Sesamum indicum

Scientific Name

***Sesamum indicum* L.**

Synonyms

Anthadenia sesamoides Lem., *Capraria integerrima* Miq., *Dysosmon amoenum* Raf., *Sesamum africanum* Todaro, *Sesamum brasiliense* Vell., *Sesamum luteum* Retz., *Sesamum malabaricum* J. Burm., *Sesamum mulayanum* N. C. Nair, *Sesamum oleiferum* Moench, *Sesamum orientale* L., *Sesamum trifoliatum* Mill., *Volkameria orientalis* Kuntze, *Volkameria sesamoides* Kuntze.

Family

Pedaliaceae

Common/English Names

Beniseed, Benneseed, Gingelly Sesame, Sesame, Semsem.

Vernacular Names

Albanian: Suzami;
Amharic: Selit;
Arabic: Juljulan, Simsim, Sumsum, Zelzlane;
Armenian: Shooshma, Shooshmayi Good (Seeds), Shushma, Shushmayi Kut;
Azeri: Küncüt, Hint Küncütü;
Belarusian: Kunžut, Sezam;
Brazil: Gergilim;
Bulgarian: Susam;
Burmese: Hnan Zi;
Catalan: Sèsam;
Chamorro: Ahonholi;
Chinese: Chi Ma, Hak Chi Mah (Black Sesame), Hei zhi ma, Hú má, Hu ma ren, Wuh Ma, Zhi Ma, Zi Moa;
Croatian: Sezam;
Czech: Sezam, Sezam indický, Sezam východní, Sezamové Semínko;
Danish: Indisk Sesam, Sesam;
Dutch: Sesamkruid, Sesamzaad;
Esperanto: Sezamo;
Eastonian: Harilik Seesam, Kunžuut;
Farsi: Konjed;
Finnish: Seesami;
French: Sésame, Sésame Blanc, Teel, Till;
Galician: Sésamo;
German: Sesam, Vanglo;
Greek: Sesami, Sesamon, Sousami;
Hebrew: Sumsum, Shumshum;
Huasa: Ridi;
Hungarian: Szezám, Szézámfű, Szézámmag;
Icelandic: Sesamfrae;
India: Til (Assamese), Til (Bengali), Thileyo, Thileyokoli (Dhivehi), Spin (Garo), Tal (Gujarati), Gingli, Kali Til, Saphed Til, Til (Hindu), Acchellu, Ellu, Tila (Kannada), Til (Maithili), Chitelu, Ellu, Thilam (Malayalam),

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Til, Ashadital, Bariktil (Marathi), Chhawchii (Mizoram), Rasi (Oriya), Til (Punjabi), Til, Tila (Sanskrit), Ellu, Yellu (Tamil), Nuvvulu, Tillu (Telugu), Enme (Tulu), Til, Konjed (Urdu);
Indonesian: Wijen;
Irish: Seasaman;
Italian: Sesame, Sesamo;
Japanese: Goma, Kuro Goma (Black Sesame), Koba, Shima;
Kazakh: Künjit;
Khasi: Neiong, Nei;
Korean: Chamggae, Cham-Kkae, Ggaessi, Ggae, Kkae, Ssisaem;
Laotian: Man Nga, Nga;
Latvian: Sēzama Sēklas;
Lithuanian: Indinis Sezamas, Sezamas;
Maltese: Ġulġlien;
Malaysia: Bene, Bijan;
Naga (Tankhul): Hāngsi;
Nepali: Til, Hamo, Til (Newari);
Pahlavi: Kunijd;
Papiamento: Zjozjolí;
Philippines: Langa (Bikol), Langa, Lunga (Bisaya), Langa (Ibanag), Longis (Ifugao), Lenga (Iloko), Langis (Pampangan), Linga (Sambali), Ajonjoli (Spanish), Lunga (Sulu), Langa, Linga, Lingo (Tagalog);
Polish: Sezam Indyjski;
Portuguese: Gergelim, Gimgelim, Sésamo;
Romanian: Susan;
Russian: Kunzhut, Sezam;
Serbian: Sezam, Susam, Suzam;
Slovak: Sezam Indický, Sezam;
Slovenian: Sezama;
Spanish: Ajonjoli, Alegría, Sesame, Sésamo;
Sri Lanka: Tala (Sinhala);
Swahili: Simsim, Ufuta, Wangila;
Swedish: Sesam;
Thai: Ngaa, Nga Dam, Nga Khao;
Tibetan: Telu, Til kara, Khyuma; *Turkish*
Turkish: Susam;
Turkmen: Künji;
Ukrainian: Sezam;
Uzbek: *Uzbek*: Kunjut;
Vietnamese: Cây Vừng, Mè, Hắc Chi Ma, Vừng;
Yiddish: Sumsum, Sezam, Kunzhit.

Origin/Distribution

Sesame is believed to have originated in Africa, and is regarded to be the oldest oilseed crop known to man. Evidence from interspecific hybridization and phytochemical analysis indicate that the progenitor of sesame occurred in the Indian subcontinent (Bedigian et al. 1985). From here, sesame was introduced to Mesopotamia in the Early Bronze Age and by 2000 BC where it became a crop of enormous importance. Mesopotamia became the hub of distribution of sesame into the Mediterranean. By the second century BC, sesame became a prominent oil crop in China. Today sesame is cultivated pantropically.

Agroecology

Sesame is a crop of the tropics and subtropics. With newer cultivars and summer plantings its range has extended into the temperate areas. Sesame is cultivated mainly between 25°S and 25°N, but extends further to 40°N in China, Russia and the United States, 30°S in Australia and 35°S in South America. It is grown from sea level to 1,800 m altitude. The crop has an optimal day temperature of 25–27°C, below 20°C growth is retarded and below 10°C germination is suppressed Sesame requires 90–120 frost free days.

Yield is optimal with well distributed annual rainfall of 500–650 mm during the growing season. Rainfall late in the season prolongs growth and increases shattering losses. Strong wind can cause shattering at harvest and result in yield losses. Sesame is very drought-tolerant, due in part to an extensively branched root system which also improves soil structure. Sesame is intolerant of wet conditions. Sesame is adaptable to many soil types, but it thrives best on well-drained, fertile soils of medium texture and with pH ranging from 5.5 to 8.0, but most cultivars are intolerant of salinity. Growth and subsequent yield will be reduced on gravelly or sandy soils due to their poor moisture retention capacity.

Edible Plant Parts and Uses

Sesame seeds, both pale and dark coloured, and sesame oil, are widely used in various cuisines all over the world. The small sesame seed is used whole in cooking for its rich nutty flavour, and also yields sesame oil. In general, the paler varieties of sesame appear to be more prized in the West and Middle East, while both the pale and black varieties are valued in the Far East. Sesame seeds are used as spice for flavouring in food dishes, pastries and cakes, and other food industries. Sesame oil from the seed is used in cooking salad oils and margarine. Sesame oil and foods fried in sesame oil have a long shelf life because the oil contains an antioxidant called sesamol. Black sesame seed are especially good on salmon and other fish dishes. The simplest and now commonest use of sesame is as whole seeds sprinkled over cakes, breads (bagels and hamburger buns), in cookies and wafers, sushi food, and steamed rice noodle rolls called '*chee cheong fun*' like poppy seeds. Sesame seeds may be baked into crackers, often in the form of sticks. Sesame seeds can be ground into a paste, *tahini* (Sesame butter) or powder and used as flour, added to bread, vegetables, and used to make sweetmeat, halva, and for the preparation of rolls, crackers, cakes and pastry products in commercial bakeries. The seeds can also be fermented into *tempeh.* The seeds can also be sprouted and used in salads. Leaves raw or cooked can be used in soups and as potherbs.

About a third of Mexico sesame seed crop is purchased by McDonald enterprise for their sesame seed buns. In Mexican cuisine, sesame is used in the popular sauce *mole rojo* or *mole poblano* to accompany baked turkey. Sesame seeds are often sprinkle over artisan breads and baked in traditional form to coat the smooth dough, especially on whole wheat flat breads or artisan nutrition bars, such as *alegrías*. Good acceptance was obtained with the bread prepared with 30% sesame flour + 70% wheat flour (Salgado and Gonçalves 1988). Its external and internal appearance, as well as its organoleptic characteristics were close to the bread with 100% wheat flour. Sesame flour at the 50% proportion gave a bread of medium quality.

Toasted sesame seeds are a common spice in Eastern Asia; it is often sprinkled over Chinese, Korean and Japanese dishes. Black sesame appears frequently in Chinese, Japanese and Korean dishes where meat or fish is rolled in the seeds before cooking for a crunchy coating. In Chinese cuisine, sesame seeds and oil are used in dishes like dim sum, sesame seed ball (*mátuǎn* or *jin deui*), and Chinese noodles. Chinese sesame paste (*zhi ma jiang*) is made from toasted sesame seeds and has a very strong flavour resembling Chinese sesame oil; it is used mainly for salad dressings and sauces for cold appetizers like Sichuanese *guai wei ji si,* a salad dish made from precooked chicken meat cut in fine slivers with a dressing of soy sauce, sugar, black vinegar (*hei cu*), sesame paste, sesame seeds, chilli oil and toasted Sichuan pepper. Sesame oil is used as a condiment to flavour hot and sour Szechuan soup *suanla tang* and noodles. Sesame paste is also made in a delicious dessert soup called *chi ma wu.* In Vietnam, sesame seeds are used in *bánh rán,* deep fried glutinous rice balls and as a condiment flavour in various noodles. Sesame oil and roasted or raw seeds is also very popular in Korean cuisine, used to marinate meat and vegetables. Chefs in tempura restaurants blend sesame and cottonseed oil for deep-frying. Japanese *tempura* is made by deep-frying battered vegetables in a mixture of one part sesame oil and ten parts vegetable oil. In Japanese cuisine, *goma-dofu* is made from sesame paste and starch. Dark sesame oil forms part of *shichimi togarashi*, an exotic spice blend of Japan Szechuan pepper. A simpler mixture from toasted black sesame seeds with about 10% salt called *gomashio* is a popular Japanese tabletop condiment, usually sprinkled over dry colourful rice dishes and noodle dishes.

In Maharashtra, southwest India and Myanmar, a hot-pressed sesame oil is the preferred cooking medium. In Manipur, black sesame is widely used in popular dishes in 'Thoiding' and in 'Singju' a kind of hot spicy salad comprising vegetables, gingers and chillies. In Assam, black sesame seeds are used to make *til pitha* (pancake) and *tilor laru* (sesame seed balls) during

Assamese festive occasions (*bihu*). In Punjab and Tamil Nadu, a sweet sesame ball is made from sesame seeds and sugar, called *pinni* (Urdu), *ell urundai* (Tamil), *ellundai* (Malayalam), *yellunde* (Kannada) and *tilgul* (Marathi). In Tamil Nadu, sesame oil used extensively in their cuisine, *milagai podi*, a ground powder made of sesame, lentils and dry chili with jaggery, is used to enhance flavor and consumed along with other traditional foods such as *dosa* (bread) and *idli* (savoury cake of rice and lentils).

In South Asian, Middle East, and East Asian cuisines, popular treats are made from sesame mixed with honey, jaggery or syrup and roasted into a sesame candy. In the Democratic Republic of Congo and Angola, ground sesame seeds or *wangila* is a favourite dish cooked usually with smoke fish or lobsters. In Togo, the seeds are used in soups.

In the Middle East, sesame seeds are popularly used for *tahini*, starch and as the key ingredient for the confection *halvah*. *Tahini* is used as a flavouring for hummus, a sauce for kebabs and bread dips. In Jordan, Syria and Lebanon, dried, untoasted sesame seeds are used with sumac and thyme in the spice mixture *zahtar,* and the Egyptian *dukka*.

Plate 1 Sesame plant habit

Botany

An erect annual herb growing to 1.2 m high branched with quadrangular, pubescent or glabrescent short branches or unbranched (Plates 1 and 2) depending on varieties. Leaves opposite or alternate (Plates 2 and 3); petiole 3–11 cm on lower leaves; leaf blade variable lanceolate to ovate, or 3-parted, 4–20 by 2–10 cm; upper stem leaves oblong to linear-lanceolate, 0.5–2.5 cm wide, base cuneate, margin entire. Flowers white (Plates 1, 2 and 3), pink, or mauve-pink with darker markings, with strong unpleasant odour, bracteate; pedicel up to 5 mm long with 2 basal glands. Calyx 2–6 mm long, lobes linear to narrowly lanceolate, hairy and persistent. Petals obtuse, 2–3 cm long, pubescent. Stamens 1 cm long. Ovary 1–2 mm long, pilose, oblong. Petals 2–3 cm long, pubescent, obtuse. Capsule narrowly oblong, loculicidal, acuminate at apex and rounded at base, 1.5–3 cm × 6–7 mm; beak broad and short. Seeds black, brown or white, oval, small, 2–3 mm long, 1–1.5 mm wide, smooth, arranged horizontally in capsule (Plates 4a, 4b, 5, 6a and 6b).

Nutritive/Medicinal Properties

Nutrient value of whole, dried sesame seeds per 100 g edible portion was reported as: water 4.69 g, energy 573 kcal (2,397 kJ), protein 17.73 g, total lipid (fat) 49.67 g, ash 4.45 g, carbohydrate 23.45 g, total dietary fibre 11.8 g, total sugars 0.30 g, Ca 975 mg, Fe 14.55 mg, Mg 351 mg, P 629 mg, K 468 mg, Na 11 mg, Zn 7.75 mg, Cu 4.082 mg, Mn 2.460 mg, Se 34.4 µg, thiamine 0.791 mg, riboflavin 0.247 mg, niacin 4.515 mg, pantothenic acid 0.050 mg, vitamin B-6 0.790 mg, total folate 97 µg, β-carotene 5 µg,

Plate 2 Flowers and fruits

Plate 3 Fruits and leaves

vitamin E (α-tocopherol) 0.25 mg, total saturated fatty acids 6.957 g, 14:0 (myristic) 0.124 g, 16:0 (palmitic) 4.441 g, 18:0 (stearic) 2.090 g, total monounsaturated fatty acids 18.759 g, 16:1 undifferentiated (palmitoleic) 0.149 g, 18:1 undifferentiated (oleic) 18.521 g, 20:1 (gadoleic) 0.070 g, total polyunsaturated fatty acids 21.773 g, 18:2 undifferentiated (linoleic) 21.375 g, 18:3 undifferentiated (linolenic) 0.376 g, phytosterols 714 mg, tryptophan 0.388 g, threonine 0.736 g, isoleucine 0.763 g, leucine 1.358 g, lysine 0.569 g, methionine 0.586 g, cystine 0.358 g, phenylalanine 0.940 g, tyrosine 0.743 g, valine 0.990 g, arginine 2.630 g, histidine 0.522 g, alanine 0.927 g, aspartic acid 1.646 g, glutamic acid 3.955 g, glycine 1.215 g, proline 0.810 g and serine 0.967 g (USDA 2011). Nutrient value of sesame cooking oil per 100 g edible portion was reported as: energy 884 kcal (3,699 kJ), total lipid 100 g, total choline 0.2 mg, vitamin E (α-tocopherol) 1.40 mg, vitamin K (phylloquinone) 13.6 µg, total saturated fatty acids 14.200 g, 16:0 (palmitic) 8.9 g, 18:0 (stearic) 4.8 g, total monounsaturated fatty acids 39.700 g, 16:1 undifferentiated (palmitoleic) 0.200 g, 18:1 undifferentiated (oleic) 39.3 g, 20:1 (gadoleic) 0.200 g, total polyunsaturated fatty acids 41.700 g, 18:2 undifferentiated (linoleic) 41.300 g, 18:3 undifferentiated (linolenic) 0.300 g and phytosterols 865 mg (USDA 2011). Sesame seed and wheat germ had the highest total phytosterol content (400–413 mg/100 g) while Brazil nuts the lowest (95 mg/100 g) (Phillips et al. 2005). White sesame (WS) seed contained 22.20% protein and 52.61% fat while black sesame (BS) seeds contained 20.82% protein and 48.40% fat (Kanu 2011). Moisture was higher in WS than BS but ash was higher in BS than WS and the amount was significantly different. Carbohydrate was higher in BS than WS. Vitamins and sugars varied in quantity for the two seed types. Oleic and linoleic, were the major unsaturated fatty acids while

Plate 4a White sesame seeds

Plate 4b Close-up white sesame seeds

Plate 5 Brown sesame seeds

palmitic and stearic were the main saturated fatty acids significantly observed in both seed types. Both types were higher in essential amino acids with the exception of lysine.

Plate 6a Black sesame seeds

Plate 6b Close-up black sesame seeds

Sesame seed was found to contain 5.7% moisture, 20% crude protein, 3.7% ash, 3.2% crude fiber, 54% fat and 13.4% carbohydrate (Nzikou et al. 2009). The seeds were found to be good sources of minerals. Potassium (851.35 mg/100 g) was the highest, followed in descending order by phosphorus (647.25 mg/100 g), magnesium (579.53 mg/100 g), calcium (415.38 mg/100 g) and sodium (122.50 mg/100 g). The physical properties of the oil extracts showed the state to be liquid at room temperature. Sesame oil was found to contain high levels of unsaturated fatty acids, especially oleic (up to 38.84%) and linoleic (up to 46.26%), classifying it in the oleic-linoleic acid group. The dominant saturated acids were palmitic (up to 8.58%) and stearic (up to 5.44%). No essential differences in the oil components were found among the three sesame varieties (Yoshida et al. 2007). γ-Tocopherol was present in highest concentration, and δ-, and α-tocopherols in very small amounts. Sesamin

and sesamolin were the main lignan components. Separation of the complex mixture of total triacylglycerol, provided 12 different groups of triacylglycerol. With a few exceptions, the major TAG components were SM2 (6.5–6.7%), SMD (19.8–20.7%), M2D (15.0–26.3%), MD2 (23.6–35.0%), and D3 (7.7–10.7%) (where S = saturated fatty acid, M = monoene, D = diene, and T = triene).

Oleic (O) and linoleic (L) acids were the major fatty acids followed by palmitic (P) and stearic acids in *Sesamum indicum* and three wild species *Sesamum alatum*, Thonn., *S. radiatum*, Schum & Thonn. and *S. angustifolium*, (Oliv) Engl (Kamal-Eldin et al. 1992b) . The major triacylglycerols were: LLO (20–25%), LLL (10–20%), LOO (15–19%), PLL (8–11%) and PLO (6–10%). *S. alatum* was also different from the other three species in having higher percentages of PLO (10.1%) and OOO (8.7%) compared to 6.3–8.1% of PLO and 3.4–4.9% of OOO in the other three species. Oils from the three wild species contained more unsaponifiable material (2.3–2.4%) compared with the cultivated *S. indicum* species (1.1–1.3%) (Kamal-Eldin et al. 1992a). Considerable differences were observed in the total sterol contents and the relative proportions of the three sterol fractions in the oils from the four species studied. Sitosterol, campesterol, stigmasterol and Δ5-avenasterol were the major desmethyl sterols in all four species. The monomethyl sterol fraction consisted primarily of obtusifoliol, gramisterol, cycloeucalenol and citrostadienol. Cycloartenol and 24-methylene cycloartanol were the predominant dimethyl sterols. The oils from wild seeds were characterized by higher percentages of unsaponifiables (4.9%, 2.6% and 3.7%, respectively) compared to *S. indicum* (1.4–1.8%), mainly due to their high contents of lignans (Kamal-Eldin and Appelqvist 1994). Total sterols accounted for circa 40%, 22%, 20% and 16% of the unsaponifiables of the four species, respectively. The four species were different in the relative percentages of the three sterol fractions (the desmethyl, monomethyl and dimethyl sterols) and in the percentage composition of each fraction. Campesterol, stigmasterol, sitosterol and Δ^5-avenasterol were the major desmethyl sterols, whereas obtusifoliol, gramisterol, cycloeucalenol and citrostandienol were the major monomethyl sterols, and α-amyrin, β-amyrin, cycloartenol and 24-methylene cycloartanol were the main dimethyl sterols in all species. Differences were also observed among the four species in sterol patterns of the free sterols compared to the sterol esters. *Sesamum alatum* contained less tocopherols (210–320 mg/kg oil), and *S. radiatum* and *S. angustifolium* contained more tocopherols (ca. 750 and 800 mg/kg oil, respectively) than did *S. indicum* (490–680 mg/kg oil). The four species were comparable in tocopherol composition, with γ-tocopherol representing 96–99% of the total tocopherols. The four species varied widely in the identity and levels of the different lignans. The percentages of these lignans in the oils of *S. indicum* were sesamin (0.55%) and sesamolin (0.50%). *Sesamum alatum* showed 1.37% of 2-episesalatin and minor amounts of sesamin and sesamolin (0.01% each). *Sesamum radiatum* was rich in sesamin (2.40%) and contained minor amounts of sesamolin (0.02%), where *S. angustifolium* was rich in sesangolin (3.15%) and also contained considerable amounts of sesamin (0.32%) and sesamolin (0.16%).

A survey of 11 diverse *Sesamum indicum* genotypes from eight countries revealed that sesamin, α-tocopherol, δ-tocopherol and γ-tocopherol levels were 0.67–6.35 mg/g, 0.034–0.175 μg/g, 0.44–3.05 μg/g and 56.9–99.3 μg/g respectively, indicating that the sesame seed accessions contained higher levels of sesamin and γ-tocopherol compared with α-tocopherol and δ-tocopherol (Williamson et al. 2008). Significant differences were observed among the 11 different sesame genotypes suggesting that genetic, environmental and geographical factors influence sesamin and desmethyl tocopherol content.

Sesame seeds germinated readily in dark chambers maintained near 100% relative humidity at 35°C without presoaking reaching >99% germination rate in 4 days with the final moisture content of 2% (w/w) (Hahm et al. 2009). With, germinated derooted sesame seeds (DSS) showed marked reduction in fat content (23%) and

were found rich in linolenic acid, P, and Na, increasing from 0.38% (w/w), 445 mg/100 g, and 7.6 mg/100 g before germination to 0.81% (w/w), 472 mg/100 g, and 8.4 mg/100 g after germination, respectively. DSS after germination contained considerable amount of Ca (462 mg/100 g), higher than that of soybean. Germinated DSS presented an excellent source of sesamol (475 mg/100 g), a potent natural antioxidant, and α-tocopherol (32 mg/100 g), the most active form of vitamin E.

Sesame seeds were found to contain small amounts of lipid soluble lignans sesamolinol, sesaminol and pinoresinol which occurred as glucosides; sesaminol glucosides sesaminol 2′- O-β-d-glucopyranoside,sesaminol2′-O-β-d-glucopyranosyl (1→2)-O-β-d-glucopyranoside and sesaminol 2′-O-β-d- glucopyranosyl (1»2)-O-[β-d-glucopyransyl (1»6)]-[β-d-glucopyranoside] (Osawa et al. 1985; Katsuzaki et al. 1992, 1993, 1994a). Three novel lignan glucosides were isolated as the water-soluble antioxidative components from the 80% ethanol extracts of sesame seed; their structures were determined as pinoresinol 4′-O-β-D-glucopyranosyl(l→6)-β-D-glucopyranoside (KP1), pinoresinol 4′-O-β-D-glucopyranosyl-(l→2)-β-D-glucopyranoside (KP2), and the lignan triglucoside pinoresinol 4′-O-β-D-glucopyranosyl(l→2)-O-[β-D-glucopyranosyl-(l→6)]-β-D-glucopyranoside (KP3) (Katsuzaki et al. 1993, 1994a). These lignan glucosides possessed unique glucosidic linkages, in particular KP3, with branched (1→2)- and (l→6)-linkages. The most abundant lignan glucosides in sesame seed were found to be sesaminol triglucoside (Ryu et al. 1998). The content of sesaminol triglucoside in 100 g seeds ranged from 14.1 to 91.3 mg with a mean value of 68.4 mg; that of sesaminol diglucoside from 8.2 to 18.3 mg with a mean value of 11.6 mg; and that of sesaminol monoglucoside from 5.4 to 19.5 mg with a mean value of 8.3 mg. The total content of sesaminol glucoside was 88.3 mg in 100 g of sesame seeds. Also, the sesamolinol content in 100 g sesame seed ranged from 17.6 to 28.5 mg, with a mean of 20.5 mg. A new lignan glucoside, sesamolinol diglucoside [2-(3-methoxy-4-(O-β-D-glucopyranosyl(1→6)-O-β-D-glucopyranoside)phenoxyl)-6-(3,4-methylenedioxyphenyl)-cis-3,7-dioxabicyclo-(3.3.0)-octane] was found in sesame seeds (both black and white) in levels ranging from <5 to 232 mg/100 g of seeds (Moazzami et al. 2006a). Analysis of 65 different samples of sesame seeds indicated that the content of sesaminol triglucoside ranged from 36 to 1,560 mg/100 g of seed (mean 637) and that of sesaminol diglucoside ranged from 0 to 493 mg/100 g of seed (mean 75) (Moazzami et al. 2006b). No significant difference was found between sesaminol glucoside contents in black and white sesame seeds.

A study found great variation in the types and amounts of lignans in sesame seeds, seed products and oils (Moazzami et al. 2007). The total lignan content of 14 sesame seeds ranged between 405 and 1,178 mg/100 g and the total lignan content in 14 different products, including tahini, ranged between 11 and 763 mg/100 g.

The biosynthesis of the sesame lignans, (+)-sesamin and (+)-sesamolin in sesame seeds, was found to result from stereoselective coupling of E-coniferyl alcohol to give (+)-pinoresinol which was then subsequently metabolized (Kato et al. 1998). This enantiomer (+)-pinoresinol is metabolized further in maturing seeds to afford (+)-piperitol, (+)-sesamin, and (+)-sesamolin. Among 16 lignans identified from sesame perisperm (coat), two new lignans, (+)-saminol and (+)-episesaminone- 9-O-β-D-sophoroside were isolated (Grougnet et al. 2006). Additionally, the relative stereochemistry of (-)-sesamolactol, previously reported as todolactol A epimer, was unequivocally defined using X-ray crystallography. A new anthraquinone derivative, Z)-6,7-dihydroxy-2-(6-hydroxy-4-methyl-3-pentenyl)anthraquinone, named anthrasesamone F was isolated from the seeds of *Sesamum indicum* (Kim and Park 2008).

Lipids from all-seeded microwaved roasted sesame strains (black, brown and white) were comparable in their total fatty acid composition, with linoleic, oleic, stearic and palmitic acids as the major acids (Yoshida et al. 1995). The total lipids were isolated into the following five fractions: triacylglycerols (TAG), diacylglycerols, free fatty acids, polar lipids and steryl esters. The TAG were slightly and randomly hydrolysed by microwaves, but was still representing 900 g/kg

of the total lipids at 30 minutes of roasting. Although burning and bitter tastes occurred at the time, the tocopherols and lignans still amounted to over 80% of the original level. Major lipid components of sesame seeds were triacylglycerols and phospholipids, while steryl esters, free fatty acids and sn-1,3- and sn-1,2-diacylglycerols (DAGs) were minor ones (Yoshida et al. 2001). Following electric-oven roasting, a significant increase was observed in free fatty acids and in both forms of DAG (primarily sn-1,3-DAG). The greatest phospholipids losses were observed in phosphatidylethanolamine, followed by phosphatidylcholine and phosphatidylinositol. On the other hand, the amounts of γ-tocopherol and sesamin remained at over 80% and 90% respectively of the original levels after roasting at 220°C. The principal characteristics of the positional distribution of fatty acids were still retained after 25 minutes of roasting: unsaturated fatty acids, especially linoleic and/or oleic, were predominantly concentrated in the sn-2-position, and saturated fatty acids, especially stearic and/or palmitic, primarily occupied the sn-1- or sn-3-position. The results suggested that unsaturated fatty acids located in the sn-2-position were significantly protected from oxidation during roasting at elevated temperatures. The concentrations of radiation-induced hydrocarbons in sesame seeds increased almost linearly with the applied doses of 0.5–4 kGy (Lee et al. 2008a). The hydrocarbons, 1,7-hexadecadiene and 8-heptadecene, were detected only in the irradiated samples before and after three types of treatments (steaming, roasting, and oil extraction) at doses ³0.5 kGy, but they were not detected in non-irradiated samples before and after treatment. These two hydrocarbons could be used as markers to identify irradiated sesame seeds. The concentrations of the three detected 2-alkylcyclobutanones, 2-dodecylcyclobutanone (2-DCB), 2-tetradecylcyclobutanone (2-TCB), and 2- (5′-tetradecenyl)cyclobutanone (2-TeCB), also linearly increased with the irradiation dose. These compounds could be detected at irradiated doses above 0.5 kGy but not in non-irradiated samples. The three types of treatments had no significant effect on the levels of 2-alkylcyclobutanones.

Sesame Seed Oil

The percentages of individual acids of fatty acids of sesame seed oil were found to be: palmitic, 11%; stearic, 6%; arachidic, 1%; oleic, 43%; linoleic, 39% (Sengupta and Roychoudhury 1976). Triglyceride composition of the was composed of 8%, 41% and 51%, GS2U, GSU2 and GU3 respectively.

Besides abundant oleosin, three minor proteins, Sop 1, 2, and 3, were found in sesame (*Sesamum indicum*) oil bodies (Lin et al. 2002). The gene encoding Sop1, named caleosin for its calcium-binding capacity, had recently been cloned. Sop2, tentatively named steroleosin may represent a class of dehydrogenases/reductases involved in plant signal transduction regulated by various sterols. In subsequent study, the found that sesame seed oil bodies comprised a triacylglycerol matrix shielded by a monolayer of phospholipids and proteins (Lin et al. 2005). These surface proteins include an abundant structural protein, oleosin, and at least two minor protein classes termed caleosin and steroleosin. Two steroleosin isoforms (41 and 39 kDa), one caleosin (27 kDa), and two oleosin isoforms (17 and 15 kDa) were identified in oil bodies isolated from sesame seeds. Studies suggested that succinylation of α-globulin the major protein fraction from *Sesamum indicum* improved the functional characteristics of α-globulin such as emulsion activity and emulsion stability and increased values for bulk density, water absorption capacity, oil absorption capacity, foam capacity and foam stability (Zaghloul and Prakash 2002).

Sesame (*Sesamum indicum* L.) seed and oil were found to contain abundant lignans, including sesamin, sesamolin and lignan glycosides (Rangkadilok et al. 2010). Studies showed that there was a large variation of sesamin and sesamolin contents in sesame and sesame oil products in Thailand. The sesamin and sesamolin contents in seeds showed that the mean values of sesamin and sesamolin were 1.55 mg/g (range n.d.–7.23 mg/g) and 0.62 mg/g (range n.d.–2.25 mg/g), respectively. The range of total tocopherols of these sesame lines was 50.9–211 μg/g seed. In commercial sesame oils, the ranges of sesamin and sesamolin

were 0.93–2.89 mg/g oil and 0.30–0.74 mg/g oil, respectively, and tocopherol contents were 304–647 μg/g oil. The study revealed the extensive variability in sesamin, sesamolin and tocopherol contents among sesame products. The content of sesamin and sesamolin in ten commercial virgin and roasted sesame oils was in the range of 444–1,601 mg/100 g oil (Moazzami et al. 2007). In five refined sesame oils, sesamin ranged between 118 and 401 mg/100 g seed, episesamin between 12 and 206 mg/100 g seed, and the total contents of sesaminol epimers between 5 and 35 mg/100 g seed, and no sesamolin was found.

The mean total lignin content in 14 commercial brands of sesame oils was found to be 11.5 mg/g; 82% and 15% of the lignans were sesamin, and sesamolin, respectively (Wu 2007). The level of sesamol increased after heating at 180°C for 20 minutes. Heating at 200°C for 20 minutes caused a significant loss of sesamolin and sesamol. Cooking at temperatures above 200°C will cause loss of some lignans, but sesamin, a source of phytoestrogen, was relatively heat-stable. Ingestion of 10 g of sesame oil was calculated to be adequate to provide the level of lignans that might benefit cardiovascular health, as found by other studies. The sesame oil prepared at a 200°C roasting temperature gave the best flavour score (Yen 1990). The highest value of sesamol and γ-tocopherol was in oils roasted at 200–220°C. The fatty acid content of the oil was reduced considerably, especially in oleic and linoleic acids, when the roasting temperature was over 220°. The amounts of chlorophyll and sesamolin decreased with increasing roasting temperature. The phospholipid content was reduced from 690 mg/kg in unroasted oil to 0 mg/kg in the oil prepared using a 260° roasting temperature. The oils from roasted and roasting plus steaming sesame seeds showed higher oxidative stability than other processed oils (Abou-Gharbia et al. 2000). Different lipid classes and subclasses present and their fatty acid composition influenced the oxidative status of sesame oil. Neutral lipids constituted about 91.0%, monoglycolipids 2.4% and diglycolipids 3.5%, while phospholipids constituted 3.0% of the total lipids. Moreover, different processing treatments show considerable effects on lipid fractions. The influence on all components after roasting plus steaming was more pronounced than microwaving treatment.

Several studies have been reported on the flavor components of sesame oil (Soliman et al. 1986; Shimoda et al. 1996, 1997; Park et al. 1995; Schieberle 1996; Schieberle et al. 1996; Cadwallader and Heo 2001; Tamura et al. 2010). The following volatile compounds : 1-(5-methyl-2-furanyl)-1-propanone; 3-formylthiophene; 2-propyl-4-methylthiazole; 2-ethyl-4-methyl-1 H-pyrrole; 2-ethyl-6-methylpyrazine; 2-ethyl-5-methylpyrazine; 4,5-dimethylisothiazole; 4, 5-dimethylthiazole; 2,6-diethylpyrazine; 2-ethyl-2,5-dimethylpyrazine; 1-(2-pyridinyl)ethanone, and 1-(1-methyl-1 H-pyrrol-2-yl)ethanone were considered to be principal contributors of sesame seed oil flavor (Shimoda et al. 1996). Soliman et al. (1986) identified 32 volatile constituents from white sesame seeds, including 10 aldehydes, 5 ketones, 6 alcohols, 4 esters and 7 pyrazines were identified. Among them 4-(5-methyl-2-furyl)-3-buten-2-one was reported for the first time in the aroma of roasted white sesame seeds. Park et al. (1995) identified 66 volatiles in toasted sesame oil. Among these, dimethylsulfide, 4-methylthiazole, 2,4-dimethylthiazole, methylpyrazine, 2,5-dimethylpyrazine, dihydro-4, 5-dimethyl-2(3 H)-furanone, dodecane, tetradecane, 2,6-bis(1,1-dimethylethyl)-4-methyl phenol, N,N-bis (2-hydroxyethyl)-dodecamide, cyclododecane, 2,3-dihydro-1,1,3-trimethyl-3-phenyl-1H-indene, tetradecanoic acid, pentadecanoic acid, hexa-decenal, hexadecanoic acid, 9-octadecenoic acid, ocladecanoic acid, [1,1′:3′,1 ′I-tephenylJ-1′-ol and bis (2-ethyl hexyl)phthalate were the major volatiles identified.

Sesame Volatiles and Flavour Components

Aroma extract dilution analysis (AEDA) of an extract prepared from moderately roasted sesame (180°C; 10 minutes) afforded 41 odour-active volatiles (Schieberle 1996). Of the 18 aroma compounds showing very high Flavour Dilution

factors in the range of 128–2,048, ten compounds [2-furfurylthiol; 2-phenylethylthiol; 2-methoxyphenol;4-hydroxy-2,5-dimethyl-3(2H)-furanone; 2-pentylpyridine; 2-ethyl-3,5-dimethylpyrazine; acetylpyrazine; (E,E)-2,4-decadienal; 2-acetyl-1-pyrroline and 4-vinyl-2-methoxy-phenol] were quantified and their odour activity values (OAV; ratio of concentration to odour threshold) were calculated. On the basis of high OAVs in oil, especially 2-acetyl-1-pyrroline (roasty), 2-furfurylthiol (coffee-like), 2-phenylethylthiol (rubbery) and 4-hydroxy-2,5-dimethyl-3(2H)-furanone (caramel-like) were elucidated as important contributors to the overall roasty, sulphury odour of the crushed sesame material. Among the 41 odorants, a garlic, carbide-like smelling compound with a comparatively high flavour dilution factor was identified as 4-methyl-3-thiazoline (Schieberle et al. 1996). The amount of volatile flavor compounds in sesame oil is greatly affected by the roasting process. Shimoda et al. (1997) reported that the ratio of the amount of volatile components in deep-roasted oils was increased by 2–7 times in deep-roasted oil as compared with that of light-roasted oils. The recoveries of total volatiles were 9,726 and 2,014 ppb from deep- and light-roasted oils, respectively. The relative amount of monoalkylpyrazines decreased in contrast to the increases of di alkylpyrazines and trialkylpyrazines with increase in the degree of roasting. 1H-pyrrole-2-carboxyaldehyde, the most abundant pyrrole, was the only volatile that decreased in deep-roasted oil. The concentration of 4,5-dimethylisothiazole, 4,5-dimethylthiazole, 2-propyl-4-methylthiazole, and 2-butyl-5-methylthiazole increased in deep-roasted oil. Hexanal, (E)-2-heptenal, and (E,E)-2,4-decadienal occurred in almost the same levels. Guaiacol and 2-furanmethanethiol increased from 32 to 321 ppb and from 6 to 40 ppb, respectively, in deep-roasted oil. Forty-nine odorants were detected from roasted sesame seed oils with detection volumes (DVs) from 8 to 1,000 nL (Cadwallader and Heo 2001). Those detected with DVs from 8 to 40 nL were 1-octen-3-one, 4,5-epoxy-(E)-2-decenal, 2-acetyl-3-methylpyrazine, 2-methoxyphenol, 2,3-diethyl-5-methylpyrazine, 3-methylbutanal, (E)-2-nonenal, 2-methoxy-4-vinylphenol, and an unidentified compound (plastic aroma note).

Aroma extract dilution analysis revealed 32 odorants from freshly pan-roasted sesame seeds in the Flavour Dilution (FD) factor range of 2 – 2,048, 29 of which could be identified (Tamura et al. 2010). The highest FD factors were found for the coffee-like smelling 2-furfurylthiol, the caramel-like smelling 4-hydroxy-2,5-dimethyl-3(2 H)-furanone, the coffee-like smelling 2-thenylthiol (thiophen-2-yl-methylthiol), and the clove-like smelling 2-methoxy-4-vinylphenol. In addition, 9 odor-active thiols with sulfurous, meaty, and/or catty, black-currant-like odors were identified for the first time in roasted sesame seeds. Among them, 2-methyl-1-propene-1-thiol, (Z)-3-methyl-1-butene-1-thiol, (E)-3-methyl-1-butene-1-thiol, (Z)-2-methyl-1-butene-1-thiol, (E)-2-methyl-1-butene-1-thiol, and 4-mercapto-3-hexanone were previously unknown as food constituents. The relatively unstable 1-alkene-1-thiols represented a new class of food odorants and were suggested as the key contributors to the characteristic, but quickly vanishing, aroma of freshly ground roasted sesame seeds. The most important compounds identified in the roasted sesame oils were 2-furfurylthiol and guaiacol (Ho and Shahidi 2005). 2-Furfurylthiol, with an intense coffee-like odor, increased from 16 ppb in roasted oil processed at 160°C for 30 minutes to 158 ppb in the oil processed at 200°C for 30 minutes. Guaiacolhas a burnt and smoky odor and the amount of guaiacol increased from 147 ppb in roasted oil processed at160°C for 30 minutes to 718 ppb in the oil processed at 200°C for 30 minutes. Other odor active compounds identified included acetylpyrazine, 2-ethyl-3,5-dimethylpyrazine, 2,3-diethyl-5-methylpyrazine, trans,trans-2,4-decadienal and 2-ethyl-5-methylpyrazine.

Sesame Seed Flour/ Debittered and Defatted Sesame Seed Flour/Meal

A study on the functional and nutritional properties of sesame flour, concentrate and enzymatic hydrolysates, demonstrated that nitrogen

solubility of the hydrolysates was improved, in water (85%) and at different pHs (91–95%), by the action of neutrasa 0.5 L and alcalasa 0.6 L enzymes, yielding a product with good emulsifying and improved foaming properties (Saad and Pérez 1984). The flour and the concentrate had PER (protein efficiency ratio) values of 1.2. Supplementation of one of the hydrolysates with soya hydrolysate (1:1), improved the PER to a value similar to that of casein.

Defatted sesame meal (approximately 40–50% protein content) is very important as a protein source for human consumption due to the presence of sulfur-containing amino acids, mainly methionine (Bandyopadhyay and Ghosh 2002). Sesame protein isolate (SPI) was produced from dehulled, defatted sesame meal and used as a starting material to produce protein hydrolysate by papain. Protein hydrolysates were found to have better functional properties than the original SPI. Significant increase in protein solubility, emulsion activity index, and emulsion stability index were observed. The greatest increase in solubility was observed between pH 5.0 and 7.0. The molecular weight of the hydrolysates was also reduced significantly during hydrolysis. These improved functional properties of different protein hydrolysates would make them useful products, especially in the food, pharmaceutical, and related industries

There was slight increase (about 10%) in protein content of sprouted sesame seeds; sprouting was to remove the bitter taste (Badifu and Akpagher 1996). The foaming capacity of flours from untreated, sprouted and boiled seeds were 34.6%, 38.5% and 11.5%, respectively. The flour from the boiled seeds had the highest foam stability. The emulsion capacity of flours from the untreated or sprouted seeds was the same (27.6 g oil/g sample) while that from boiled seeds was 12.9 g oil/g sample. Emulsion stability with prolonged storage appeared to be more with flours from the sprouted or boiled seeds than that from the untreated ones. The water absorption properties of flours from the untreated, sprouted and boiled seeds were 8.0, 5.9 and 6.5 g water/g sample, respectively whereas the oil absorption capacity was the same (5.9 g oil/g sample). The bitter taste in flours from the untreated or sprouted seeds was high. The bitter taste was not detected in flour from boiled seeds and the functional properties of the flour were not deleteriously affected except foaming and emulsion capacity. Thus boiling debittered the seed and the quality of sesame flour obtained after boiling could still serve its role in traditional dishes and in the formulation of some other conventional food products. Defatting increased the crude protein, ash, crude fiber, carbohydrate and mineral contents of sesame flour (Egbekun and Ehieze 1997). Defatted flour showed comparatively better foam capacity and stability, water absorption and emulsion capacities than full fat flour but diminished bulk density and oil absorption capacity. Nitrogen solubility was pH dependent with a minimum at pH 4 and maximum at pH 8. Maximum nitrogen solubility (95%) was recorded for defatted flour while that for the full fat flour was 60%.

Phytochemicals in Other Plant Parts

From a water extract of *Sesamum indicum* plant, two new, and six known phenylethanoid glycosides, and three new triglycosides which had the same sugar sequence were isolated (Suzuki et al. 1993). Six flavones were isolated from sesame flowers: apigenin (1), ladanetin (2), ladanetin-6-O-β-D-glucoside (3), apigenin-7-O-glucuronic acid (4), pedalitin (5), and pedalitin-6-O-glucoside (6) (Hu et al. 2007a). Ten compounds were isolated from the 95% ethanol extract of the flower and elucidated as latifonin (1), momor-cerebroside (2), soya-cerebroside II (3), 1-O-β-D-glucopyranosyl- (2S, 3S, 4R, 5E,9Z)-2-N-(2′-hydroxytetracosanoyl) 1,3,4-trihydroxy-5,9-octadienine (4), 1-O-β-D-glucopyranosyl-(2S, 3S, 4R, 8Z)-2-N-(2′R) 2′-hydroxytetracosanoyl) 3,4-dihydroxy-8-octadene (5), (2S, 1″ S) -aurantiamide acetate (6), benzyl alcohol-O-(2′-O-β-D-xylopyranosyl, 3′-O-β-D-glucopyranoside)-β-D-glucopyranoside (7), β-sitosterol (8), daucosterol (9) and D-galacititol (10) (Hu et al. 2007b). Compounds 2–4 were cerebroside, being rare to be found in land plants and were reported to possess many bioactivities. Sesamin, sesamolin,

stigmasterol, β-sitosterol and stigmasterol-3-O-β-D-glucoside were isolated from the petroleum ether fraction of the alcoholic extract of residual aerial parts of sesame after seed collection (Khaleel et al. 2007). Ferulic acid, rhamnetin, verbascoside, kaempferol-3-O-β-D-glucuronide and mequelianin (quercetin-3-O-β-D-glucuronide) were isolated from the butanol fraction. The content of the major constituents, namely sesamin and sesamolin, were also determined. A red naphthoquinone, named hydroxysesamone, (2,5,8-trihydroxy-3-(3-methyl-2-butenyl)-1,4-naphthoquinone) was isolated from the roots of Sesamum indicum together with a known yellow naphthoxirene derivative, 2,3-epoxy-2,3-dihydro-5,8-dihydroxy-2-(3-methyl-2-butenyl)-1,4-naphthoquinone, named 2,3-epoxysesamone (Hasan et al. 2001). Three anthraquinones, named anthrasesamones A, B and C, were isolated from the roots of Sesamum indicum, and their respective structures were characterised as 1-hydroxy-2-(4-methylpent-3-enyl)anthraquinone, 1,4-dihydroxy-2-(4-methylpent-3-enyl)anthraquinone and 2-chloro-1,4-dihydroxy-3-(4-methylpent-3-enyl) anthraquinone (Furumoto et al. 2003). Two known anthraquinones were also isolated from the roots and characterized as 2-(4-methylpent-3-enyl) anthraquinone and (E)-2-(4-methylpenta- 1,3-dienyl)anthraquinone. Anthrasesamone C is a rare chlorinated anthraquinone in higher plants. Another two anthraquinone derivatives, named anthrasesamones D and E, were isolated from the roots and characterised as 1,2,4-trihydroxy-3-(4-methylpent-3-enyl)anthraquinone and 1,2-dihydroxy-3-(4-methylpent-3-enyl)anthraquinone (Furumoto et al. 2006).

Biological Activities of Sesame Lignans

Sesame is a rich source of lignin phytoestrogens. Sesame contains very high levels (up to 2.5%) of furofuran lignans mainly sesamin, sesamolin, and sesaminol glucosides, all with beneficial neutraceutical functions (Namiki 1995, 2007; Kamal-Eldin et al. 2011). Research had indicate the novel synergistic effect of sesame lignans with tocopherols for the anti-aging effects of sesame resulting from the inhibition of metabolic decomposition of tocopherols by sesame lignans (Namiki 2007). Sesame lignans modulate fatty acid metabolism, lowering fatty acid concentration in liver and serum due to acceleration of fatty acid oxidation and suppression of fatty acid synthesis, and the controlling influence on the ratio of n-6/n-3 polyunsaturated fatty acids under excess intake of either n-6 or n-3 fatty acids in the diet. Sesame lignans have been reported to lower the cholesterol concentration in serum, especially in combination with tocopherol, due to the inhibition of absorption from the intestine and suppression of biosynthesis in the liver. Studies also showed other useful activities of sesame lignans like acceleration of alcohol decomposition in the liver, antihypertensive, immunoregulatory, anticarcinogenic, antioxidant, cardiovascular activities and other functions (Namiki 1995, 2007; Kamal-Eldin et al. 2011) as elaborated below.

Antioxidant Activity

Unsaponifiables from the brown sesame variety were markedly different in their composition from those of the white variety (Mohamed and Awatif 1998). The brown variety contained higher amounts of total sterols and tocopherols but lower amounts of sesamin, sesamolin and total hydrocarbons than the white variety. Roasting the seeds at 180°C for 30 minutes increased some effective antioxidant compounds. These included relatively higher percentages of sesamol, $\Delta^{24,28}$ ethylidene sterols (Δ^5 and Δ^7-avenasterols), squalene, as well as tocopherols and some active browning substances. Additionally, unsaponifiable matter from unroasted (USM) and roasted white sesame seeds (RSM) was added individually to sunflower oil at levels of 0.02%, 0.05% and 0.1% and their effectiveness was compared with a control (no additives) at 63°C. Results indicated that both USM and RSM had antioxidant activity which increased with increasing concentration. Compared to USM, the RSM was a better antioxidant in most cases. Moreover, the addition of 0.1% RSM gave a strong antioxidative efficiency and this could be

used as an alternative natural antioxidant for food applications.

Studies suggested that sesamolin and its metabolites the sesame lignans, sesaminol and sesamolinol may contribute to the antioxidative properties of sesame seeds and oil (Kang et al. 1998). Lipid peroxidation activity, measured as 2-thiobarbituric acid reactive substances, was significantly lower in the kidneys and liver of the sesamolin-fed rats than in the controls. Liver weight was significantly greater in the sesamolin-fed rats than in the controls. In addition, the amount of 8-hydroxy-2′-deoxyguanosine excreted in the urine was significantly lower in the sesamolin-fed rats. The results supported the hypothesis that sesame lignans reduced susceptibility to oxidative stress. In a subsequent study, the authors found that feeding defatted sesame flour to rabbits did not protect cholesterol-induced hypercholesterolemia, but may decrease susceptibility to oxidative stress in rabbits fed cholesterol, perhaps attributable to the antioxidative activity of sesaminol (Kang et al. 1998). Serum total cholesterol, phospholipid, triglyceride and HDL cholesterol concentrations were unaffected by the addition of the defatted sesame flour. Lipid peroxidation activity, measured as 2-thiobarbituric acid reactive substances (TBARS), was lower in the liver and serum of rabbits fed the deffated sesame flour plus cholesterol than in rabbits fed the cholesterol diet.

Dachtler et al. (2003) used the Rancimat assay to study the effect of the sesame oil extracts as well as pure sesame lignans and γ-tocopherol on the oxidative stability of sunflower oil (lignan-free). The Rancimat assay revealed the following oxidative stability order: sesame oil extract < sesame oil deodorizer distillate < sunflower oil (no added sesame oil extracts) < sesamol < sesaminol-enriched sesame oil extract. In addition, the Trolox® equivalent antioxidant capacity (TEAC) assay revealed a slightly different antioxidant activity order: sesamin < sesame oil extract < sesaminol-enriched sesame oil extract < sesamol. The authors concluded that the sesaminol-enriched extract exerted strong antioxidant activity and was therefore suitable to increase the oxidative stability of edible oils high in polyunsaturated fatty acids. Using a nanosecond pulse radiolysis technique, 5-hydroxy-1,3-benzodioxole sesamol efficiently scavenged hydroxyl, one-electron oxidizing, organo-haloperoxyl, lipid peroxyl, and tryptophanyl radicals (Joshi et al. 2005). In biochemical studies, it was found to inhibit lipid peroxidation, hydroxyl radical-induced deoxyribose degradation, and DNA cleavage.

Studies demonstrated that the graded-dose (25–1,000 μg/ml) of aqueous and ethanolic seed extracts from *S. indicum* markedly scavenged the nitric oxide, superoxide, hydroxyl, 1,1-diphenyl-2-picrylhydrazyl and 2,2′-azinobis-(3-ethylbenzothiazoline-6-sulfonic acid) radicals and, showed metal chelating ability as well as reducing capacity in Fe^{3+} ferricyanide complex and ferric reducing antioxidant power assays (Visavadiya et al. 2009). In biological models, both extracts were found to inhibit metal-induced lipid peroxidation in mitochondrial fractions, human serum and LDL oxidation models. In lipoprotein kinetics study, both extracts significantly increased lag phase time along with reduced oxidation rate and conjugated dienes production. Ethanolic extract of *S. indicum* showed higher amounts of total polyphenol and flavonoid content as compared to their counterpart. Overall, ethanolic extract of *S. indicum* possessed strong antioxidant capacity and offered effective protection against LDL oxidation susceptibility. Sesame ethanol seed extract showed 92.00% inhibition and 56.00% reduction ability in hydrogen donation and reducing power assays, respectively at maximum concentration of the extract tested (Nahar and Rokonuzzaman 2009). The antioxidant activity of the extract in all these in-vitro assays was compared with standard antioxidant (ascorbic acid). Results from the linoleic acid system showed that the antioxidant activity of black sesame seed extracted by supercritical carbon dioxide extraction SC-CO_2 followed the order: extract at 35°C, 20 MPa > BHT > extract at 55°C, 40 MPa > extract at °C, 30 MPa > Trolox > solvent extraction > α-tocopherol. The SC-CO_2 extracts exhibited significantly higher antioxidant activities comparable to that by n-hexane

extraction. The extracts at 30 MPa presented the highest antioxidant activities assessed in the DPPH method. At 20 MPa, the EC_{50} increased with temperature, which indicated that the antioxidant activity was decreased in a temperature-dependent manner. The significant differences of antioxidant activities were found between the extracts by SC-CO_2 extraction and n-hexane. However, no significant differences were exhibited among the extracts by SC-CO_2 extraction. The vitamin E concentrations were also significantly higher in SC-CO_2 extracts than in n-hexane extracts, and its concentrations in extracts corresponded with the antioxidant activity of extracts.

The free radical scavenging capacity (RSC) of sesame antioxidants expressed by the second-order rate constant (k_2) was calculated for the quenching reaction with (DPPH) radical and compared with those of butylated hydroxytoluene and α-tocopherol (Suja et al. 2004). The k_2 values for sesamol, sesamol dimer, sesamin, sesamolin, sesaminol triglucoside, and sesaminol diglucoside were 4.00×10^{-5}, 0.50×10^{-5}, 0.36×10^{-5}, 0.13×10^{-5}, 0.33×10^{-5} and 0.08×10^{-5} μM^{-1} s^{-1}, respectively.

The methanol extract of sesame (*Sesamum indicum*) seeds afforded 29 compounds including seven furofuran lignans (Kuo et al. 2011). Among these isolates, (+)-samin (1) was obtained from the natural source for the first time. In addition, (-)-asarinin (30) and sesamol (31) were generated by oxidative derivation from (+)-sesamolin (2) and (+)-sesamin (3), two abundant lignans found in sesame seeds. The in-vitro antioxidant potential of the seven isolated lignans (1–7) and the two derivatives (30 and 31) were examined for the scavenging activities on DPPH free radicals and superoxide anions in addition to chelating capability of ferrous ions and reducing power. The results suggested that, besides the well-known sesamolin and sesamin, the minor sesame lignans (+)-(7 S,8′R,8R)-acuminatolide (5), (-)-piperitol (6), and (+)-pinoresinol (7) were also adequate active ingredients and may be potential sources for nutritional and pharmacological utilization based on their in-vitro antioxidant potential.

Total phenolic, flavonoid and flavonol contents in sesame cake extract were 1.94 (mg gallic acid equivalent (GAE)/g dry weight (DW)), 0.88 (mg quercetain equivalent (QE)/g DW), and 0.40 (mg QE/g DW), respectively (Mohdaly et al. 2011). Sesame cake extract exerted protective effect in stabilizing sunflower oil (SFO) and soybean oil (SBO). It exhibited stronger antioxidant activity in SFO and SBO than butylated hydroxytoluene (BHT) and butylated hydroxyanisole (BHA), while its antioxidant activity was less than that of tert-butyl hydroquinone (TBHQ) as evaluated by (DPPH) radical scavenging capacity, and β-carotene/linoleic acid test system.

Lee et al. (2008b) investigated the effects of lignan compounds sesamol, sesamin, and sesamolin, extracted from roasted sesame oil, on oxidation of methyl linoleate (ML) during heating. conjugated dienoic acid (CDA) contents, *p*-anisidine value (PAV), and methyl linoleate decreased with heating time at 180°C. The antioxidant activity of sesame oil lignan compounds, sesamol, sesamin, and sesamolin in methyl linoleate oxidation during heating tended to be higher than that of α-tocopherol. The contents of lignan compounds in samples decreased with heating time due to their degradation, but the degradation rates were lower than that of α-tocopherol. This study suggested sesame oil lignan compounds could be used as antioxidants in oil at high temperatures for deep-fat frying due to their higher effectiveness and stability than α-tocopherol.

Roasting of sesame seeds for longer time and at higher temperature, generated more sesamol in sesame oil (Lee et al. 2010). Sesame oil from sesame seeds roasted at 247°C for 28 min had the highest oxidative stability. Higher oxidative stability of sesame oil may be related to the continuous generation of sesamol from the degradation of sesamolin during thermal oxidation rather than the initial antioxidant content.

Studies showed that sesame oil had the highest FRAP (Ferric Reducing/Antioxidant Power) value (803 μM), followed by canola oil (400 μM), and sunflower, peanut, corn and olive oils (100–153 μM) (Cheung et al. 2007). Oils with higher intrinsic antioxidant content showed higher resistance to oxidation.

Lipid and Alcohol Metabolism Activity

Animal studies showed sesamin, a sesame lignan, to be a potent inducer of hepatic fatty acid oxidation (Ashakumary et al. 1999). Dietary sesamin dose-dependently increased both mitochondrial and peroxisomal palmitoyl-coenzyme A (CoA) oxidation rates. Mitochondrial activity almost doubled in rats on the 0.5% sesamin diet. Peroxisomal activity increased more than ten-fold in rats fed a 0.5% sesamin diet in relation to rats on the sesamin-free diet. Dietary sesamin greatly increased the hepatic activity of fatty acid oxidation enzymes and induced increase in the gene expression of mitochondrial and peroxisomal fatty acid oxidation enzymes. In contrast, dietary sesamin decreased the hepatic activity and mRNA abundance of fatty acid synthase and pyruvate kinase, the lipogenic enzymes. However, this lignan increased the activity and gene expression of malic enzyme, another lipogenic enzyme. An alteration in hepatic fatty acid metabolism may therefore account for the serum lipid-lowering effect of sesamin in the rat. Studies showed that as dietary level of sesamin increased up to 0.4%, the activity and gene expression of enzymes involved in fatty acid synthesis including acetyl-CoA carboxylase, fatty acid synthase, ATP-citrate lyase and glucose-6-phosphate dehydrogenase decreased (Ide et al. 2001). Dietary sesamin dose-dependently decreased the sterol regulatory element binding protein-1 (SREBP-1) mRNA level, and the value in rats fed a 0.4% sesamin diet was approximately one-half that in those fed a sesamin-free diet. The findings suggested that dietary sesamin-dependent decrease in lipogenic enzyme gene expression was attributed to the suppression of the gene expression of SREBP-1 as well as the proteolysis of the membrane-bound precursor form of this transcriptional factor to generate the mature form. Dietary studies in rats showed that a diet containing sesamin and fish oil in combination synergistically increased hepatic fatty acid oxidation primarily through up-regulation of the gene expression of peroxisomal fatty acid oxidation enzymes (Ide et al. 2004). Dietary sesamin increased fatty acid oxidation enzyme activities in all groups of rats given different fats (palm, safflower, fish oil). A diet containing sesamin and fish oil in combination appeared to increase many of these parameters synergistically. In particular, the peroxisomal palmitoyl-CoA oxidation rate and acyl-CoA oxidase activity levels were much higher in rats fed sesamin and fish oil combination than in animals fed sesamin and palm or safflower oil combination.

Studies suggested that sesamin ingestion regulated the transcription levels of hepatic metabolizing enzymes for lipids and alcohol in rats (Kiso 2004). Twenty-four hours after sesamin ingestion, over 40% of the dose of sesamin was detected in bile as glucuronides of 2-(3, 4-methylenedioxyphenyl) -6-(3, 4-dihydroxyphenyl)-cis-dioxabicyclo[3.3.0] octane and 2-(3, 4-dihydroxyphenyl)-6-(3, 4-dihydroxyphenyl)-cis-dioxabicyclo[3.3.0] octane. Both metabolites showed strong radical scavenging activities against not only superoxide anion radical but also hydroxyl radical. Sesamin could be classified as a pro-antioxidant. Gene expression of hepatic lipid oxidation enzymes were increased but the transcription of the genes encoding the enzymes for fatty acid synthesis was decreased. Further in sesamin rats, the gene expression of aldehyde dehydrogenase was increased about three-fold, whereas alcohol dehydrogenase, liver catalase and CYP2E1 were not changed. Sesamin had been reported to have multiple functions such as stimulation effect of ethanol metabolism in mice and human, and prevention of ethanol-induced fatty liver in rats (Kiso et al. 2005). Results of a DNA microarray analysis in rats suggested that sesamin ingestion regulated the transcription levels of hepatic metabolizing enzymes for alcohol and lipids. The gene expression levels of the early stage enzymes of β-oxidation including long-chain acyl-CoA synthetase, very long-chain acyl-CoA synthetase and carnitine palmitoyltransferase were not changed, however, those of the late stage enzymes of β-oxidation including trifunctional enzyme in mitochondria, and acyl-CoA oxidase, bifunctional enzyme and 3-ketoacyl-CoA thiolase in peroxisomes, were significantly enhanced by sesamin ingestion. Also, in sesamin rats, the gene expression of aldehyde dehydrogenase was

increased about three-fold, whereas alcohol dehydrogenase, liver catalase and CYP2E1 were not changed

Further studies suggested that sesamin regulated the metabolism of lipids, xenobiotics, and alcohol at the mRNA level (Tsuruoka et al. 2005). The ingestion of sesamin dissolved in olive oil up-regulated the expression of 38 genes, 16 of which encode proteins possessing a lipid-metabolizing function, and 16 of which encode proteins possessing a xenobiotic/endogenous substance metabolizing function. In particular, sesamin significantly increased the expression of β-oxidation-associated enzymes in peroxisomes and auxiliary enzymes required for degradation, via the β-oxidation pathway, of unsaturated fatty acids in mitochondria. Sesamin ingestion also resulted in an increase in the gene expression of acyl-CoA thioesterase involved in acyl-CoA hydrolase and very-long-chain acyl-CoA thioesterase and also induced the expression of the gene for aldehyde dehydrogenase, an alcohol-metabolizing enzyme. Dietary sesamin and docosahexaenoic and eicosapentaenoic acids were found to synergistically increase the gene expression of enzymes involved in hepatic peroxisomal fatty acid oxidation in rats (Arachchige et al. 2006). Sesamin and sesamolin dose-dependently increased the activity and mRNA abundance of various enzymes involved in hepatic fatty acid oxidation in rats (Lim et al. 2007). The increase was much greater with sesamolin than with sesamin. In contrast, they decreased the activity and mRNA abundance of hepatic lipogenic enzymes despite dose-dependent effects. Sesamin and sesamolin were equally effective in lowering parameters of lipogenesis. Sesamin compared to sesamolin was more effective in reducing serum and liver lipid levels despite sesamolin more strongly increasing hepatic fatty acid oxidation. Differences in bioavailability may contribute to the divergent effects of sesamin and sesamolin on hepatic fatty acid oxidation.

Ide et al. (2009) found that compared to a lignan-free diet, a diet containing sesamin, episesamin and sesamolin caused more than 1.5- and 2-fold changes in the expression of 128 and 40, 526 and 152, and 516 and 140 hepatic genes, respectively. The lignans modified the mRNA levels of not only many enzymes involved in hepatic fatty acid oxidation, but also proteins involved in the transportation of fatty acids into hepatocytes and their organelles, and in the regulation of hepatic concentrations of carnitine, CoA and malonyl-CoA. Sesame lignans stimulated hepatic fatty acid oxidation by affecting the gene expression of various proteins regulating hepatic fatty acid metabolism. The changes in the gene expression were generally greater with episesamin and sesamolin than with sesamin. In terms of amounts accumulated in serum and the liver, the lignans ranked in the order sesamolin, episesamin and sesamin. The differences in bioavailability among these lignans appeared to be important to their divergent physiological activities.

Supplementation of sesame seeds at levels of 200 g/kg to the experimental diets in rats increased both the hepatic mitochondrial and the peroxisomal fatty acid oxidation rate (Sirato-Yasumoto et al. 2001). Increases were greater with sesame cultivars rich in lignans than with the conventional cultivar Maskin. Noticeably, peroxisomal activity levels were >3 times higher in rats fed diets containing sesame seeds from lignan lines than in those fed a control diet without sesame. Diets containing seeds from lignin rich lines, compared to the control and Masekin diets, also significantly increased the activity of hepatic fatty acid oxidation enzymes including acyl-CoA oxidase, carnitine palmitoyltranferase, 3-hydroxyacyl-CoA dehydrogenase, and 3-ketoacyl-CoA thiolase. In contrast, diets containing sesame lowered the activity of enzymes involved in fatty acid synthesis including fatty acid synthase, glucose-6-phosphate dehydrogenase, ATP-citrate lyase, and pyruvate kinase. Serum triacylglycerol concentrations were lower in rats fed diets containing sesame from lignin rich lines than in those fed the control or Masekin diet. It was apparent that sesame rich in lignans more profoundly affected hepatic fatty acid oxidation and serum triacylglycerol levels. Thus, consumption of sesame rich in lignans resulted in physiological activity to alter lipid metabolism in a potentially beneficial manner.

In a randomized crossover study, 16 postmenopausal women were supplemented in their diets with food bars containing either 25 g unground flaxseed, sesame seed, or their combination (12.5 g each) (flaxseed + sesame seed bar, FSB) for 4 week each, separated by 4 week washout periods (Coulman et al. 2009). Total serum n-3 fatty acids increased with flaxseed and FSB while serum n-6 fatty acids increased with sesame seed. Urinary lignans increased similarly with all treatments. Plasma lipids and several antioxidant markers were unaffected by all treatments, except serum γ-tocopherol (GT), which was increased with both sesame seed and FSB. The findings indicated that fatty acids and lignans from unground seed in food bars were absorbed and metabolized; however, except for serum γ-tocopherol, the 25 g unground seed had minimal antioxidant and lipid-lowering effects in postmenopausal women.

Hypolipidemic and Hypocholesteremic Activity

(+)-sesamin was found to be a potent and specific inhibitor of delta 5 desaturase in polyunsaturated fatty acid biosynthesis in the arachidonic acid-producing fungus, *Mortierella alpine* and rat liver microsomes (Shimizu et al. 1991). (+)-Sesamolin, (+)-sesaminol and (+)-episesamin also inhibited only delta 5 desaturases of the fungus and liver. In normocholesterolaemic stroke-prone spontaneously hypertensive (SHRSP) rats fed a regular diet, both sesamin and episesamin significantly increased the concentration of serum total cholesterol, which was due to an increase of high density lipoprotein (HDL) subfraction rich in apoE (apoE-HDL) (Ogawa et al. 1995). In addition, both compounds effectively decreased serum very low density lipoprotein (VLDL). In the liver, only episesamin significantly decreased the activity of microsomal acyl-CoA:cholesterol acyltransferase. In hypercholesterolaemic SHRSP fed a high-fat and high-cholesterol diet (HFC diet), only episesamin improved serum lipoprotein metabolism with an increase in apoA-I and a decrease in apoB. In the liver, both sesamin and episesamin significantly suppressed cholesterol accumulation. Only episesamin significantly increased the activity of microsomal cholesterol 7α-hydroxylase. These results indicated that sesamin may be effective in preventing cholesterol accumulation in the liver. In comparison with sesamin, episesamin may be effective in the regulation of cholesterol metabolism in the serum and liver. A study on male patients with hypercholesterolemia suggested that sesamin could reduce serum cholesterol especially LDL-C, a risk factor for atherosclerosis (Hirata et al. 1996) Sesamin treatment significantly reduced total cholesterol, LDL-C, and apoprotein (apo) B compared to placebo group. Results of studies suggest that sesame ingestion benefited postmenopausal women by improving blood lipids, antioxidant status, and possibly sex hormone status (Wu et al. 2006). After sesame treatment, plasma total cholesterol (TC), LDL-C, the ratio of LDL-C to HDL-C, thiobarbituric acid reactive substances in oxidized LDL, and serum dehydroepiandrosterone sulfate decreased significantly. The ratio of α- and γ-tocopherol to TC increased significantly by 18% and 73%, respectively. Serum sex hormone-binding globulin and urinary 2-hydroxyestrone increased significantly by 15% and 72%, respectively, after sesame treatment.

Studies showed that LDL receptor-deficient mice fed an atherogenic diet had an almost three-fold increase in serum cholesterol levels but no effect was observed for triglyceride levels (Peñalvo et al. 2006). Stanol ester alone or together with sesamin significantly attenuated the elevation of the cholesterol levels. Sesamin alone did not affect the elevation of the diet-induced cholesterol level and it did not enhance the effect of stanol ester.

Administration of sesame seed powder to hypercholesteraemic rats resulted in a significant decrease in plasma, hepatic total lipid and cholesterol contents and, plasma LDL-cholesterol contents with an elevation in plasma HDL-cholesterol content (Visavadiya and Narasimhacharya 2008). Further, these animals also exhibited enhanced fecal excretion of cholesterol, neutral sterol and bile acid along with increases in hepatic HMG-CoA reductase activity and bile acid

concentration. Additionally sesame seed feeding improved the hepatic antioxidant status (catalase and SOD enzyme activities) with a decrease in lipid peroxidation. No significant changes in lipid and antioxidant profiles occurred in the normocholesteraemic rats administered with sesame seed powder. These beneficial effects of sesame seed on hypercholesteraemic rats appeared to be due to its fibre, sterol, polyphenol and flavonoid content, enhancing the fecal cholesterol excretion and bile acid production and as well as increasing the antioxidant enzyme activities.

Antidiabetic Activity

Flavonoids from *Sesamum indicum* elicited hypolipidemic and hypoglycemic activities in rats and raised the hemoglobin levels (Anila and Vijayalakshmi 2000). Studies indicated that hot-water extract from defatted sesame seeds and the methanol eluent fraction in the diet had a reductive effect on the plasma glucose concentration of diabetic KK-Ay mice, and this effect was suggested to have been caused by the delayed glucose absorption (Takeuchi et al. 2001). The alcoholic, petroleum ether and butanol extracts of sesame residual aerial plant parts significantly restored the reduced levels of glutathione in the hyperglycaemic diabetic rats (Khaleel et al. 2007). The total alcoholic extract was the most potent exhibiting comparable activity to that of vitamin E at the tested doses. All tested extracts showed a reductive effect on blood glucose level of diabetic rats. The total alcoholic extract showed a more powerful effect than its fractions. The stronger activity of the total alcoholic extract over its fractions might be attributed to a synergistic effect of the lignans present mainly in the petroleum ether fraction, and the phenolic compounds present in the butanol fraction. Sesame lignans, rhamnetin, ferulic acid, verbascoside and mequelianin had been reported to possess antioxidant activity. The researchers concluded that the alcoholic extract may be useful in alleviating oxidative stress and attenuating the hyperglycaemic response associated with diabetes.

In an open label study of type 2 diabetes mellitus patients, combination therapy of sesame oil and glibenclamide showed an improved antihyperglycaemic effect with 36% reduction of glucose and 43% reduction of glycated haemoglobin, HbA1c compared to sesame oil or glibenclamide monotherapy (Sankar et al. 2011). Significant reductions in the plasma TC, LDL-C and TG levels were noted in sesame oil (20%, 33.8% and 14% respectively vs. before treatment) or combination therapies (22%, 38% and 15% respectively vs. before treatment). Plasma HDL-C was significantly improved in sesame oil (15.7% vs. before treatment) or combination therapies (17% before treatment). Significant improvement was observed in the activities of enzymatic and non-enzymatic antioxidants in patients treated with sesame oil and its combination with glibenclamide. The authors asserted that, sesame oil exhibited synergistic effect with glibenclamide and could provide a safe and effective option for the drug combination that may be very useful in clinical practice for the effective improvement of hyperglycemias.

Anticancer Activity

The alcohol extract from *Sesamum indicum* flower inhibited tumour growth in sarcoma 180 (S180) and Hep22 (H22) tumorigenic mice (Xu et al. 2003). Studies found sesamin and episesamin isolated from unroasted sesame seed oil induced apoptosis in human lymphoid leukemia Molt 4B cells (Miyahara et al. 2000). Exposure of human lymphoid leukemia Molt 4B cells to sesamin and episesamin led to both growth inhibition and the induction of programmed cell death (apoptosis). The results suggested that growth inhibitions by sesamin and episesamin of Molt 4B cells resulted from the induction of apoptosis in the cells. Harikumar et al. (2010) found that sesamin, a lipid-soluble lignin isolated from *S. indicum*, inhibited the proliferation of a wide variety of tumour cells including leukemia, multiple myeloma, and cancers of the colon, prostate, breast, pancreas, and lung. Sesamin also potentiated tumour necrosis factor-α-induced apoptosis

and this correlated with the suppression of gene products linked to cell survival (e.g., Bcl-2 and survivin), proliferation (e.g., cyclin D1), inflammation (e.g., cyclooxygenase-2), invasion (e.g., matrix metalloproteinase-9, intercellular adhesion molecule 1), and angiogenesis (e.g., vascular endothelial growth factor). Sesamin down regulated constitutive and inducible NF-κB activation induced by various inflammatory stimuli and carcinogens, and inhibited the degradation of IκBα, the inhibitor of NF-κB, through the suppression of phosphorylation of IκBα and inhibition of activation of IκBα protein kinase. The inhibition of IκBα protein kinase activation was found to be mediated through the inhibition of TAK1 kinase. Their results showed that sesamin may have potential against cancer and other chronic diseases through the suppression of a pathway linked to the NF-κB signalling.

Studies in mice with MCF-tumours, lignan-rich sesame seed negated the tumour-inhibitory effect of tamoxifen by reducing apoptosis but beneficially interacted with tamoxifen on bone in ovariectomized athymic mice (Sacco et al. 2008). Sesame seed combined with tamoxifen induced higher bone mineral content, bone mineral density, and biomechanical strength in the femur and lumbar vertebrae than either treatment alone.

Vitamin E (α-Tocopherol) Enhancing Activity

Vitamin E has been recognised as an important dietary component with antiaging function (Meydani 1992). Studies in rats demonstrated that γ-tocopherol in sesame seed exerted vitamin E activity equal to that of α-tocopherol through a synergistic interaction with sesame seed lignans (Yamashita et al. 1992). Indices of vitamin E activity were ascertained as changes in red blood cell hemolysis, plasma pyruvate kinase activity, and peroxides in plasma and liver. The sesame seed diet had high vitamin E activity, whereas this activity was low in the γ-tocopherol diet. In an additional experiment, sesame lignin (sesaminol or sesamin)-fed groups exhibited vitamin E activity comparable to that observed in the sesame seed-fed group in the earlier experiment. Yamashita et al. (1995) reported that sesame seed lignans enhanced vitamin E activity in rats fed a low α-tocopherol diet and caused a marked increase in α-tocopherol concentration in the blood and tissue of rats fed an α-tocopherol-containing diet with sesame seed or its lignans. Sesamin and α-tocopherol were found to synergistically suppress lipid-peroxide in rats fed a high docosahexaenoic acid diet (Yamashita et al. 2000). TBARS concentrations in plasma and liver were significantly increased by docosahexaenoic acid, but were completely suppressed by sesamin. α-tocopherol concentrations in plasma and liver decreased by addition of docosahexaenoic acid, but were restored to control level with sesamin. Both flaxseed and sesame seed were reported to contain more than 40% fat, about 20% protein, and vitamin E, mostly γ-tocopherol and considerable amounts of plant lignans (Yamashita et al. 2003). However, flaxseed contained 54% α-linolenic acid, but sesame seed only 0.6%, and the chemical structures of flaxseed and sesame lignans were different. Dietary studies in rats showed that that sesame seed and its lignans induced higher γ-tocopherol and lower TBARS concentrations; whereas flaxseed lignans had no such effects (Yamashita et al. 2003). Further, α-linolenic acid produced strong plasma cholesterol-lowering effects and higher TBARS concentrations. Further studies suggested that the sesame lignan seminol increased tocopherol concentrations in animals by suppressing the conversion of γ-tocopherol to γ-CEHC (2, 7, 8-trimethyl-2(2′-carboxyethyl)-6-hydroxychroman), a γ-tocopherol metabolite (Yamashita et al. 2007). HMR (7-hydroxymatairesinol), a structurally different dibenzylbutyrolactone type lignin from sesame seed, did not have such properties.

Dietary docosahexaenoic acid elevated the thiobarbituric acid reactive substance (TBARS) concentration and also increased the red blood-cell hemolysis induced by the dialuric acid in rats while dietary sesamin and sesaminol lowered the TBARS concentrations and decreased the red blood hemolysis (Ikeda et al. 2003). Additionally, dietary sesamin and sesaminol elevated the α-tocopherol concentrations in the plasma, liver, and brain of the rats fed a diet with or without

DHA. The results suggested that dietary sesame lignans decreased lipid peroxidation as a result of elevating the α-tocopherol concentration in rats fed docosahexaenoic acid. Further studies by Ikeda et al. (2007) suggested that dietary sesame seed and its lignin, sesamin stimulated ascorbic acid synthesis as a result of the induction of UDP-glucuronosyltransferase 1A and 2B-mediated metabolism of sesame lignan in rats. Data from ODS (Osteogenic Disorder Shionogi) inherently scorbutic rats, also suggested that dietary sesame seed enhanced antioxidative activity in the tissues by elevating the levels of two antioxidative vitamins, vitamin C and E. Sesame seed elevated the γ-tocopherol concentration in the various ODS rat tissues and the ascorbic acid concentrations in the kidney, heart and lung, while reducing the thiobarbituric acid reactive substance concentration in the heart and kidney.

The tocopherols, the major vitamers of vitamin E, are believed to play a role in the prevention of human aging-related diseases such as cancer and heart disease (Cooney et al. 2001). Studies in humans found that consumption of as little as 5 mg of γ-tocopherol per day over a 3-day period from sesame seeds significantly elevated serum γ-tocopherol levels (19.1% increase) and depressed plasma β-tocopherol (34% decrease) (Cooney et al. 2001). No significant changes in baseline or post-intervention plasma levels of cholesterol, triglycerides, or carotenoids were seen for any of the intervention groups. All subjects consuming sesame seed-containing muffins had detectable levels of the sesame lignan sesamolin in their plasma. The results suggested that consumption of moderate amounts of sesame seeds appeared to significantly increase plasma γ-tocopherol and alter plasma tocopherol ratios in humans. The results were in accord with the effects of dietary sesame seeds observed in rats leading to elevated plasma γ-tocopherol and enhanced vitamin E bioactivity.

Antihypertensive Activity

Sesamin (lignin from sesame oil) feeding in rats ameliorated the development of deoxycorticosterone acetate (DOCA)-salt-induced vascular hypertrophy in both the aorta and mesenteric artery (Matsumura et al. 1995). The treatment with DOCA and salt for 5 weeks significantly increased the weight of the left ventricle plus the septum, however, this increase was significantly suppressed in the sesamin group. These findings strongly suggested sesamin to be useful as a prophylactic treatment in the development of hypertension and cardiovascular hypertrophy. Dietary feeding of rats with sesamin markedly reduced the two-kidney, one-clip (2K, 1C) renal hypertension and also ameliorated vascular hypertrophy (Kita et al. 1995). Sesamin feeding was much more effective as an antihypertensive regimen in salt-loaded SHRSP (stroke-prone spontaneously hypertensive) rats than in unloaded SHRSP rats, thereby suggesting that sesamin was more useful as a prophylactic treatment in the malignant status of hypertension and/or hypertension followed by water and salt retention (Matsumura et al. 1998). Dietary sesamin also efficiently improved the abnormal vasodilator and vasoconstrictor responses in DOCA-salt hypertensive animals (Matsumura et al. 2000). Sesamin ameliorated the DOCA suppressed acetylcholine (ACh)-induced endothelium-dependent relaxation of aortic rings. This improvement appeared to be related to a nitric oxide (NO)-dependent component of ACh-induced action, because sesamin feeding did not affect the responses to ACh in the presence of NO synthase inhibitor. Sesamin feeding and triple therapy also significantly improved the DOCA-salt-induced impairment of endothelium-dependent relaxation (Nakano et al. 2003). In addition, dietary sesamin prevented DOCA salt-induced increases in aortic NADPH oxidase activity and subunit mRNA expression (Nakano et al. 2008). All these effects may contribute to the anti-oxidant and antihypertensive activity of sesamin. In a double-blind, cross-over, placebo-controlled trial of 25 middle-aged subjects with mild hypertension, 4 week administration of 60 mg sesamin significantly decreased blood pressure by an average of 3.5 mmHg systolic BP and 1.9 mmHg diastolic BP compared with placebo (Miyawaki et al. 2009). The results suggested that sesamin had an antihypertensive effect in humans. Epidemiological studies

suggested that a 2–3 mmHg decrease in blood pressure reduced the rate of cardiovascular diseases; therefore, it is considered that blood pressure reduction achieved by sesamin may be meaningful to prevent cardiovascular diseases.

The petroleum ether soluble fraction of sesame roots at concentrations up to 180 ug/ml concentration significantly inhibited phenylephrine-induced and KCl-induced contraction in isolated rat aorta in a concentration dependent manner (Suresh Kumar et al. 2008). The vasorelaxant activity was not blocked by propranolol (10 μM), atropine (1 μM) indomethacin (10 μM) and glibenclamide (10 μM). However, in absence of functional endothelium, the extract exhibited little relaxation, indicating that the vasorelaxant activity of sesame root extract was chiefly mediated through endothelium-dependent pathway.

Separate studies suggested that the enhancement of endothelium-dependent vasorelaxation induced by sesamin metabolites SC-1 m (piperitol), SC-1 (demethylpiperitol), SC-2 m [(1R, 2S,5R,6S)-6-(4-hydroxy-3-methoxyphenyl)-2-(3,4-dihydroxyphenyl)-3,7-dioxabicyclo[3,3,0] octane], and SC-2 [(1R,2S,5R, 6S)-2,6-bis(3,4-dihydroxyphenyl)-3,7-dioxabicyclo-[3,3,0] octane] was one of the important mechanisms of the in-vivo antihypertensive effect of sesamin (Nakano et al. 2006). SC-1, SC-2 m, and SC-2, but not SC-1 m, exhibited potent radical-scavenging activities against the xanthine/xanthine oxidase-induced superoxide production. On the other hand, SC-1 m, SC-1, and SC-2 m produced endothelium-dependent vasorelaxation in phenylephrine-precontracted rat aortic rings, whereas SC-2 had no effect. Neither SC-1 m nor SC-1 changed the expression level of endothelial nitric oxide synthase protein in aortic tissues. The antihypertensive effects of sesamin feeding were not observed in chronically NG-nitro-L-arginine -treated rats or in deoxycorticosterone acetate-salt-treated endothelial nitric oxide synthase-deficient mice.

The results of a randomized study involving 22 women and 9 men with prehypertension showed that 4-week administration of black sesame meal significantly decreased systolic blood pressure (129.3 vs. 121.0 mmHg,) and malondialdehyde (MDA) level (1.8 vs. 1.2 μmol/L,), and increased vitamin E level (29.4 vs. 38.2 μmol/L) (Wichitsranoi et al. 2011). In the black sesame meal group, the change in systolic blood pressure tended to be positively related to the change in MDA ($R = 0.50$), while the change in diastolic blood pressure was negatively related to the change in vitamin E ($R = -0.55$). The finding suggested the possible antihypertensive effects of black sesame meal on improving antioxidant status and decreasing oxidant stress and may have a beneficial effect on prevention of cardiovascular diseases.

Cardiovascular Activity

Sesamol was found to induced nitric oxide release from human umbilical vein endothelial cells in a dose-dependent manner, the expression of endothelial NO synthase (eNOS) at both transcription and translation levels; and NO synthase (NOS) activity in endothelial cells (Chen et al. 2005). The content of cGMP was also increased by sesamol through nitric oxide signalling. The transcription of eNOS induced by sesamol was confirmed through the activation of PI-3 kinase-Akt (protein kinase B) signalling. The results demonstrated that sesamol induced NOS signalling pathways in human umbilical vein endothelial cells and suggested a role for sesamol in cardiovascular reactivity in-vivo.

In a randomized, placebo-controlled crossover intervention trial of overweight or obese men and women, supplementation with 25 g/day of sesame could significantly increase the exposure to mammalian lignans (Wu et al. 2009). However, this did not cause any improvement in markers of cardiovascular disease risk in overweight or obese men and women. Urinary excretion of the mammalian lignans, enterolactone and enterodiol, increased by approximately eightfold. Blood lipids and blood pressure were not altered. In addition, markers of systemic inflammation (C-reactive protein, interleukin-6, tumour necrosis factor-α) and lipid peroxidation (F(2)-isoprostanes) were not affected.

Antiinflammatory Activity

The data from studies suggested that sesame seed oil containing sesamin and Quil A, a fat emulsifying saponin when present in the mice diet exerted cumulative effects that resulted in a decrease in the levels of dienoic eicosanoids with a reduction in interleukin IL-1β, prostaglandin-E2 and thromboxane-B2 and a concomitant elevation in the levels of IL-10 that were associated with a marked increase in survival in mice (Chavali et al. 1997). Chronic ethanol drinking, at the dietary level of 23% (w/w), significantly increased the plasma IgA and IgM concentrations in rats, irrespective of the presence of 0.1% and 0.2% sesaminol, but the effects disappeared with 0.2% sesamin (Nonaka et al. 1997). A significant IgG-elevating effect of these lignans was also found. Although ethanol drinking did not influence splenic leukotriene B4 production, sesaminol tended to decrease it dose dependently, while sesamin increased the plasma prostaglandin E2 concentration. These results suggested that sesaminol and sesamin appeared to have a diverse effect on the plasma levels of immunoglobulins and eicosanoids.

Following a lethal dose of lipopolysaccharide endotoxin injection, all control animals died, survival was 40% in the sesame seed oil group and 27% and 50%, respectively, in those fed Quil-A-supplemented control and sesame seed oil diets. Further studies showed that sesamin, sesamol and other lignans in sesame seed oil appeared to be responsible for an increase in mice survival after caecal ligation and puncture and also for an increase in the IL-10 levels in response to a nonlethal dose of endotoxin in mice (Chavali et al. 2001). The authors asserted that lignans present in the non-fat portion of sesame seed oil (SSO) could inhibit delta-5 desaturase activity, resulting in an increase in the accumulation of dihomo-γ-linolenic acid and, subsequently, decreased the production of proinflammatory dienoic eicosanoids with a concomitant increase in the secretion of less inflammatory monoenoic eicosanoids. Studies showed that sesamin significantly inhibited lipopolysaccharides-stimulated IL-6 mRNA and protein, and to a lesser degree TNF-α, in BV-2 microglia (Jeng et al. 2005). Sesamin and sesamolin also reduced LPS-activated p38 mitogen-activated protein kinase (MAPK) and nuclear factor (NF)-κB activations. The results suggested that sesamin inhibited LPS-induced IL-6 production by suppression of p38 MAPK signal pathway and NF-κB activation.

Animal studies showed that sesaminol triglucoside, the main sesame lignin, had anti-inflammatory and estrogenic activities via metabolism of intestinal microflora (Jan et al. 2010). After oral administration of sesaminol triglucoside to Sprague-Dawley rats, the concentrations of major sesaminol triglucoside metabolites in rectum, cecum, colon, and small intestines were higher than those in liver, lung, kidney, and heart. The study demonstrated that sesaminol triglucoside may be metabolized to form the catechol metabolites first by intestinal microflora and then incorporated via intestine absorption into the cardiovascular system and transported to other tissues. Sesaminol triglucoside metabolites significantly reduced the production of IL-6 and TNF-α in RAW264.7 murine macrophages stimulated with lipopolysaccharide. The estrogenic activities of sesaminol triglucoside metabolites were also established by ligand-dependent transcriptional activation through estrogen receptors.

Oestrogenic Activity

After 8 weeks of a diet rich in sesame pericarp, the expression of oestrogen receptors (ERα and ERβ) in the prostate and uterus tissues of male and female Wistar rats were determined (Anagnostis and Papadopoulos 2009). Significant increase in the expression of ERβ in prostate and uterus was evident. No statistically significant change was observed in the expression of ERα in uterus but in prostate, the increase was more evident. In both tissues, a shift of the ratio of ERα: ERβ in favour of ERβ was evident, indicating, a beneficial effect of the diet provided upon the health status of the animals. It was suggested that this effect could be attributed to the lignans present in the pericarp which exerted phyto-oestrogenic activity.

Neuroprotective and Cognitive Activity

Dietary sesaminol glycosides (SG) from sesame seeds showed a protective effect against Abeta-induced learning and memory deficits in mice in the passive avoidance and the Morris water maze test (Um et al. 2009). Injection of β-amyloid protein (Abeta)(25–35) in mice caused significant neuronal loss in the CA1 and CA3 regions of the hippocampus, but SG supplement showed decrease of the Abeta(25–35) induced neuronal loss. The SG supplementation significantly decreased thiobarbituric acid reactive substance values and 8-hydroxy-2′-deoxyguanosine (8-OHdG) levels in brain tissue. SG also reversed the activity of glutathione peroxidase (GPx), which is decreased by Abeta. The results suggested that sesaminol glycosides protected against cognitive deficits induced by Abeta (25–35), in part through its antioxidant activity.

Defatted sesame seeds extract (DSE) (0.1–10 μg/ml) significantly reduced e neuronal cell death and inhibited lipid peroxidation induced by oxygen-glucose deprivation followed by reoxygenation ischemia in the rat brain (Jamarkattel-Pandit et al. 2010). DSE (30, 100 and 300 mg/kg, p.o.) given twice at 0 and 2 hours after onset of ischemia reduced brain infarct volume dose-dependently and improved sensory-motor function. The results showed that DSE may be effective in ischemia models by an antioxidative mechanism.

Studies showed that oral administration of sesamin (30 mg/kg) twice, 30 minutes before the onset of ischemia and 12 hours after reperfusion in rats reduced the neurological deficits in terms of behaviour and reduced the level of thiobarbituric acid reactive species (TBARS), and protein carbonyl (PC) in the different areas of the brain when compared with rats with brain injury after middle cerebral artery occlusion (MCAO) (Khan et al. 2010). A significantly depleted level of glutathione and its dependent enzymes (glutathione peroxidase [GPx] and glutathione reductase [GR]) in MCAO group were protected significantly in MCAO group treated with sesamin. The study suggested that sesamin may be able to attenuate the ischemic cell death and may play a crucial role as a neuroprotectant in regulating levels of reactive oxygen species in the rat brain. Thus, sesamin may be a potential compound in stroke therapy.

Hepatoprotective Activity

Studies suggested sesamin to be a prodrug and the enzymatic metabolites containing the catechol moieties in their structures, namely (1R,2S,5R,6S)-6-(3,4-dihydroxyphenyl)-2-(3,4-methylenedioxyphenyl)-3,7-dioxabicyclo[3,3,0]octane and (1R,2S,5R,6S)-2,6-bis (3,4-dihydroxyphenyl)-3,7-dioxabicyclo[3,3,0] octane, were responsible for the protective effects of sesamin against oxidative damage in the rat liver (Nakai et al. 2003). All the metabolites exhibited strong radical scavenging activities. The same metabolites were found as glucuronic acid and/or sulfic acid conjugates in substantial amounts in rat bile after oral administration of sesamin. Another study showed that *Sesamum indicum* had potent hepatoprotective activity against carbon tetrachloride induced hepatic damage in rats (Kumar et al. 2011b). The substantially elevated SGOT (serum glutamic oxaloacetic transaminase), SGPT (serum glutamic pyruvic transaminase), Alkaline phosphatase, acid phosphatase, total protein albumin and total bilirubin were restored to normal levels by the ethanol extract of *S. indicum* seeds. This was further supported by histological examination of the rat's liver sections.

Antityrosinase Activity

Sesamol a phenolic degradation product of sesamolin from sesame seed inhibited both diphenolase and monophenolase activities with midpoint concentrations of 1.9 and 3.2 μM, respectively (Kumar et al. 2011a). It was a competitive inhibitor of diphenolase activity and a non-competitive inhibitor of monophenolase

activity. Sesamol inhibited melanin synthesis in mouse melanoma B16F10 cells in a concentration dependant manner with 63% decrease in cells exposed to 100 μg/ml sesamol. Apoptosis was induced by sesamol, limiting proliferation.

Wound Healing Activity

In the excision and burn wound models, the sesame seed and oil treated animals displayed significant reduction in period of epithelization and wound contraction (50%) (Kiran and Asad 2008). In the incision wound model, a significant increase in the breaking strength was observed. Seeds and oil treatment (250 mg and 500 mg/kg; po) in dead space wound model, produced a significant increase in the breaking strength, dry weight and hydroxyproline content of the granulation tissue. The results suggested that sesame seed and oil applied topically or administered orally possessed wound healing activity. Using incision, excision and dead space wounds inflicted on albino rats , the tensile strength significantly increased with sesamol at 471.40 g when compared to control at 300.60 g in normal and sesamol suppressed healing (Shenoy et al. 2011). No significant change was observed in duration of wound contraction and lysyl oxidase when compared to control at 2.98 mg. Sesamol treated rats showed a significant rise in hydroxyproline levels at 6.45 mg when compared to control at 1.75 mg. The results indicated that sesamol, the main anti-oxidative constituent contained mainly in the processed sesame seed oil, could be a promising drug in normal as well as delayed wound healing processes.

Analgesic Activity

Sesame ethanol seed extract showed a significant dose-dependent inhibition on the writhing response produced by induction of acetic acid (Nahar and Rokonuzzaman 2009). The extract produced about 48.19% and 75.46% writhing inhibition at the doses of 250 and 500 mg/kg, respectively, which was comparable to the standard drug ibuprofen where the inhibition was about 71.82% at the dose of 25 mg/kg.

Fertility Activity

The results obtained in studies of male Wistar rats showed that ethanolic extract of *Sesamum indicum*, vitamin C and their combination were capable of significantly increasing body weight gain, seminal parameters, testosterone level, and body antioxidant activities (Ashamu et al. 2010) The results suggested that they promoted fertility via their testosterone-increasing effects and their antioxidant effects.

Metabolism of Sesame lignans

Coulman et al. (2005) demonstrated in a randomized crossover study of healthy postmenopausal women that precursors from unground whole flaxseed and sesame seed were converted by the bacterial flora in the colon to mammalian lignans enterolactone and enterodiol and that sesame seed, alone and in combination with flaxseed, produced mammalian lignans equivalent to those obtained from flaxseed alone. Sesame seed was found to be a rich source of mammalian lignan precursors and Sesamin was one of the major precursors of mammalian lignans as observed in vitro and in rats (Liu et al. 2006). The total plant lignan concentration in sesame seed (2,180 μmol/100 g) was higher than that in flaxseed (820 μmol/100 g). In-vitro fermentation with human faecal inoculum showed conversion of sesamin to the mammalian lignans. when fed to female Sprague-Dawley rats for 10 days, sesamin (15 mg/kg body weight) and a 10% sesame seed diet resulted in greater urinary mammalian lignan excretion (3.2 and 11.2 μmol/day, respectively), than the control (< 0.05 μmol/day).

Sesame lignin, sesaminol triglucoside with methylenedioxyphenyl moieties in its structure, was metabolized, via intestinal microbiota, to a catechol moiety (Jan et al. 2009). The major

sesaminol triglucoside metabolite was characterized as 4-[((3R,4R)-5-(6-hydroxybenzo[d][1,3]dioxol-5-yl)-4-(hydroxymethyl)tetrahydrofuran-3-yl)methyl]benzene-1,2-diol. Sesaminol triglucoside could be converted to enterolactone and enterodiol by rat intestinal microflora which may have protective effects against hormone-related diseases such as breast cancer. Studies in Sprague-Dawley rats indicated that sesame sesaminol and its epimer2-episesaminol were poorly absorbed prior to reaching the rectum and that substantial amounts pass from the small to the large intestine, where they were metabolized by the colonic microflora to tetrahydrofuranoid metabolites (Jan et al. 2011). Sesaminol in plasma was largely present as phase II conjugates, and the seven metabolites were detected as the 2-episesaminol, sesaminol-6-catechol, methylated sesaminol-catechol, R,R-hydroxymethylsesaminol-tetrahydrofuran, S,R-hydroxymethylsesaminol-tetrahydrofuran, enterolactone, and enterodiol. Excretions of sesaminol in urine and faeces within the 24 hour period were equivalent to 0.02% and 9.33% of the amount ingested, respectively.

Genotoxicity Studies

Studies found that sesamin did not damage DNA in-vivo and that sesamin and episesamin had no genotoxic activity (Hori et al. 2011). Episesamin showed negative results in the Ames test (bacterial reverse mutation assay) with and without S9 mix, in the in-vitro chromosomal aberration test in cultured Chinese hamster lung cells with and without S9 mix, and in the in-vivo comet assay using the liver of Sprague-Dawley rats. Sesamin showed negative results in the Ames test with and without S9 mix. In the in-vitro chromosomal aberration test, sesamin did not induce chromosomal aberrations in the absence of S9 mix, but induced structural abnormalities at cytotoxic concentrations in the presence of S9 mix. Oral administration of sesamin at doses up to 2.0 g/kg did not cause a significant increase in either the percentage of micronucleated polychromatic erythrocytes in the in-vivo bone marrow MN test or in the % DNA in the comet tails in the in-vivo comet assay.

Allergy Problem

All ten patients tested had positive IgE antibodies and skin prick tests (SPTs) to sesame (Pastorello et al. 2001). The major, clinically most important allergen of sesame seeds was a protein with molecular mass of about 9,000. It was not glycosylated, the amino acid sequence showed it was a 2S albumin with a pI of 7.3; the small and the large subunits, forming the whole protein, showed pI values of 6.5 and 6.0. In another study, 24 of the 28 subjects diagnosed as allergic to sesame had sesame-specific IgE (Wolff et al. 2003). A 14 kDa protein belonging to the 2S albumin family was recognised by 22 of the 24 sera used. The reactivity of the 14 kDa protein with most of the sera indicated that was the major sesame allergen, later identified as 2S albumin precursor; and its peptide which reacted positively in the dot blot test evidently contained an epitope(s). Some minor sesame allergens, of higher molecular weight, were also found. Four sesame seed allergens were identified paving the first step toward generating recombinant allergens for use in future immunotherapeutic approaches (Beyer et al. 2002). The IgE-binding protein at 45 kd, which was recognized by 75% of the 20 patients, was found to be a 7S vicilin-type globulin, a seed storage protein of sesame and named Ses i 3. The protein at 7 kd was found to be a 2S albumin, another seed storage protein of sesame and named Ses i 2. Further, the proteins at 78 and 34 kd were found to be homologous to the embryonic abundant protein and the seed maturation protein of soybeans, respectively. The authors maintained that the detection of conserved IgE binding epitopes in common food allergens might be a useful tool for predicting cross-reactivity to certain foods.

Traditional Medicinal Uses

Sesame leaves, flowers, roots, seeds, and seed oil have been employed for various ailments in traditional medicine especially in Asia and Africa (Dalziel 1955; Burkill 1966; Grieve 1971; CSIR 1972; Duke and Ayensu 1985; Chopra et al. 1986;

Bown 1995; Chevallier 1996). The leaves, seeds, and seed oil are official in various national pharmacopoeias.

Sesame seeds are considered astringent, emollient, nourishing, tonic, lenitive, diuretic, laxative, antiphlogistic and galactogogue. A poultice made of the seeds is applied to ulcers, blisters, head sores on children and venereal sores in women. A plaster made of the ground seeds is applied to burns and scalds. A powder made from the roasted and decorticated seed is used externally and internally as an emollient. The seeds are especially useful in haemorrhoids and constipation, taken in decoction or as sweetmeats. A compound decoction of the seeds with linseed is used in coughs and as an aphrodisiac. Ground to a paste with water, they are given with butter for bleeding piles; if taken in large quantities, they are capable of producing abortion. The seed is used as tonic for the liver and kidney. It is taken internally for convalescence, chronic dry constipation, dental caries, osteoporosis, stiff joints, and dry cough and to treat premature hair loss and greying. Seed is employed to increase milk production in nursing mothers. The seeds are given as a laxative for children.

Both the seeds and the oil are used as demulcents in dysentery and urinary diseases in combination with other similar medicine types. Sesame oil is mildly laxative, emollient and demulcent and also promotes menstruation. Sesame oil is used as an antirheumatic in massage treatment. Sesame oil is used to treat dry constipation in the elderly. Mixed with lime water, sesame oil is used externally for burns, boils and ulcers.

The leaves, which are rich in mucilage, mixed with water, are employed in infantile cholera, diarrhoea, dysentery, catarrh, bladder troubles, acute cystitis, and strangury. An infusion of the leaves is also used as demulcent. The leaves also used as emollient poultices. The leaves are also astringent. A lotion prepared from leaves and roots are used as a hair-wash, and are considered to stimulate hair growth. A decoction of the root is used to treat asthma and coughs.

In traditional Chinese medicine, the dried flowers have been used to cure alopecia, frostbite and constipation; the flowers have been employed as a cure for verruca vulgaris and verruca plana (Hu et al. 2007a, b).

Other Uses

The production of biodiesel from sesame seed oil was found to be a viable alternative to diesel fuel (Saydut et al. 2008). Transesterification showed improvement in fuel properties of sesame seed oil which was obtained in 58wt/wt.%, by traditional solvent extraction.

Sesame oil can be used in the manufacture of soaps, paints, perfumes, pharmaceuticals and insecticides. The oil is also used as illuminant and is used in barrier creams to protect the skin from harmful UV light radiation. When added to the insecticide pyrethrum it acts as a synergist, doubling its potency. Sesame meal, left after the oil is pressed from the seed, is an excellent high-protein (34–50%) feed for poultry and livestock. The addition of sesame to the high lysine meal of soybean produces a well balanced animal feed.

Chlorosesamone, hydroxysesamone and 2,3-epoxysesamone isolated from sesame roots all showed antifungal activities toward *Cladosporium fulvum* (Hasan et al. 2001).

Comments

Sesame oil is a high-quality edible oil and is one of the most expensive cooking oils.

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