Nutritional, Medicinal and Industrial Uses of Sesame (*Sesamum indicum* L.) Seeds - An Overview

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Summary

Sesame (*Sesamum indicum* L.) seeds have been grown in tropical regions throughout the world since prehistoric times. Sesame seed, a rich source of protein, is one of the first crops processed for oil production. Its non-culinary application includes its use as an ingredient in soap, cosmetics, lubricants and medicines. Sesame seeds also contain two unique substances: sesamin and sesamolin known to have a cholesterol-lowering effect in humans and to prevent high blood pressure. Both of these were also reported to increase the hepatic mitochondrial and the peroxisomal fatty acid oxidation rate in experimental animals. Cephalin, a phospholipid from sesame seed has been reported to possess hemostatic activity. The oil has wide medical and pharmaceutical applications. It is mildly laxative, emollient and demulcent. The seeds and fresh leaves may be used as a poultice. The antibacterial activity of seeds against *Staphylococcus* and *Streptococcus* as well as common skin fungi, such as athlete's foot fungus has also been well recognized. The oil is also known to maintain high density lipoprotein cholesterol (HDL) and lower low density lipoprotein cholesterol (LDL). Refined sesame oil is rich with antioxidant components like lignans allowing for greater shelf-life of foods plus improving their flavor and taste. In addition to its use as an antioxidant, sesame oil contains a large amount of linoleate in triglyceride form that selectively inhibit malignant melanoma growth. Off-late, the work has also been oriented towards the production of biodiesel from sesame seed oil as a viable alternative to the diesel fuel. The ethno-botanical and medicinal uses of this commercially important, nutritionally rich oilseed need to be explored for better utilization.

Key words

Sesamum indicum, health benefits, biofuel, nutraceutical

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Introduction

India is one of the major producers of many oilseed crops like groundnut, mustard, rapeseed, sesame seed, etc. Traditionally, Indians consume substantial quantity of edible oils mainly as a cooking medium. Among the oilseed crops, sesame has been cultivated for centuries, particularly in Asia and Africa, for its high content of edible oil and protein. It is commonly known as til (Hindi), hu ma (Chinese), sesame (French), goma (Japanese), gergelim (Portuguese) and ajonjoli (Spanish).

Sesame (*Sesamum indicum* L.) is one of the world's important oil crops. Its primary marketable products are the whole seeds, seed oil and meal. While sesame seeds have been grown in tropical regions throughout the world since prehistoric times, traditional myths hold that their origins go back even further. According to Assyrian legend, when the Gods met to create the world, they drank wine made from sesame seeds. These seeds were thought to have first originated in India and were mentioned in early Hindu legends. In these legends, tales are told in which sesame seeds represent a symbol of immortality. From India, sesame seeds were introduced throughout the Middle East, Africa and Asia. Sesame seeds were one of the first crops processed for oil as well as one of the earliest condiments (de Carvalho et al., 2001). These seeds were brought to the United States from Africa during the late 17th century. Currently, the largest commercial producers of sesame seeds include India, China and Mexico.

Sesame seeds add a nutty taste and a delicate, almost invisible crunch to many Asian dishes. They are also the main ingredients in '*tahini*' (sesame seed paste) and the wonderful Middle Eastern sweet called '*halvah*'. Sesame seeds may be the oldest condiment known to man dating back to as early as 1600 BC. They are highly valued for their oil which is exceptionally resistant to rancidity. "Open sesame", the famous phrase from the Arabian Nights, reflects the distinguishing feature of the sesame seed pod, which bursts open when it reaches maturity. The pods are tiny, flat ovals, measuring about 3 mm long. Seed color can vary, though they are usually beige or creamy white when husked. Sesame oil, other than its use as cooking medium, has certain industrial applications as it is used to make hair oil, hydrogenated oil and certain medicines (Salunkhe et al., 1991; Suja et al., 2004; Quasem et al., 2009). The present review highlights the food/nutritional, medicinal and pharmaceutical uses of sesame seeds.

Plant habitat and characteristics

Sesame, a member of Pedaliaceae family, is an annual shrub with white bell-shaped flowers with a hint of blue, red or yellow with or without branches (Martin and Leonard, 1967). It is grown for the production of seeds that are rich in oil content. It comes in a variety of colors, creamy-white to charcoal-black (Fig. 1). In general, the paler varieties of sesame seem to be more valued in West and Middle East, while the black varieties are prized in the Far East. Sesame is found in tropical, subtropical, and southern temperate areas of the world, particularly in India, China, South America and Africa. It has utmost economical importance and is primarily grown by small farmers in developing countries. The plant grows best in tropical climates, sandy, well drained soil with hot climate and moderate rainfall. It is propagated by seed sown in spring and takes about four months for the seeds to ripen fully. Sesame is a tropical herbaceous annual that grows 1-2 m tall. The plant has an unpleasant odor. The leaves vary from ovate to lanceolate and are hairy on both sides. The flowers are purple to whitish, resembling foxglove, followed by 3 cm capsules/fruits containing numerous seeds (McCormick, 2001). Each plant may bear 15-20 fruits, which contain 70-100 seeds. It matures in 80–180 days when the stems are cut and hung upside down for the ripe seeds to fall out to be collected on mats. Mechanical harvesting is also used, with total worldwide production of almost four billion pounds annually.

Figure 1. Sesame seeds

Products and cultivation of sesame

Sesame is grown for its seeds and the primary use of the sesame seed is as a source of oil for cooking. The young leaves may also be eaten in stews and the dried stems may be burnt as fuel with the ash used for local soap making but such uses are entirely subordinate to seed production (Table 1). The crop of sesame is commercialized in a number of forms. Most sesame seeds are processed directly into oil by the grower or within the producing region but are also sold in various stages of processing, for various uses, such as meal, paste, confections and bakery products (Salunkhe et al., 1991). Once harvested, the seeds are cleaned and dried to about 8% moisture and then stored before crushing. The seeds are typically crushed intact for the oil. This, however, yields a meal that is bitter and somewhat indigestible due to the presence of the fibrous husk. As such the meal is only useful as cattle feed. The quality of the meal can be improved by removing the seed coat, dehulling, before crushing (Morris, 2002). In India, where sesame meal is an important food, this process is a standard feature of an oil extraction plant. The meal is remarkable for its high protein content, which again is rich in methionine and tryptophan. Since these amino acids are missing from a number of other sources of vegetable protein, such as soy, sesame meal or flour can be added to recipes to give a better nutritional balance to health food products (Prakash, 1985; Quasem et al., 2009). Dehulling is also important for the production of the ground seed pastes such as *tahini* and for confectionery uses. The dehulled seeds are extensively used in the

Table 1. Products of sesame and its uses

Part used	Products	Description
Seeds	Confectionery and Biscuits	Fried seeds bound together with sugar syrup, whole seeds baked into Biscuits, popular in northern Europe either incorporated into breads or as decorative toppings, a paste of sesame seeds is used as an ingredient in eastern Mediterranean and Middle Eastern foods
Oil	Varied uses	To treat ulcers and burns, low grade oil is used in making soaps, paints, lubricants, and illuminants
Cake	Food and feed	Protein rich useful supplement, used in some Indian cooking

ground form where they comprise the base material of *tahini*, a paste used as an ingredient in Eastern Mediterranean and Middle Eastern foods. The seeds, hulled or dehulled, roasted or raw are now widely used in the European and North American bakery industry as a garnish on bread products. Dehulling has always been a major problem for the sesame industry and a variety of solutions have been sought. The most basic approach is largely manual: the skins are rubbed off the wetted seed by hand. Mechanical techniques now use a similar combination of wetting and rubbing.

Alkali treatment is also used to strip the hull and this tends to result in a whiter seed. The dehulling process, no matter what the method, always involves wetting the seed, which leads to considerable drying costs. As a result, the price of de-hulled seed is at least 30% above the natural type (Morris, 2002). Dehulling is said to reduce the storage ability of the seed, particularly in hot climates. Only a small proportion of the global sesame harvest enters International trade. For the most part, the oil is expressed locally and used locally for cooking or the seeds themselves are eaten, particularly after being fried. The oil is also useful in the industrial preparation of perfumery, cosmetics (skin conditioning agents and moisturizers, hair preparations, bath oils, hand products and make-up), pharmaceuticals (vehicle for drug delivery), insecticides, and paints and varnishes. However, all of these uses are comparatively insignificant in terms of the quantities used (Chakraborthy et al., 2008).

Table 2. Regional sesame production and trade

Region	Area harvested (milion ha)	Production (t)	Imports (t)	Export (t)
Asia	4.48	2,547	6901	342
Africa	2.80	953	60	422
South America	0.14	79	4	54
Central America	0.13	81	32	37
North America	0	0	54	3
Europe	0.40	2	146	25
Oceania	0	0	8	0
World	7.55	3,662	996	884

Adopted from FAO, 2005

Table 3. World's major sesame producers

Country	Area harvested (ha)	Production (t)
China	660	800
India	1850	750
Myanmar	1370	606
Sudan	1700	331
Uganda	210.8	121
Nigeria	165.1	83
Pakistan	135.2	75
Ethiopia	93.1	72
Bangladesh	80.1	55
Central African Republic	42.1	47
Thailand	63.9	46
Tanzania	104.8	45
Egypt	29.9	41
Guatemala	55.8	39
Chad	95.1	39
Paraguay	67.9	37

Adopted from FAO, 2005

Global production of sesame seed, as estimated by FAO (2005), is 3.15 mn tonnes per year having risen from 1.4 mn tonnes in the early 1960's. The largest producers are China and India, each with an annual harvest around 750,000 tonnes followed by Myanmar (425,000 tonnes) and Sudan (300,000 tonnes). These figures are only rough estimates of the situation as sesame is a smallholder crop and much of the harvest is consumed locally, without record of the internal trade and domestic processing. Global exports of sesame seeds are estimated to have reached 657,000 tonnes having risen from 427,000 tonnes in 1988. India is now the single largest exporter of sesame seed, with exports of some 180,000 tonnes, with Sudan in second exporting over 138,000 tonnes per year. In 1988 China was the principal exporter in the world (Dogan and Zeybek, 2009; Roy et al., 2009). Table 2 shows the sesame production and trade worldwide and Table 3 enlists the major sesame producers (FAO, 2005).

Nutritional profile of sesame seeds

Sesame oil is highly stable and rarely turns rancid in hot climates. It is rich in unsaturated fatty acids where the fatty acids composition is 14% saturated, 39% mono-unsaturated, and 46% poly-unsaturated fatty acids (Toma and Tabekhia, 1979). Carbohydrates in sesame seed are composed of 3.2% glucose, 2.6% fructose and 0.2% sucrose while the remaining quantity is dietary fibers. The nutrient composition of sesame seeds is enlisted in Table 4 and 5. Also, they have desirable physiological effects including antioxidant activity, blood pressure and serum lipid lowering potential as proven in experimental animals and humans (Sirato-Yasumoto et al., 2001). The major protein fraction (globulin) in sesame contains about 95% of 13S globulin and seems to be a simple, salt soluble, very susceptible to heat denaturation and similar in subunit structure to soybean 11S globulin with more hydrophobic properties. The last property limits the use of sesame proteins in certain food formulation, particularly in fluids and beverages, which indicates the need to modify the functionality of sesame proteins before it can be

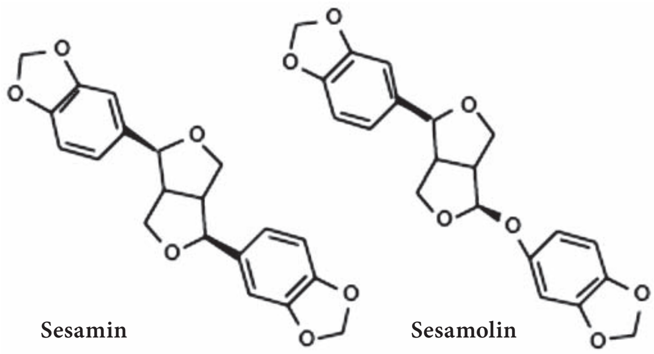

Figure 2.
Chemical structure of bioactive compounds from sesame

used in processing of imitated dairy products. Functional properties reflect the intrinsic physical attributes of the protein as influenced by interactions with food components and the processing treatments. Sesame is rich in sulfur containing amino acids and limited in lysine and contains significant amounts of oxalic (2.5%) and phytic (5%) acids (Kapadia et al., 2002). Because oxalic acid is present in the hulls, decortication can remove most of it. Decorticated sesame seeds have the following composition: 45-63% oil, 19-31% (averaging about 25%) proteins, about 14% carbohydrates and about 3% ash. Unlike many oilseeds, sesame meal is devoid of anti-tryptic compounds. Sesame oil is very rich in polyunsaturated fat used in margarine production and cooking oils. Sesame seeds contain two unique substances, sesamin and sesamolin (Fig. 2) whence during refinement the two phenolic antioxidants, sesamol and sesaminol, are formed. Both of these substances belong to lignans and have been shown to possess cholesterol-lowering effect in humans (Ogawa et al., 1995; Hirata et al. 1996) and to prevent high blood pressure and increase vitamin E supplies in animals (Yamashita et al., 1992; Kamal-Eldin et al., 1995). Sesame seeds are an excellent source of copper and calcium. It is also rich in phosphorous, iron, magnesium, manganese, zinc and vitamin B_1. A chlorinated red naphthoquinone pigment possessing antifungal activity, named chlorosesamone (2-chloro-5, 8-dihydroxy-3-3methyl-2-butenyl)-1, 4- naphthoquinone), has been reported from sesame root (Hasan et al., 2000). In another research, three anthraquinones, Anthrasesamones A, B and C, were isolated from the root of sesame (Furumoto et al., 2003). Anthrasesamone C is a rare chlorinated anthraquinone in higher plants. The total phytosterol content in sesame seeds is ~400 mg/100 g, which is higher as compared to English walnuts and Brazil nuts (113 mg/100g and 95 mg/100 g, respectively) (Phillips et al., 2005). Just a quarter-cup of sesame seeds supplies 74.0% of the daily value (DV) for copper, 31.6% of the DV for magnesium and 35.1% of the DV for calcium. This rich assortment of minerals translates into many medicinal properties.

Medicinal properties of sesame seeds and health issues

Sesame oil is mildly laxative, emollient and demulcent. The seeds and fresh leaves are also used as a poultice. The oil has wide medical and pharmaceutical application. Sesamin has been found to protect the liver from oxidative damage. The oil has been used for healing wounds for thousands of years. It is naturally antibacterial for common skin pathogens such as *Staphylococcus* and *Streptococcus* as well as common skin fungi such as athlete's foot fungus. It is anti-viral and anti-inflammatory. In recent experiments in Holland by Ayurvedic physicians, the oil has been used in the treatment of several chronic diseases including hepatitis, diabetes and migraines.

Analgesic activity of the ethanolic extract of *Sesamum indicum* has been tested by acetic acid-induced writhing model in mice by Nahar and Rokonuzzaman (2009). Acetic acid causes algesia by liberation of endogenous substances, which then excite the pain nerve endings (Raj, 1996). The study concluded that the extract produced a significant writhing inhibition at the doses of 500 mg/kg, which is comparable to the standard drug Ibuprofen at the dose of 50 mg/kg.

Sesame oil has been found to inhibit the growth of malignant melanoma *in vitro* and the proliferation of human colon cancer cells (Smith and Salerno, 1992). In the tissues beneath the skin, this oil neutralizes oxygen radicals. It penetrates into the skin quickly and enters the blood stream through the capillaries. Molecules of sesame seed oil maintain good cholesterol (high density lipoprotein, HDL) and lower bad cholesterol (low density lipoprotein, LDL) (Sirato-Yasumoto et al., 2001).

Table 4. Nutrient composition of sesame seeds

Nutrient	Quantity (%)
Moisture	04.0-05.3
Protein	18.3-25.4
Oil	43.3-44.3
Saturated Fatty Acids (% in oil)	14.0
Monounsaturated Fatty Acids (% in oil)	39.0
Polyunsaturated Fatty acids (% in oil)	46.0
Ash	05.2-06.2
Glucose	03.2
Fructose	02.6
Sucrose	0.2
Phytosterols	0.4

Table 5. Amino acid and fatty acid composition in sesame seeds

Nutrient	Quantity
Amino acid (g/16g N)	
Threonine	3.1-3.7
Valine	3.9-4.6
Cysteine + methionine	2.8-4.8
Isoleucine	4.0-4.2
Phenylalanine + tyrosine	6.4-9.6
Histidine	2.7
Tryptophan	1.3-1.5
Lysine	2.6-2.7
Argenine	12.0
Fatty acid (%)	
Palmitic acid (16:0)	11.7
Stearic acid (18:0)	05.2
Oleic acid (18:1)	41.4
Linoleic acid (18:2)	39.4
Linolenic acid (18:3)	00.4
Arachidic acid (20:0)	00.4
Behenic acid (22:0)	00.6

In an experiment at the Maharishi International College in Fairfield, Iowa, students rinsed their mouths with sesame oil, resulting in an 85% reduction in the bacteria which causes gingivitis. As nose drops, sniffed back into the sinuses, sesame oil has cured chronic sinusitis. As a throat gargle, it kills *Streptococcus* and other common cold bacteria. It helps sufferers of psoriasis and dry skin ailments. It is a useful natural UV protector.

Sesame oil is used after exposure to wind or sun to calm the burns. It nourishes and feeds the scalp to control dry scalp dandruff and to kill dandruff causing bacteria. It has been successfully used in the children's hair to kill lice infestations. It protects the skin from the effects of chlorine in swimming pool water. Used before and after radiation treatments, sesame oil helps neutralize the flood of oxygen radicals, which such treatment inevitably causes (Cooney et al., 2001). On the skin, oil soluble toxins are attracted to sesame oil molecules that can then be washed away with hot water and a mild soap. Internally, the oil molecules attract oil soluble toxins and carry them into the blood stream and then out of the body as waste. Used as a douche mixed with warm water, the oil controls vaginal yeast infections. Sesame oil absorbs quickly and penetrates through the tissues to the very marrow of the bone. It enters into the blood stream through the capillaries and circulates. The liver does not sweep sesame oil molecules from the blood, accepting those molecules as friendly (Chakraborthy et al., 2008). Sesame oil helps joints keep their flexibility. It keeps the skin supple and soft. It heals and protects areas of mild scrapes, cuts and abrasions. It helps tighten facial skin, particularly around the nose and controls the usual enlargement of pores as skin ages. Sesame oil helps control eruptions and neutralizes the poisons that develop both on the surface and in the pores. Used on baby skin, particularly in the area covered by a diaper, sesame seed oil protects the tender skin against rash caused by the acidity of body wastes. In the nose and ears, it protects against common skin pathogens. For school going children, who are in the presence of other children with colds and sniffles, the oil swabbed in the nose protects against air borne viruses and bacteria (Johnson et al., 2001; Morris, 2002).

Older men make zinc-rich foods such as sesame seeds as a regular part of their healthy way of eating in order to contribute towards their bone mineral density. Although osteoporosis is often thought to be a disease for which postmenopausal women are at highest risk, it is also a potential problem for older men. Almost 30% of hip fractures occur in men, and one in eight men over age 50 will have an osteoporotic fracture. A study of 396 men ranging in age from 45-92 found a clear correlation between low dietary intake of zinc, low blood levels of the trace mineral, and osteoporosis at the hip and spine (Hyun et al., 2004).

The beneficial effects of phytosterols are so dramatic that they have been extracted from soybean, corn and pine tree oil and added to processed foods, such as "butter"-replacement spreads, which are then touted as cholesterol-lowering foods (Takashi et al., 2003). It is not necessary to settle for an imitation "butter" when sesame seeds are a naturally rich source of phytosterols and cardio-protective fiber, minerals and healthy fats as well. Sesame seeds have the highest total phytosterol content (400-413 mg/100 g), and English walnuts and Brazil nuts the lowest (113 mg/100 g and 95 mg/100 g, respectively). Phytosterols are believed to reduce blood levels of cholesterol, enhance the immune response and decrease risk of certain cancers.

Many health benefits of sesame may be attributed to its lignan especially sesamin (Jeng and Hou, 2005). Sesamin binds to and activates a receptor in the body called Peroxisome Proliferator-Activator Receptor Alpha (PPARalpha). PPARalpha is highly expressed in muscle, liver, kidneys and heart and is involved in the regulation of lipid metabolism, specifically the transcription of genes involved in the â-oxidation of fatty acids and lipogenesis. Activation of PPARalpha increases gene expression of the fatty acid oxidation enzymes and decreases gene expression of lipogenic enzymes. In other words, sesamin increases the fat burning process and decreases the storage of fat in the body (Penalvo et al., 2006). This compound is also effective in preventing an increase in the serum triacylglycerol level following ethanol consumption in the rat (Akimoto, 1993).

Fat is mainly oxidized in mitochondria and peroxisomes of skeletal muscle cells and the liver. Activation of PPARalpha by sesamin increases fat oxidation in these organelles by increasing the expression levels of enzymes involved in â-oxidation of fatty acids (Sirato-Yasumoto et al., 2001). As its name suggests, Peroxisome Proliferator-Activator Receptor causes the creation of additional peroxisomes which in turn lead to more fat oxidation. In addition, sesamin increases the expression of the mitochondrial enzyme carnitine palmitoyl transferase (CPT) that is rate limiting enzyme in â-oxidation of fatty acids. It carries fatty acids across the membrane into the mitochondria by binding to them. Increased expression of CPT allows more fatty acids to be transported into the mitochondria where they can be oxidized. PPARalpha activation also increases uncoupling proteins (UCPs) which decrease the efficiency of mitochondria. As a result of that amount of energy needed to produce the same amount of energy increase. Wasting calories would lead to a greater caloric expenditure and therefore fat loss. Through increasing the expression of enzymes involved in â-oxidation and increasing UCPs, PPARalpha activation by sesamin increases the rate and capacity of cells to burn fat (Sawada et al., 2001; Kushiro et al., 2002).

Apart from increasing the fat oxidation, sesamin has also been proven to decrease lipogenesis by decreasing lipogenic enzymes of liver. Sesamin has been shown to decrease the lipogenic gene expression of sterol regulatory element binding protein-1 (SREBP-1), acetyl-CoA carboxylase and fatty acid synthase, that means less fat is esterified in the liver and therefore less fat synthesis (Ide et al., 2003). The effect of sesamin on enzymes involved in catabolism and anabolism of fatty acids has been summarized in Table 6.

Ketogenesis occurs when fatty acid oxidation is increased to a point where the liver cannot metabolize all the fatty acids for energy. Excess acetyl-CoA (generated through catabolism of fat, glucose and amino acid) is converted to ketone bodies in the liver and released into the blood-stream for use by other tissues especially the brain. Ketogenesis is very important process during low carbohydrate diets because the brain uses only glucose as fuel. When glucose is low, the brain will turn towards ketone bodies for its energy. Sesamin has been shown to increase the production of ketone bodies.

Table 6. Effects of sesamin on enzymes involved in catabolism and anabolism of fatty acids

Enzymes	Nature of activity
Catabolism of fatty acids (â-oxidation)	
Carnitine palmitoyltransferase	Activation
Acyl-CoA oxidase	Activation
3-hydroxyacyl-CoA dehydrogenase	Activation
3-ketoacyl-CoA thiolase	Activation
2,4-dienoyl-CoA reductase	Activation
$Ä^3$, $Ä^2$ - enoyl-CoA isomerase	Activation
Anabolism of fatty acids (lipogenic activity)	
Fatty acid synthase	Inhibition
ATP-citrate lyase	Inhibition
L-Pyruvate kinase	Inhibition
Glucose-6-phosphate dehydrogenase	Inhibition

Increased production of ketone has protein-sparing effect as less amino acids are needed to create ketones eventually sparing muscle mass while dieting (Fukuda, 1998 and 1999). Besides these metabolic regulations, sesamin supplementation provides many health benefits also. Sesamin has been shown to be antihypertensive and an antioxidant. It increases the recycling of vitamin E, improves liver functions and provides protection against alcohol induced oxidative stress. Sesamin decreases cholesterol levels while increasing HDL levels. Anti-inflammatory activity of the sesamin has also been reported (Ide et al., 2003).

Several allergic reactions to sesame are becoming increasingly frequent, especially among young children and can sometimes results in anaphylaxis. Because sesame is often a 'masked allergen' especially in restaurant meals, the risk of severe reaction is significant. People allergic to sesame characteristically avoid sesame seeds and oils, but accidental exposures do occur often. Sesame oil is one of the few vegetable oils being used unrefined in food applications. As a result it is hazardous to those allergic to the seed proteins. Just 3 ml of sesame oil is enough to induce an allergic reaction. Non-IgE-mediated anaphylaxis to sesame is reported by Stern and Wuthrich (1998). A person with no personal or familial history of allergic or atopic disorders got recurrent anaphylactic reactions after ingestion of sesame and no evidence of an IgE-mediated mechanism was found.

Food and industrial uses of sesame seeds

There are many foods with sesame as an ingredient. The food uses of sesame have been enlisted in Table 7. Europeans use it as a substitute for olive oil. Sesame oil is an excellent salad oil and is used by the Japanese for cooking fish. Aqua hulled sesame seeds undergo a special hulling process which produces a clear white seed. These seeds are washed, dried and used on hamburger buns. This special process makes the seeds to stick to the bun while maintaining a white color after baking. Nearly 35% of the imported crop from Mexico is purchased by McDonalds to prepare sesame seed buns. The seeds are also used on bread and then eaten in Sicily. In Greece, seeds are used in cakes, while in Togo and Africa the seeds are a main soup ingredient. Mechanically hulled sesame seed enriches bakery and candles and is also the base for the creamy, sweet wholesome tahini. Sesame flour has high protein content, high levels of methionine and tryptophan and 10-12% sesame oil. Sesame seeds contain three times more calcium than a comparable measure of milk.

Refined sesame oil has antioxidant properties allowing for its greater shelf-life for use in the food industry. Roasted sesame oil resists rancidity due to the antioxidants formed during seed roasting and the particular roasted sesame flavor improves taste of fried products. African countries use the seeds as spice, seed oil, frying vegetables and meat, eaten raw or fried and used in confections such as candy and baking. Other products sold in US grocery and health stores with sesame seed as an ingredient include sesame crackers, honey puffed kasha, sesame blue chips, unhulled sesame seed and sesame seed candy. Many recipes contain sesame seeds as an ingredient such as sesame seed sprouts, sesame spread, tanferine and sesame, sesame seed cookies, hummus, sesame seed bagels, sesame granola, sesame broccoli rice, sesame mustard sauce, ginger sesame chicken, sesame pastry, sesame seed sauce and sesame green beans. Sesame meal is excellent feed for poultry and livestock.

Table 7. Culinary uses of sesame seeds

Food	Country
Sesame cakes, wine and brandy	Biblical Babylon
Bread stick, cracker, salad and cooking oil	Worldwide
Raw, powdered and roasted seed	India
Substitute for olive oil	Europe
Bread	Sicily
Cakes	Greece
Soup, spice and seed oil	Africa
Salad and fish oil	Japan
Confectionery	China
Sesame seed buns, chips	United States

Several industrial uses have been compiled for sesame (Table 8). African people use sesame to prepare perfumes and cologne has been made from sesame flowers. Myristic acid from sesame oil is used as an ingredient in cosmetics. Sesamin has bactericide and insecticide activities plus it also acts as an antioxidant that can inhibit the absorption of cholesterol and the production of cholesterol in the liver. Sesamolin also has insecticidal properties and is used as a synergist for pyrethrum insecticides (Morris, 2002). Sesame oil is used as a solvent, oleaginous vehicle for drugs, skin softener and used in the manufacture of margarine and soap. Chlorosesamone, obtained from roots of sesame, has antifungal activity (Begum et al., 2000).

Today, energy demand is increasing while world fossil energy resources are increasingly depleted. The vegetable oil is potentially able to replace mineral oil in future. In the early days of diesel engines, vegetable oils were tested (their original compositions unchanged) as a possible motor fuel but the idea never took hold owing to incompatibility problems such as deterioration of the oil with time, high viscosity, and fouling of the engine. Recently the biodiesel route has been reactivated for a number of reasons like: (a) it has been found that vegetable oil can be transformed via esterification into a product that is much more adequate as a diesel fuel than the original oil itself; (b) a wide variety of vegetable oils can be used as raw material for transesterification; this has led to the idea that biodiesel production could be a way

Table 8. Industrial, nutraceutical and pharmaceutical uses of sesame seeds

Uses	Phytochemicals of sesame
Industrial	
Antifungal	Chlorosesamone
Bactericidal and insecticidal (synergist for pyrethrum insecticides)	Sesamin and sesamolin
Cosmetics and soap	Myristic acid
Nutrceutical	
Antioxidant and Inhibiting cholesterol production	Lecithin and lignans
Reducing hepatic steatosis	Lecithin
Cardioprotective	Fiber and sesame oil
Enhanced Hepatic (mitochondrial and peroxisomal) fatty acid oxidation	Sesamin and sesamolin
Skin softener	Sesame oil
Hemostatic acativity	Cephalin
Decreased dermatitis	Lecithin
Pharmaceutical	
Treatment of nasal mucosa dryness, blurred vision, dizziness, anxiety, head ache and insomnia	Sesame oil
Oleaginous vehicle for drugs and laxative	Sesame oil
Hypoglycaemic	Flavonoids
Inhibition of malignant melanoma	Linoleate in triglyceride form
Cancer preventive	Myristic acid

Table 9. Yields of biodiesel from common crops

Source	Biodiesel yield (barrels per year per square mile)
Cotton	382
Soybean	542
Sesame	807
Safflower	905
Tung oil tree	1091
Sunflower	1113
Peanuts	1233
Rapseed	1385
Olives	1407
Jojoba	2116
Jatropha	2204
Coconut	3131
Oil palm	6927

to extend the role of agriculture (more jobs created and reduced financial burden for petroleum imports in developing countries).

Biodiesel is produced through transesterification, a process in which organically derived oils are combined with alcohol (ethanol or methanol) in the presence of a catalyst to form ethyl or methyl ester (Zhang et al., 2003). Biodiesel can be blended with diesel fuel or used 100% directly in an engine. Biodiesel can be derived from agricultural crops or sources such as palm oil, coconut, soybean, peanut, castor, sesame, rape seed oils, waste vegetable oils, or microalgae oils. Biodiesel is physically similar to petroleum diesel but has the merit of being derived from natural, renewable sources. A blend of 20% biodiesel with 80% petroleum (B20) can be used in all diesel-burning equipment, including compression-ignition engines and oil heat boilers, without modifications.

Very recently, Ahmad et al. (2010) has prepared biodiesel from sesame oil by its transesterification with methanol in the presence of NaOH as catalyst and maximum yield of 92% was achieved at 60°C. The fuel properties of sesame biodiesel (100%) such as specific gravity @ 60/60°F was 0.887, flash point 110°C, pour point -18°C, kinematic viscosity @ 40°C 5.77, cetane number 53, and sulfur contents 0.0083. Engine fueling with sesame biodiesel and its blends (B20%, B10%, and B5%) in terms of fuel consumption, efficiency, and power outputs appeared to have equal performance compared to mineral diesel. There is no obvious change in engine power output even at 100% biodiesel. It was also observed that the environmental performance of sesame biodiesel was superior to that of mineral diesel. This study supports the production of biodiesel from sesame seed oil as a viable alternative to the diesel fuel. Sesame and other oil crops are a promising new energy supply sources. The potential of some plant oils that can be used to produce biodiesel has been presented in Table 9.

Nutraceuticals and pharmaceutical uses of sesame

Many nutraceutical uses of sesame have been summarized in Table 8. Using decorticated sesame seeds, sesame milk has been prepared. The newly developed products offer a family of dairy analogues, which can be declared as health foods that can be used as dairy substitutes or extenders (Jihad et al., 2009). Sesame lignans have antioxidant and health promoting activities (Nakai et al., 2003). Feeding sesame lignans to rats have shown to reduce Fe^{2+} induced oxidative stress. Compared with those fed with groundnut oil, sesame oil fed rats had lower levels of hepatic thiobarbituric acid reactive substances, serum glutamate oxaloacetate transaminase activities and serum glutamate pyruvate transaminase activities. The level of these enzymes indicates protection against Fe^{2+} induced oxidative stress (Hemalatha et al., 2004; Hu et al., 2004). The antioxidant and free radical scavenging activities of sesamol using a nanosecond pulse radiolysis technique have been reported by several scientists (Unnikrishnan et al., 2005; Juan et al., 2005). A good free radical scavenging potency of antioxidants from sesame cake extract has also been reported (Shyu and Hwang, 2002; Suja et al., 2004). Antifungal activity toward *Cladosporium fulvum* of Chlorosesamone, hydroxysesamone and 2,3-epoxysesamone was established in a study by Hasan et al. (2001). Sesame seed consumption increases plasma γ-tocopherol and enhances vitamin E activity, which is reported to prevent cancer and heart diseases (Cooney et al., 2001). Sesamin is thermostable and remains at 90% of the original level after roasting (Abe et al., 2001) indicating its viability for food and non-food applications. The total phenolic content (TPC), Trolox equivalent antioxidant capacity assay, free radical scavenging capacity, inhibition of low density lipoprotein (LDL) cholesterol and metal chelating capacity of extracts of whole black and whole white sesame seeds and their hull fractions in 80% aqueous ethanol were investigated. Results demonstrated considerable antioxidant activity of sesame products tested especially black sesame hulls (Shahidi et al., 2006). Cephalin from sesame seed has hemostatic activity. Historically, fiber is used as an antidiabetic, antitumor, antiulcer, cancer preventive, cardioprotective and laxative. Fiber ranges from 27,100 to 67,000 ppm in the seed with up to 166,000 ppm in the leaf. Lecithin of sesame seeds, ranging from 58 to 395 ppm, possesses antioxidant and hepatoprotective activity. It is also likely effective for reducing hepatic steatosis in long term parenteral nutrition patients and a successful treatment for dermatitis and dry skin (Jellin et al., 2000). The antihypertensive and protective effect of sesamin against renal hypertension and cardiovascular hypertrophy is also reported (Kita et al., 1995; Matsumura et al., 1995 and 2000). Flavonoids from *S. indicum* were effective in raising the hemoglobin levels in rats (Anila and Vijayalakshmi, 2000). The effects of ethanolic extract of sesame coat on oxidation of LDL and production of nitric oxide in macrophages were investigated. The results showed that extract in the range of 0.01–0.8 mg/ml markedly inhibited copper-induced LDL oxidation and H_2O_2 induced cell damage that implies that ethanolic extract could exhibit a protective action on biomolecules and generation of inflammatory mediators *in vitro* (Wang et al., 2007).

Several pharmaceuticals uses have also been identified from sesame (Table 8). Myristic acid has cancer preventive capability and is found in sesame seed ranging from 328 to 1,728 ppm. Sesame oil is used as a solvent for intramuscular and has nutritive, demulcent, and emollient properties and has been used as a laxative. Sesame flower extract possess tumor inhibiting effect. The effect of alcohol extract from *Sesamum indicum* flower on tumor growth in tumorigenic mouse and on weight of immune organs showed inhibiting effect on tumor growth and had not distinct effect on weight of thymus and spleen in mice (Chakraborthy et al., 2008). A study conducted on rat liver denotes that sesame profoundly affects hepatic fatty acid oxidation and serum triacylglycerol levels (Sirato-Yasumoto et al., 2001). Therefore, consumption of sesame rich in lignans results in physiological activity to alter lipid metabolism in a potentially beneficial manner. In another study it has been suggested by the researchers that hot-water extract of defatted sesame delayed glucose absorption which had a reductive effect on the plasma glucose concentration of genetically diabetic mice (Takeuchi et al., 2001).

Sesamin, one of the major components of lignan of sesame seeds, has received a great deal of interest regarding its potential as a hypocholesterolemic agent, especially after the positive results reported by Hirata et al. (1996) in humans. A clear hypocholesterolemic effect elicited by sesamin (alone or in combination with vitamin E) was reported in studies conducted in rats (Sugano et al., 1990; Hirose et al., 1991; Nakabayashi et al., 1995; Kamal-Eldin et al., 2000) or in cultured rat cells (Umeda-sawada et al., 1994). The oil was used during the 4th century by the Chinese as a remedy for toothaches and gum diseases. Other uses of sesame include the treatment of blurred vision, dizziness, and headaches. The Indians have used sesame oil as an antibacterial mouthwash, to relieve anxiety and insomnia. A recent clinical trial proved that sesame oil was significantly more effective for treating nasal mucosa dryness due to dry winter climate than isotonic NaCl solution (Johnson et al., 2001). In addition, sesame oil contains large amounts of linoleate in triglyceride form that selectively inhibited malignant melanoma growth (Smith and Salerno, 2001). The leaves are rich in a gummy matter and when mixed with water form rich bland mucilage that is used in the treatment of infant cholera, diarrhoea, dysentery, cataract and bladder troubles. If taken internally it prevents hair loss and graying, convalescence, chronic dry constipation, dental caries, osteoporosis, stiff joints, and dry cough. It has marked ability to increase milk production in nursing mothers (Chevallier, 1996). Externally it is used to treat hemorrhoids and ulcers (Chopra et al., 1986). The seed are rich in high calories so overweight peoples should use them very cautiously (Uzun et. al, 2007). The oil is laxative and also promotes menstruation. Table 10 provides additional ethno-botanical uses of sesame.

Table 10. Ethnobotanical use of sesame seeds

Use	Country
Cancer	Germany
Cold	Dominican Republic
Colic	Haiti
Constipation, impotency, laxative, malaria, cold, cancer, diarrhea, sore, venereal and wart	China
Cough	Venezuela
Dysentery	Turkey
Laxative	Mexico
Tumor	India

Conclusion and future scope

Sesame plant being easy to grow is well suited for cultivation in crop rotation. This plant is one of the plants where the oil content in seed is high. This produce is not only in use for culinary purposes, but also in various applications such as industrial, engineering, and pharmaceutical. The ethno-botanical and medicinal uses of this commercially important, nutritionally rich oilseed need to be explored for better utilization. Sesamin possess the capacity to increase the fat burning process and decrease the storage of fat in the body by modifying the gene expression of the fatty acid oxidation enzymes. It has potential application in the development of nutraceuticals for weight reduction. Off-late, the work has also been oriented towards the production of biodiesel from sesame seed oil as a viable alternative to the diesel fuel.

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