46] reported a decrease in the antigenic properties of sesame protein solutions following exposure to high hydrostatic pressure (varying from 100 to 500 MPa) at various pH values for a duration of 10 minutes. The decrease in antigenicity found can be due to the effect of high hydrostatic pressure on the protein's shape, which caused it to adopt a compact and tightly packed structure that concealed the allergen epitopes. The possible reduction in the ability of sesame protein solution to cause an immune response may be due to the decreased ability of certain sesame allergens to cause allergies.

Supercritical (Subcritical) Extraction

Supercritical carbon dioxide extraction is a method that effectively preserves the nutritional and physiological qualities of oil while avoiding the harmful effects of oxidation at high temperatures [58]. Shi et al. [59] performed a comparative examination of the chemical characteristics, antioxidant capability, and oxidative stability of sesame oil using supercritical and subcritical techniques. The study's findings revealed that the processing techniques had a minimal effect on the fatty acid and triacylglycerol content of the oil. Corso etal.[60].stablished the appropriateness of using compressed propane as a solvent for extracting sesame oil. They discovered that this process necessitated less time and pressure compared to carbon dioxide extraction. Liu etal. [61] successfully enhanced the extraction conditions, leading to a remarkable 95.56% output of sesame oil without compromising its nutritious content.

Impact On the Functioning of the Body

Multiple studies have documented the presence of natural lignans, namely sesamin and sesamolin, in sesame seeds. These lignans have been found to possess diverse pharmacological properties, including anti-inflammatory, antioxidant, anti-cancer, anti-hypertensive, anti-melanogenic, auditory protection, anti-cholesterol, and other potent bioactive effects. Additionally, they exert a safeguarding influence on the cardiovascular system, liver, and renal organs [62,63,64].

Antioxidant Effect

Oxidative stress refers to the overproduction of free radicals, which disrupts the balance of antioxidants and homeostasis. The generation and elimination of free radicals are balanced, and this balance is kept by the "redox" mechanism [65]. Sesamin has been discovered to effectively eliminate free radicals and have antioxidant properties within the body. Ruankham et al. [66] discovered that sesamin hindered the generation of reactive oxygen species (ROS) generated by H2O2 in human neuroblastoma. Additionally, it enhanced the activities of catalase (CAT) and superoxide dismutase (SOD) to safeguard cells from oxidative stress. Sesamin was able to counteract the reduction of SIRT1 and SIRT3 levels caused by H_2O_2. There is a hypothesis that suggests sesamin has the ability to influence the signaling pathway of SIRT1-SIRT3-FoxO3a and reduce the oxidative damage caused by H_2O_2. Furthermore, it was shown that the augmentation of cell death (apoptosis) following H_2O_2 therapy was linked to the activation of cystatin-3/7, the increase in BAX expression, and the decrease in BCL-2 expression. Sesamin, on the other hand, was able to counteract these alterations, thereby reducing the extent of apoptosis. Consequently, sesamin holds potential as an anti-apoptotic medication.Furthermore, Fan et al. (67) discovered that sesamin inhibition targets SIRT3, which can restore normal levels of cardiac SIRT3 and SOD in mice undergoing aortic constriction surgery. Additionally, it can prevent cardiac remodeling that relies on SIRT3 by decreasing ROS levels.

Cholesterol-Lowering and Lipid-Regulating Effects

Multiple investigations have demonstrated that sesamin possesses strong lipid-lowering effects. The primary reason for Sesamin's capacity to lower lipid levels is its impact on crucial stages of fatty acid and cholesterol metabolism. It achieves this by reducing the levels of LDL, VLDL, and TG, which are known to induce the development of atherosclerosis. Additionally, Sesamin also increases the levels of HDL, which is known to defend against atherosclerosis.Liang et al. (68) demonstrated the advantageous effects of sesamin in the regulation of lipids and reduction of cholesterol levels. Sesamin exhibited a dose-dependent decrease in the mRNA levels of NPC1L1, ACAT2, MTP, ABCG5, and ABCG8. Additionally, it influenced the expression of genes associated with proteins and enzymes involved in cholesterol absorption. Sesamin did not impact the expression of LDL-C receptor mRNA and hepatic SREBP2. Nevertheless, it resulted in a dosage-dependent rise in mRNA levels for CYP7A1, while causing a dosage-dependent decline in mRNA levels for HMG-CoA reductase and LXRα. These findings indicate that sesamin reduces cholesterol levels by suppressing the activity of genes responsible for transporting cholesterol into the body.Sesamin impacts various areas of cholesterol metabolism. It inhibits the production of cholesterol and reduces the expression and activity of CYP7A1 by suppressing HMGCR. Additionally, it can downregulate various sterol transporter levels, resulting in a decrease in cholesterol absorption and an increase in the excretion of neutral steroids through feces. Sesamin also helps maintain balanced cholesterol levels by increasing the expression of RCT sterol transporters and activating the PPARγ1, LXRα, and MAPK regulatory pathways (69). Thus, sesamin shows potential as a beneficial substance for lowering LDL and VLDL levels while boosting HDL levels.

Protect Liver and Kidney Function

Sesamin was seen to effectively counteract the increase in ALT, AST, and total bilirubin levels, promote the increase in SOD and GSH-Px antioxidant activities, and considerably decrease the increase in IL-6 and COX-2 levels in mice with liver fibrosis (68) . Sesamin exhibits potent inhibitory effects on NF-κB activity, effectively blocking its translocation from the cytoplasm to the nucleus. This mechanism contributes to its beneficial hepatoprotective and anti-fibrotic properties.

Guo et al. (70) discovered that sesamin has the ability to decrease levels of serum ALT, AST, ALP, urea nitrogen, and creatinine in rats that were induced with adriamycin. This reduction in levels effectively safeguards the functions of the liver and kidneys. In the meantime, sesamin was found to have a substantial effect on reducing MDA and 4-hydroxynonenal levels in liver and kidney tissues produced by adriamycin. Additionally, sesamin was observed to enhance the activities of antioxidant enzymes SOD, CAT, and GPX in both liver and kidney tissues. Sesamin is believed to have the ability to reduce the harmful effects of adriamycin-induced liver and kidney damage by preventing oxidative stress.Rousta et al. (75) discovered that varying levels of sesamin had a safeguarding impact on acute renal damage generated by LPS in mice. The administration of this substance resulted in a considerable decrease in serum urea nitrogen and creatinine levels. It also prevented the elevation of MDA, SOD activity, catalase activity, glutathione content, and Nrf2 levels in renal tissues generated by LPS. However, it did not have a significant impact on nitrite content. Furthermore, sesamin shown the ability to restore the irregularities in NF-κB, Toll-like receptor 4, COX-2, DNA breakage, TNF-α, and IL-6 levels caused by LPS induction. This suggests that sesamin may mitigate LPS-induced acute kidney injury by diminishing renal oxidative stress, inflammation, and apoptosis.A study conducted by Cao et al. (71) shown that sesamin exhibited a notable reduction in fluorine-induced kidney injury and apoptosis in carp, with the extent of this effect being dependent on the dosage. Furthermore, sesamin was found to prevent the production of reactive oxygen species (ROS) in the kidneys and alleviate oxidative stress. The results demonstrated a notable suppressive impact on renal cystatin-3 activity and a decrease in the amount of p-JNK protein in the kidneys of fish exposed to fluorine. This suggests that sesamin provides protection against renal oxidative stress and apoptosis via modulating the JNK signaling pathway.

Anti-Inflammatory Effect

Research has demonstrated that sesamin possesses anti-inflammatory properties (72). TNF-α has a significant impact on the development of rheumatoid arthritis (78). Khansai et al. discovered that sesamin effectively decreased the mRNA expression of IL-6 and IL-1 in human primary synovial fibroblast cell lines. This indicates that sesamin prevented the expression of pro-inflammatory cytokines mRNA caused by TNF-α (73). The main metabolites of sesamin found in human plasma after oral administration of sesamin are believed to be sesamin catechol conjugates. Catechol glucuronides induce anti-inflammatory effects in macrophage-like J774.1 cells by causing demyelination, which subsequently inhibits the production of interferon beta and inducible nitric oxide synthase. Research discovered that SC1, a metabolite of CYP450 derived from sesamin, exhibited more potent anti-inflammatory effects compared to sesamin in J774.1 cells, which are murine macrophage-like cells (74).

Hypoglycemic Effect

Type 2 diabetes mellitus is a chronic metabolic illness that affects the way the body processes fat, protein, and carbohydrates. It is recognized as a significant global public health issue, with its incidence steadily rising worldwide. Empirical research has demonstrated that white sesame oil possesses the ability to mitigate the detrimental impacts of diabetes (75). The researchers randomly assigned male Sprague Dawley rats to four groups: a standard diet group, a normal control group, a diabetic control group, and a diabetic sesame oil group. The rats in the diabetic sesame oil group were fed a meal containing 12% white sesame oil. Blood samples were collected and evaluated at 0, 30, and 60 days. The study employed a two-way repeated measures ANOVA to evaluate the variations across groups and across different days. Initially, the fasting blood-glucose and insulin levels were comparable in both diabetic groups, with an average of 248.4 ± 2.8 mg/dL and 23.4 ± 0.4 μU/mL, respectively. Following a period of 60 days, the fasting blood-glucose levels were notably higher in the diabetic control rats (298.0 ± 2.3 mg/dL) compared to the diabetic sesame oil group (202.1 ± 1.0 mg/dL) ($p < 0.05$). The findings demonstrated that the intake of white sesame oil had a notable impact on lowering high blood sugar levels and mitigating various indicators of liver strain. Additionally, it exhibited a protective effect on cardiovascular and renal well-being.Devarajan et al. conducted an 8-week study where they randomly assigned patients with type 2 diabetes to different treatment groups. They found that patients treated with a mixture of sesame oil, glibenclamide, or a combination of both had significantly lower levels of fasting and postprandial glucose at weeks 4 and 8. The difference in glucose levels was statistically significant ($p < 0.001$) (76). At week 8, there was a substantial decrease ($p < 0.001$) in HbA1c, total cholesterol, triglycerides, LDL cholesterol, and non-HDL cholesterol. Additionally, there was a significant increase ($p < 0.001$) in HDL cholesterol. This study also showed that sesame oil has the ability to alleviate the symptoms of high blood sugar in individuals with type 2 diabetes and enhance their lipid profile.

Protection of the Cardiovascular System

Hypertension is a contributing factor to the development of cardiovascular disease. By 2025, the global population of individuals with hypertension is projected to surpass 1.5 billion. Research has indicated that consuming a diet that is high in polyunsaturated fatty acids and vitamin E can be advantageous in decreasing hypertension and the occurrence of cardiovascular diseases. Sesame seeds contain high levels of polyunsaturated fatty acids, phytosterols, lignans, and vitamin E, all of which have a positive impact on blood pressure [77]. In a clinical trial conducted by Helli etal.[78], it was discovered that sesamin supplementation had a notable effect on patients with rheumatoid arthritis. Specifically, it considerably decreased the levels of serum MDA and increased the levels of TAC. The study found that patients with rheumatoid arthritis experienced significant reductions in body weight, BMI, and systolic blood pressure after taking sesamin. This suggests that sesamin may be effective in reducing cardiovascular risk factors in these patients.The examination conducted by Khosravi-Boroujeni et al. [79] demonstrated that the ingestion of sesame seeds has a beneficial effect on reducing blood pressure. However, further investigation is required to determine the exact extent of this effect. In a study conducted by Li et al. [80], it was discovered that sesamin had a significant impact on various aspects of heart health in spontaneously hypertensive rats. Sesamin reduced heart weight, left ventricular weight, cardiomyocyte size, and the ratio of left ventricular weight to body weight. Additionally, sesamin effectively reduced mitochondrial and myofiber damage, suppressed the elevation of systolic blood pressure, and improved overall cardiac health. Simultaneously, sesamin elevated total antioxidant capacity (T-AOC), reduced cardiac malondialdehyde (MDA) content and nitrotyrosine levels, and suppressed transforming growth factor-beta 1 (TGF-β1) protein levels and mRNA expression in the left ventricle.

Anti-Tumor Effect

Multiple investigations have demonstrated that sesamin possesses strong anticancer effects. The primary mechanisms by which sesamin exerts its anticancer effects include inhibiting cell proliferation, promoting cell death, reducing inflammation, preventing metastasis, inhibiting blood vessel formation, and promoting cellular self-degradation. The precise signaling processes initiated by sesamin in cancer cells have not yet been completely elucidated. However, the STAT3, JNK, ERK1/2, p38 MAPK, PI3K/AKT, caspase-3, and p53 signaling pathways are crucial in promoting the anticancer properties of sesamin [3].

Other Aspects

Sesamin treatment markedly decreased the quantity of developed osteoblasts as detected through TRAP staining. Sesamin did not exhibit any reduction in NFATc1 gene expression, which was in direct contrast to the observed declining trend in CathK and TRAP expression. DC-STAMP, but not Atp6v0d2, exhibited a substantial decrease in the presence of 14lM sesamin. Sesamin has the ability to hinder the process of human osteoclast differentiation, the recruitment of precursor cells, and the synthesis of F-actin. Sesamin therapy reduces the size of resorption pits and promotes the release of collagen from bone fragments. This further strengthens the inhibitory effect of sesamin on the differentiation and function of osteoclasts. Sesamin is a potentially effective phytochemical compound that hinders the process of osteoclast differentiation and impairs its functioning.Studies have demonstrated that both sesame oil and sesamin provide a therapeutic impact on hearing impairment and can enhance the function of damaged hair cells. Administering sesame oil and sesamin to ototoxic zebrafish larvae stimulated the growth of auditory cells. Sesame oil was found to cause a notable rise in the quantity of kinocilia, and it was seen that both sesame oil and sesamin improved the recovery of neural ast in a zebrafish model of sensory nerve injury, hence enhancing their functions. The level of Tecta expression in the tip region of cochlear hair cells was positively correlated with their growth. Furthermore, scientists have proven the efficacy of sesame oil in a mouse model of noise-induced hearing loss (NIHL). The hearing threshold of mice was decreased after being treated with sesame oil, indicating that sesame oil has a beneficial effect on noise-induced hearing loss (NIHL) disease. Therefore, the data unequivocally demonstrate that sesame oil and sesamin are potential options for treating and restoring hearing loss [80].

Summary and Prospects for the Future

The recent studies have provided extensive evidence that consuming sesame seeds, which are rich in bioactive components, offers several health benefits. Sesame seed-derived lignans have a wide range of potential therapeutic uses, including improving cognitive health, treating cardiovascular disease, cancer, and inflammation-related illnesses. Incorporating tocopherols extracted from sesame seeds can enhance the antioxidant capabilities of functional health meals. These molecules operate as antioxidants and can neutralise the harmful effects of reactive oxygen species, thereby protecting cell membranes and avoiding disorders like cancer and cardiovascular diseases. Phytosterols are frequently added to functional foods designed to help control cholesterol levels. Multiple studies have shown that they can effectively decrease blood cholesterol levels, boost the immune system, and lessen the likelihood of some types of cancer. Phytates are recognised for their ability to impede mineral absorption, but they also possess potential hypocholesterolemic and anticancer effects. Multiple studies also demonstrate the abundance of unsaturated fatty acids, including linoleic and oleic acid, in sesame oil, which enhances its potential to promote good health. Sesame seeds, which contain abundant oil and protein, are a good source of protein hydrolysates. These hydrolysates have various applications, including their potential use as functional components in nutraceuticals and functional meals. This is due to their bioactive peptides, which include antioxidant and antihypertensive characteristics. These findings emphasise the importance of including sesame seeds in one's diet and the possibility of using them to create dietary supplements and functional food products. Promoting the widespread use of sesame among consumers and food manufacturers is essential. Further investigation is crucial to explore the advantageous health impacts of the phytochemicals found in sesame, to comprehensively comprehend their mechanisms, and to evaluate their therapeutic effectiveness in addressing different health issues.

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