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Til (*Sesamum indicum* L.) - An Underexploited but Promising Oilseed with Multifarious Applications: A Review

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ABSTRACT

Sesame (*Sesamum indicum* L.), called as 'the queen of oilseeds', is an annual flowering plant of Pedaliaceae family. Sesame has one of the highest oil contents of any seed, which is known for properties of good health consists of a plethora of nutrients viz., proteins, carbohydrates, antioxidants, lignans, essential amino and fatty acids, and other micronutrients. With a rich and nutty flavour, it is a common ingredient in cuisines across the world. India is the largest producer of sesame. Benefits of this enigmatic crop include properties of anticancer, antioxidative, anti-immuno regulation and anti-hypersensitivity. Covering wide agro ecological regions of the world, different varieties of sesame seeds are available. They are seen growing in different parts of the world, where India being one of the major producers. The oil from this seed can be extracted by simple processes of solvent extraction and expelling or advanced supercritical extraction. Sesame which is considered as an extremely beneficial medicine has inherent power to cure many diseases. Sesame has a ray of health benefits in lowering cholesterol, controlling blood pressure, dermatological disease management and many more areas. Even in the industries, sesame oil can be utilized as biodiesel and other uses. Despite having tremendous potential, sesame remain under-estimated due to certain constraints which must be properly identified and solved for better exploitation of this wonderful oil seed. This review gives an overall impact about sesame, properties and its role in various sections.

Keywords: *Sesamum indicum*, edible oil, antioxidants, nutraceutical, health benefits

Sesame or Gingelly (*Sesamum indicum* L., 2n=26) is commonly known as 'Til' (Bengali, Hindi, Punjabi, Assamese, Marathi), 'Tal' (Gujarati), 'Nuvvulu/ Manchi nuvvulu' (Telugu), 'Ellu' (Tamil, Malayalam, Kannada), 'Tila/ Pitratarpana' (Sanskrit) and 'Rasi' (Odia) in different parts of India. Belonging to the Pedaliaceae family, it is the most ancient indigenous oil seed known and used by man. In the world, India ranks first in the area and production of sesame seeds, and it is grown in different seasons covering practically all agro-ecological zones. This herbaceous annual plant is thought to be originated in Africa. Sesame is called 'Queen of Oilseeds' due to its high quality polyunsaturated stable fatty acids those restrain oxidative rancidity. It is also stable due to the natural antioxidants such as sesamin, sesamol, sesamolin and sesamolinol that reduce the rate of oxidation. It is widely preferred for its quality of high drought tolerance and has been extensively used for thousands of years as a seed of worldwide significance for edible oil, paste, cake, confectionary purposes and flour due to its highly stable oil contents, nutritious protein (rich in methionine, tryptophan and valine) and savoury nutty roasted flavour (Anilakumar *et al*. 2010; Prakash and Naik, 2014; Pathak *et al*. 2017).

About 70% of the world's sesame seed is processed into oil and meal. Total annual consumption is about 65% for oil extraction and 35% for food. The food segment includes about 42% roasted sesame, 12% ground sesame, 36% washed sesame, and 10% roasted sesame seed with salt. There mainly two distinct types of sesame seeds are popular, viz. white and black though a few other varieties from red to rose coloured or from brown to grey are also available. White sesame seed is imported from Mexico, Guatemala and El Salvador, while black one comes from China and Thailand. Sesame oil is also referred to as *benne oil* and is a pale yellow, oily liquid and almost odourless with a bland taste. The oil consists of glycerides with about 43% oleic and linoleic each, 9% palmitic, and 4% stearic fatty acids. The present review highlights sesame seed/ oil composition and their multipurpose uses in food/nutritional, medicinal, pharmaceutical and other industries.

Plant morphology and habitat

Sesame is an annual shrub of Pedaliaceae family having 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 colours, creamy-white to charcoal-black. 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, 1-2 m tall, having an unpleasant odour, grows best in tropical climates, sandy, well-drained soil with hot climate and moderate rainfall. It is propagated by seeds sown in spring and it takes about four months for the seeds to ripen fully. The leaves vary from ovate to lanceolate and are hairy on both sides. The flowers are purple to whitish, resembling foxglove, followed by3 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.

Taxonomic hierarchy of *Sesamum indicum* Linn.

Kingdom	Plantae
Subkingdom	Viridiplantae (Green plants)
Superdivision	Embryophyta
Division	Tracheophyta (Vascular plants)
Subdivision	Spermatophytina (Seed plants)
Class	Magnoliopsida (Dicotyledons)
Superorder	Asteranae
Order	Lamiales
Family	Pedaliaceae
Genus	Sesamum
Species	indicum

Cultivation under Indian condition

The crop is grown in almost all parts of the country. India is the largest producer of sesame in the world. It also ranks first in the world in terms of sesame-growing area (about 1.95 million hectares) accounting for 25 % of the total sesame cultivated area in the world with a total production of 0.87 million tonnes and productivity of 413 kg/ ha (NMOOP, 2018). More than 85% production of til comes from West Bengal, Madhya Pradesh, Rajasthan, Uttar Pradesh, Gujarat, Andhra Pradesh and Telangana. Necessary conditions for sesame cultivation are mentioned in Table 1.

Sesame Products

Sesame is grown for its seeds and the primary use of these same 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 2). 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

Table 1: Necessary conditions for cultivation of til

Parameters	Indian scenario			
Season	*Kharif* in arid and semi-arid tropics and *rabi*/summer in cooler areas			
Climate	Semi-arid climate of Western India, Central, Eastern and Southern part of India including lower Himalayas			
Varieties	For upland cultivation, varieties with long duration of 100-110 days and for low land, varieties with duration of 80-99 days are preferred			
	Guj. Til-1, TKG-21, RT-46, AKT-64, Sekhar, Nirmala, Shubhra	RT-54, Smarak	Rama, Savitri, Varaha, Gautama, Chandana	Guj. Til-10, PKDS-8, Co-1, Paiyur-1, VRI-1, Prachi, Amrit, DS-1
	(White seeded)	(Light brown/ golden yellow seeded)	(Brown seeded)	(Dark brown/ black seeded)
Soil	Well drained light to medium textured soils having pH 5.5-8.0			
Seed rate	5 kg/ha			
Seed treatment	For prevention of seed borne diseases, seeds are treated with Bavistin @ 2 g/kg seed. Wherever bacterial leaf spot disease is a problem, seeds need to be soaked for 30 minutes in 0.025% solution of Agrimycin-100 prior to seeding.			
Sowing spacing	30-45 cm × 10-15 cm (most common); 22.5 cm × 22.5 cm			

Table 2: Products of sesame and its uses

Parts 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

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 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. 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).

Sesame seeds

Flavourful, crunchy sesame seeds are widely considered as healthy foods. Carbohydrates in sesame seed are composed of 3.2% glucose, 2.6% fructose and 0.2% sucrose while the remaining quantity is dietary fibres. The seeds are especially

rich in mono-unsaturated fatty acid, oleic acid, which comprises of up to 50% of fatty acids in them. Oleic acid helps lower LDL or 'bad cholesterol' and increases HDL or 'good cholesterol' in the blood. The seeds are also very valuable sources of dietary protein with sulphur containing amino acids that are essential for growth, especially in children. Just 100 g of seeds provide about 18 g of protein (Table 3).

Table 3: Nutrient composition of sesame seeds

Sesame seeds (*Sesamum indicum*), whole, dried, Nutritional value per 100 g (***Source:*** USDA National Nutrient date base)		
Proximate Principles	**Nutrient Value**	**RDA***
Energy	573 Kcal	29%
Carbohydrates	23.45 g	18%
Glucose	3.20 g	—
Fructose	2.60 g	—
Sucrose	0.20 g	—
Dietary Fiber	11.80 g	31%
Protein	17.73 g	32%
Fat	49.67 g	166%
Saturated Fatty Acids (% in oil)	14.00 g	—
Monounsaturated Fatty Acids (% in oil)	39.00 g	—
Polyunsaturated Fatty acids (% in oil)	46.00 g	—
Cholesterol	0 mg	0%
Vitamins		
Folates	97 mcg	25%
Niacin	4.515 mg	28%
Pantothenic acid	0.050 mg	1%
Pyridoxine	0.790 mg	61%
Riboflavin	0.247 mg	19%
Thiamin	0.791 mg	66%
Vitamin A	9 IU	<1%
Vitamin C	0	0%
Vitamin E	0.25 mg	2%
Electrolytes		
Sodium	11 mg	1%
Potassium	468 mg	10%
Minerals		
Calcium	975 mg	98%
Copper	4.082 mg	453%
Iron	14.55 mg	182%
Magnesium	351 mg	88%
Manganese	2.460 mg	107%
Phosphorus	629 mg	90%
Selenium	34.4 mcg	62.5%
Zinc	7.75 mg	70%
Phytonutrients		
β-carotene	5 mcg	—

**RDA = Recommended Dietary Allowance based on 2000 Kcal diet/day.*

Sesame seeds contain many health benefiting compounds such as sesamin, sesamol (3,4-methylene-dioxyphenol), sesaminol, furyl-methanthiol, guajacol (2-methoxyphenol), phenylethanthiol, furaneol, vinylguacol, and decadienal (Fig. 1).

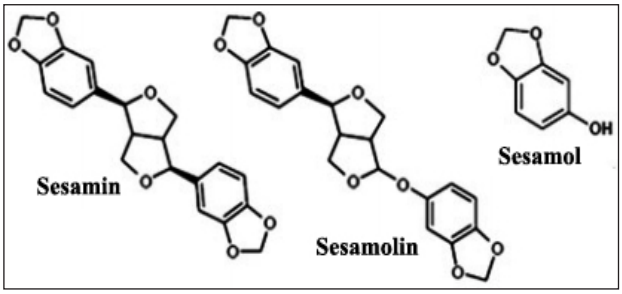

Fig. 1: Chemical structure of bioactive compounds obtained from sesame

Sesamol and *sesaminol* are phenolic anti-oxidants. Together, these compounds help stave off harmful free radicals from the human body. Sesame is among the seeds rich in quality vitamins, and minerals. They are very good sources of B-complex vitamins such as niacin, folic acid, thiamine, pyridoxine and riboflavin.100 g of sesame contains 97 μg of folic acid. Folic acid is essential for DNA synthesis. When given to expectant mothers, it may prevent neural tube defects in the new-borns. The seeds are incredibly rich sources of many essential minerals. Calcium, iron, manganese, zinc, magnesium, selenium, and copper are especially concentrated in sesame seeds. Many of these minerals have a vital role in bone mineralization, red blood cell production, enzyme synthesis, hormone production, as well as regulation of cardiac and skeletal muscle activities. Sesame seeds are also the store house of various amino and fatty acids (Table 4) that are considered vital to us.

Extraction of oil from sesame seeds

The industrialization of sesame oil is very important for food, cosmetic and pharmaceutical purposes. Final product quality and environmental aspects are the desired considerations for an adequate

extraction process. Several processes for sesame oil production include mechanical milling followed by solvent extraction using organic liquids and solvent recuperation by distillation.

Table 4: Amino acids and fatty acids composition in sesame seeds

Amino acids and fatty acids profile of sesame seeds **Source:** Indian Council of Medical Research (1991)	
Amino Acids	**Composition**
Contents	**Amount (mg/ g N)**
Arginine	750
Histidine	170
Lysine	170
Tryptophan	080
Phenylalanine	370
Tyrosine	230
Methionine	180
Cystine	120
Threonine	230
Leucine	500
Isoleucine	250
Valine	290
Fatty Acids Composition	
Contents	**Amounts (%)**
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

Super critical extraction is an alternative process which uses pressurized fluids, minimising the use of liquid organic solvents (Corso *et al*. 2010). Sesame seed gives about 45-50% by weight of highly stable oil after extraction. Lignan content contributes to 32.23% in the extract by solvent extraction. Whereas in case of supercritical extraction, the lignan content is found to be 1.5-3.5%. The main lignans account for about 10% of unsaponifiable matter in sesame oil (Reshma *et al*. 2010). By products obtained from sesame are rich sources of dietary fibres (Elleuch *et al*. 2007).

Expelling: It is the simplest method of oil extraction by crushing, without the intervention of any chemicals. The desired quality of seeds for crushing is got by naturally drying, cleaning and grading the seeds. Cleaning and grading removes physical impurities. Clean seeds are later crushed in expellers and rotary machines by adding palm jaggery. Raw sesame oil obtained is stored in tanks. The sesame cake is packed and sold in the market as animal feed. Using filter press, raw sesame oil is filtered for fine particles. The oilcake sludge from the filter press is added along with the sesame cake and crushed.

Solvent extraction: Distribution of the solute between two immiscible liquid phases which are in contact with each other, due to the density difference is the principle behind solvent extraction (Kamal-Eldin and Appelqvist, 1995). In the process, unroasted seeds are first extracted by simple mechanical pressing followed by solvent extraction. Solvent extraction of sesame seeds with polar solvents and effective seed crushing generates more stable oil than nonpolar solvents and pressed seeds. Compared to n-Hexane, Heptaneisopropanol proves to yield more stable oil. Oxidative stability of the oil is influenced by the extraction method. Solvent extraction can yield approximately 52-55 % oil from the seeds (Alam, 2007). The disadvantages related with solvent extraction are complex extraction process, high cost and not suited for small scale processing. Management of organic solvents is one of the major problems (Doker *et al*. 2009; Morris, 2002; Penalvo *et al*. 2006).

Supercritical extraction: The principle behind supercritical extraction is that, near the critical point of the solvent, its properties change rapidly with slight variations in the pressure involved (Nakabayashi *et al*. 1995). Supercritical extraction of sesame is usually carried out using carbon dioxide and propane as solvents. Extraction of oil using carbon dioxide includes 313 to 333 K temperature range, pressure variation of 19 to 25 MPa and constant flow rate of $3cm^3$/min and that using propane includes 303 to 333K range of temperature, pressures from 8 to 12 MPa and a constant flow rate of $0.8cm^3$/min (Reshma *et al*. 2010). As the pressure and the supercritical CO_2 flow rate is increased, the extraction yield can be improved and the time of the extraction process can also be reduced (Hamada *et al*. 2009). The sesame seeds used in the process are required to be dried and milled with specified particle diameter (Reshma *et al*. 2010). This process is more environmental friendly and the analytes can

be extracted faster (Nakabayashi *et al*. 1995). The disadvantage in this process includes the toxicity of the solvent and difficulty in the understanding the phase behaviour between the solvent and oil (Reshma *et al*. 2010).

Multifaceted benefits

About 70 % of the World's sesame seed is processed into oil and meal. Total annual consumption has been estimated to be about 65% for oil extraction and 35% for food. The meal left after oil extraction contains 35-50% proteins which make a rich feed for poultry and livestock. Several industrial uses have been identified in sesame. African people have used sesame to prepare perfumes and cologne that have been made from sesame flowers. Sesamin has bactericidal and insecticidal activities and it also acts as an antioxidant which can inhibit the absorptionof cholesterol and the production of cholesterol in the liver. Sesamolin also has insecticidal properties and is used as a synergist for pyrethrum insecticides(Simon *et al*. 1984). Sesame seeds are described as the 'seeds of immortality' perhaps for its resistance to oxidation and rancidity even when stored at ambient air temperature (Bedigianand Harlan, 1986). Oil is used for both dietary and therapeutic applications. List of different til products that are used worldwide are mentioned in Table 5.

Table 5: Culinary uses of sesame seeds in different countries

Food	Country
Breas stick, cracker, salad and cooking oil	World wide
Sesame cakes, wine and brandy	Babylon
Raw, powdered and roasted seeds	India
Confectionary	China
Salad and fish oil	Japan
Substitute for olive oil	Europe
Cakes	Greece
Soup, spice and seed oil	Africa
Sesame seed buns, chips	USA
Bread	Sicily

Food, Feed and Nutritional Applications

Sesame seeds feature delicate nutty flavour. Their flavour indeed becomes more pronounced once they are gently toasted under low flame heat for a few minutes. Aqua hulled, double washed and dried sesame seeds are used on hamburger buns. Roasted natural sesame seeds are used in the preparation of bread, breadsticks, cookies, chocolates and ice creams. The seeds are ground with olive or any other vegetable oils to prepare semi-solid, flavourful paste, which is then added to different recipes. Dry, toasted sesame seeds and vegetable oil are mixed into a thin light brown paste called tahini. It is one of the main ingredients in famous middle-eastern food items like dip, hummus etc. Roasted seeds are sprinkled over sandwiches, biscuits, breads, cakes, salads, stir fries, desserts, particularly sundaes and other confectionary preparations. The seeds are largely employed in the production of margarine in Europe. The seeds used in many traditional south-Indian sweet delicacies, often mixed with roasted peanuts, almonds and jaggery. Gomashio is a Japan's specialty, which uses ground sesame seeds. Sesame seed sprouts, sesame broccoli rice, ginger sesame chicken, sesame granula, sesame spread, tangerine and sesame, sesame seed sauce and sesame pastries are a few recipes of sesame. Sesame oil obtained from the seeds is one of the most sought after cooking oil in Malaysia, Indonesia and southern states of rural India. The antioxidant property of refined sesame oil contributing for its greater shelf life makes it suitable for food industry. Refined sesame oil has a very pleasant flavour and taste and is rich in polyunsaturated fatty acids where the fatty acids composition is 14% saturated, 39% mono-unsaturated (MUFA) and 46% poly-unsaturated fatty acids (PUFA). It shows synergistic activity with insecticides, such as rotenone and pyrethrum, in reducing the concentration of the insect toxin required to produce 100% mortality (Morris, 2002). The anti-oxidant and synergistic properties are provided by sesamolin and sesamin contained in the seed. They constitute about 0.3 to 0.5% and 0.5 To 1.0%, respectively.

The de-oiled meal obtained from extraction of sesame oil is mainly utilized as cattle and poultry feed (Reshma *et al*. 2010). Sesame can be a promising alternative to fish meal. It has been reported by Emadi *et al*. (2014) that substituting a part of fishmeal by sesame proteins led to the increased final weight gain, specific growth rate, protein efficiency ratio, as well as decreased food conversion ratio as compared to the control treatment. Sesame



Fig. 2: Different sesame products

meal can be used as an alternative protein source in feeding diets of carnivorous fish at least in a half rate offish meal protein (without amino acid supplementary) without any reduction ingrowth rate of rainbow trout fingerlings (Nang Thu *et al.* 2010). In addition, substituting a part of fish meal with sesame meal would result in a reduction involuntary food take in common carpfingerlings, fingerlings of merigal fish (*Cirrhinus merigala*) and rahofish, *Labeorohita* (Hossain and Jauncey, 1990). Alternating sesame cake meal in feeding diets of tilapia fish to the level of20%, decreased food expenditure without any harmful effect on fish growth rate (Ofojekwu and Kigbu, 2002).

Sesame is rich in sulphur containing amino acids and limited in lysine and contains significant amounts of oxalic (2.5%) and phytic (5%) acids (Kapadia *et al.* 2002). 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 cookingoils. Sesame seeds contain two unique substances, sesamin and sesamolin, 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 B1. 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. Like many other vegetable oils, sesame is deficient in vitamin A, but rich in vitamin E.

Medicinal and Pharmaceutical Applications

Sesame seeds, being a rich source of various nutrients and many other nutraceutical components pose numerous health benefits that have been experienced for thousands of years. Sesame oil is known since Vedic times and is the most esteemed oil in Ayurveda. Sesame oil is known for its healing properties and has a reputation as a sedative in Tibetan medicine and also used for millennia in Chinese system of medicine (Moazzami and Kamal-Eldin, 2006; El Tinay *et al*. 1976). In Ayurveda, sesame is known to cure *Tridoshas*. During Abhyanga, a form of massage, the oil is rubbed externally on the skin to improve energy flow and help free the body from impurities. In Ayurveda, sesame oil is regarded as an anti-bacterial mouthwash and it can also be applied to nostrils to relieve anxiety and insomnia. The pain associated with premenstrual syndrome (PMS) can be overcome by applying the oil on to the abdomen region. According to traditional system of medicines, sesame is known to cure bleeding dysentery, burns, ear pain, headache and impotency.

Diabetes management: Magnesium and other nutrients present in sesame seeds, especially in sesame oil have shown promising results to combat diabetes. According to Sankar *et al.* (2010), sesame oil improves the effectiveness of the oral anti-diabetic drug glibenclamide in type 2diabetic patients. Another study concluded that substitution of sesame oil as the sole edible oil has an additive effect in further lowering blood pressure and plasma glucose in hypertensive diabetics (Sankar *et al.* 2006).

Blood pressure and cholesterol management: Sesame seed oil can also boost cardiovascular health by preventing atherosclerotic lesions. High PUFA, sesamin and vitamin E content in sesame oil greatly reduces hypertension when compared to the blood pressure lowering drugs. Sesamin feeding significantly decreases the wall thickness and area of aorta and superior mesenteric artery. It also decreases histological renal damage such as the thickening of tunica intima and fibrinoid degeneration of the arterial wall, a feature not observed in normal diet (Costa *et al*. 2007). Sesamin is valuable for prophylactic treatment to fight the development of cardiac hypertrophy and renal hyper tension (Chaveli *et al*. 1998). Dietary sesamin and episesamin has shown significant increase in the gene expression of mitochondrial and peroxisomal fatty acid oxidation enzymes such as carnitinepalmitoyl transferees, acyl-CoAdehydrogenase, acyl-CoA oxidase, 3-hydroxyacyl-CoA dehydrogenase,enoyl-CoA hydratase, and 3-ketoacyl-CoA thiolase thus increasing the hepatic activity of fatty acid oxidation which is due to enhanced ketonebody production. This hepatic fatty acid metabolism accounts forlowering the serum lipid level (Kita *et al*. 1995; Hemalatha and Ghafoorunissa, 2004). Sesamin also increases the activity and gene expression of malic enzyme which has lipogenic activity (Kita *et al*. 1995). Alpha-tocopherol greatly accentuates the hypo cholesterolemic action of sesamin, although which alone does not affect the concentration of serum cholesterol (Yamada *et al*. 2008). Karatzi *et al*. (2013) reported that daily consumption of sesame oil by hypertensive men results in positive effect on endothelial dysfunction. Recently it has found that consumption of sesame oil improves the endogenous antioxidants in ischemic myocardium (Saleem *et al*. 2012). Sesamol, which also harnesses anti-atherogenic properties, is thought to be one reason for the beneficial effects; sesamol has been shown to possess over dozens of beneficial pharmacologically active properties, many of which may contribute to improving cardiovascular health.

Antioxidant and dermatological use: The important antioxidants sesaminol, sesamolinol, sesamolin and sesamin maintain the fats including Low Density Lipoproteins (LDL) which cause arteriosclerosis and are believed to promote the integrity of body tissues. These antioxidant lignans have shown hypocholesterolemic and immuno-modulatory effect (Chavali *et al*. 1997). Vitamin E, a fat soluble antioxidant, protects the body from harmful oxidizing compounds. Sesame seed oil contains gamma to copherols along with sesaminol and sesamin which possess Vitamin E like activity. Sesamol a compound found in sesame seeds and sesame oil, has been shown in some studies to protect against DNA damaged caused by radiation (Kanimozhiand Prasad, 2009; Ramachandran, 2010). UV light produces various reactive oxygen species (ROS) in the skin causing skin damage such as sunburns, wrinkles and skin cancer (Balan *et al*. 2009). The antioxidants, mainly α-tocopherol, present in sesame act as a defence against these ROS.

Oral health: One of the most prominent benefits of sesame seeds and sesame oil revolves around removing dental plaque and boosting oral health. They are involved inan activity known as oil pulling, which involves swishing oil around in your mouth hereby you can boost oral health and even whiten up your teeth. One of the study showcase the oil pulling benefits on the oral level, where oil pulling with sesame oil was shown to reduce the amount of *Streptococcus* mutants in both teeth plaque and mouth saliva, and boost overall health(Ashokan *et al*. 2008).

Respiratory ailments management: The mixture of sesame seeds with *Trachyspermum ammi* Linn. is used to treat dry cough, lung diseases and common cold. It has been reported that the young leaves are used as medicine for respiratory diseases and seed oil produces soothing effect for chest complaints (Ogunsola and Fasola, 2014). High magnesium content in sesame seeds is ableto prevent asthma by and other respiratory disorders by preventing airway spasms.

Pain and inflammation management: Sesame oil and its lignan sesamol have proved to be potent anti-inflammatory agents. They have an excellent protective effect against endotoxin-associated inflammatory damage because they inhibit the release of inflammatory mediators. Sesamol also inhibitsendotoxins from binding to its receptor; this reduces inflammatory transcription factor NF-κB activation. Sesame oil is abundant in copper, which is known for reducing pain and swelling associated with arthritis. Additionally, this mineral

helps provide strength to blood vessels, bones and joints (Hsu, 2013).

Skin and bone health: Sesame seeds are rich in zinc, which is an essential mineral for producing collagen and giving skin more elasticity. Zinc also helps in repairing of damaged tissues in the body. Sesame oil is also popularly used to sooth burns and prevents skin related disorders. In addition to promoting healthy skin, zinc has also been shown to boost bone mineral density and bone health as a whole. A study by Hyun *et al.* (2004) found a correlation between zinc deficiency and osteoporosis in the hip and spine area. Moreover, sesame seeds are a great source of calcium – a known trace mineral that is essential for bone health and preventing related conditions.

Digestive health: Sesame seeds are rich in fiber, which is known to pave way for a healthy digestive system and a healthy colon. Sesame seed coats have high total dietary fibre content (42 g/100 g seed coat dry matter) of which insoluble fibre was the largest fraction, more than 26%. Compared with cereal derivatives (corn bran, wheat bran, oat bran, and rice bran), the soluble dietary fibre content of sesame seed coats is considerably higher (0.4 and 4.1%).

Wound healing: Externally it is used to treat haemorrhoids and ulcers. The major component of sesame oil i.e. sesamol having anti-oxidative properties can be used for rapid wound healing (Fukuda *et al.* 1981) It was found that sesamol has both antioxidant activity and anti-clastogenic activity(Parihar *et al.* 2006). In a study by Shenoy *et al.* (2011) found that sesamol is a capable entity which encourages wound healing,but it's oral consumption requires higher doses because of poor oral absorption.

Effect on nervous system: When sesamin and episesamin (stereoisomer of sesamin) are ingested, sesamin is metabolised by cytochrome P40 to SC1 (2-(3,4-methylenedioxyphenyl)-6-(3, 4-dihydroxyphenyl)-3,7-dioxabicyclo Octane)which is then metabolized to SC2. Similarly episesamin is metabolized to EC1 and then EC2. These compounds are further metabolized toSC-1m, SC-2m EC-1m and EC-2m by catechol-O-methyl transferase (COMT). The primary metabolites of this cycle exhibit the most potentneural differentiation activity (Collinge, 1996).

Cancer prevention: Sesame can inhibit the growth of malignant melanoma *in vitro* and the proliferation of human colon cancer cells. Not only do sesame seeds contain an anti-cancer compound called phytate, but the magnesium in sesame seeds also possess anti-cancer properties. According to Wark *et al*. (2012), it was found that the risk of colorectal tumours decreased by 13% and the risk of colorectal cancer decreased by 12% with consumption of every 100 mg of magnesium. Sesame seed consumption increases plasma γ-tocopherol and enhances vitamin Eactivity, which is reported to prevent cancer and heart diseases (Cooney *et al*. 2001).

Anti-fungal and anti-viral activity: A chlorinated red naphthoquinone pigment possessing antifungal activity, named chlorosesam one has been reported from sesame root (Hasan *et al.* 2000). Three anthraquinones, Anthrasesamones A, B and C were isolated from the root of sesame (Furumoto *et al*. 2003). In 2006, Shittu, L.A.J. and his co-workers mentioned antiviral and antifungal activities found in sesame. The decoction of both leaves and roots was found to be effective against chicken pox and measles (anti-viral) and used as hair shampoo for *Taenia capitis* (antifungal).

Industrial and other applications

Biodiesel: 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 trans-esterification; this has led to the idea that biodiesel production could be a way to extend the role of agriculture (more jobs created and reduced financial burden for petroleum imports in developing countries).

Ahmad *et al*. (2010) has prepared biodiesel from sesame oil by its trans-esterification 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 sulphur 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. Biodiesel yield from sesame is around 807 barrels per year per square mile.

Table 6: Industrial, nutraceutical and pharmaceutical applications

Purpose	Phyto chemicals used
Industrial	
Antifungal	Cholorosesamone
Bactericidal and insecticidal (synergist for pyrethrum insecticides)	Sesamin and sesamolin
Cosmetics and soap	Myristic acid
Nutraceutical	
Antioxidant and Inhibiting cholesterol production	Lecithin and lignans
Reducing hepatic steatosis	Lecithin
Haemostatic activity	Cephalin
Decreased dermatitis	Lecithin
Cardioprotective	Fiber and sesame oil
Enhanced Hepatic (mitochondrial andperoxisomal) fatty acid oxidation	Sesamin and sesamolin
Skin softener	Sesame oil
Pharmaceutical	
Treatment of nasal mucosa dryness, blurred vision, dizziness, anxiety, headache, insomnia, menstruation trouble	Sesame oil
Oleaginous vehicle for drugs and laxative	Sesame oil
Hypoglycaemia	flavonoids
Cancer preventive	Myristic acid
Inhibition of malignant melanoma	Linoleate in triglyceride form

Several industrial, nutraceutical and pharmaceutical uses have been compiled for sesame (Table 6). 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.

Constraints and future scope

The sesame production volume amounted to about 660 thousand metric tons in the country during fiscal year 2018, down from 780 thousand metric tons in fiscal year 2017. The poor production is in consequence of the detrimental climatic conditions in the sesame producing regions of India. The adverse climate in terms of heavy rainfall and floods in the said areas has apparently retarded the sesame production and limited the estimated yield to a considerable extent. Nevertheless, demand for Indian sesame seeds is seamlessly escalating on the global as well as domestic spheres. Sesame seed has a potential application as a source nutraceuticals for human to prevent malnutrition as well as global food security. Besides, there is also enough scope for development of different value added sesame products. Various effective strategies should be adapted to produce climate ready planting material to fit the current global environment using modern breeding techniques such as development of varieties resistant to biotic stresses, drought-tolerant varieties with enhanced water use efficiency, developments of hybrids, increase in national breeding capacity etc.

CONCLUSION

The cultivation practice for sesame crop is simple and appropriate for various ecological conditions ranging from tropical to sub-tropical area. Sesame is an affluent source of nutritive and therapeutic properties. Sesame is a rich source of macro and micro nutrients including proteins, dietary lignans, vitamins, calcium, phosphorous and others but not many value added products other than sesame oil has been developed. When analyzed, it is found that

the by-products obtained extraction of oil contains comparatively high nutritive value and in future, can be consumed as a supplement for protein rich food. With the advancement in technology sesame oil when blended with rice bran or Soya or other oil can be of a great advantage with respect to nutritional aspects. Nutraceuticals and pharmaceutical products of sesame can decrease the risk of neurological, dermatological, cancer and heart disease. 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. This article gives review on multipurpose use of sesame crop and points the need for further investigation on the phytochemical profile of the same. This kind of the study can increase the tendency of using sesame in health care and other applications.

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