Value addition in sesame: A perspective on bioactive components for enhancing utility and profitability

Niti Pathak, A.K. Rai[1], Ratna Kumari, K.V. Bhat

Division of Genomic Resources, National Bureau of Plant Genetic Resources, Pusa Campus, New Delhi, [1]Department of Botany, Banaras Hindu University, Varanasi, Uttar Pradesh, India

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ABSTRACT

Sesame seed is a reservoir of nutritional components with numerous beneficial effects along with health promotion in humans. The bioactive components present in the seed include vital minerals, vitamins, phytosterols, polyunsaturated fatty acids, tocopherols and unique class of lignans such as sesamin and sesamolin. The presence of phenylpropanoid compounds namely lignans along with tocopherols and phytosterols provide defense mechanism against reactive oxygen species and increases keeping quality of oil by preventing oxidative rancidity. In this article, we have reviewed the nutraceutical, pharmacological, traditional and industrial value of sesame seeds with respect to bioactive components that hold high antioxidant value. Valuable information on superior functional components of sesame will strongly promote the use of sesame seeds in the daily diet world-wide. In spite of huge repertoire of sesame germplasm collection, limited research efforts on the use of conventional and biotechnological methodologies have resulted in minimal success in developing nutritionally superior cultivars. In consequence, value addition efforts in sesame would enable development of genotypes with high antioxidant activity and subsequently prevention of free radical related diseases. Modification of bioactive components in sesame would enable production of stabilized sesame oil with enhanced shelf life and better market value.

Key words: Bioactive components, lignans, nutraceuticals, phytosterols, tocopherols

INTRODUCTION

Sesame (*Sesamum indicum* L.) belonging to the order tubiflorae, family Pedaliaceae, is a herbaceous annual plant cultivated for its edible seed, oil and flavorsome value. It is also known as gingelly, til, benne seed and popularly as "Queen of Oilseeds" due to its high degree of resistance to oxidation and rancidity.[1] Sesame seed contains 50-60% of high quality oil which is rich in polyunsaturated fatty acids (PUFA) and natural antioxidants, sesamin, sesamolin and tocopherol homologues.[2] These bioactive components enhance the stability and keeping quality of sesame oil along with numerous health benefits. Sesame seeds are considered as valuable foods as they enhance the diet with the pleasing aroma and flavor and offer nutritional and physiological benefits. Recent studies on the antioxidant and anti-carcinogenic activities of sesame seed have greatly increased its applications in health food products that assert for liver and heart protection and tumor prevention.[3] Sesame seed is high in protein, vitamin B1, dietary fiber as well as an excellent source of phosphorous, iron, magnesium calcium, manganese, copper and zinc [Table 1]. In addition to these important nutrients, sesame seeds contain two unique substances, sesamin and sesamolin. Both of these substances belong to a group of special beneficial fibers called lignans and have a cholesterol lowering effect in humans and prevent high blood pressure and increase vitamin E supplies in animals.

Address for correspondence:
Dr. K.V. Bhat, Division of Genomic Resources,
National Bureau of Plant Genetic Resources,
Pusa Campus, New Delhi - 110 012, India.
E-mail: kvbhat2001@yahoo.com

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GENETIC WEALTH OF SESAME: VARIETIES AND GENE DIVERSITY

Sesame is believed to have been originated in India where maximum variability in genetic resources is available. Wide diversity is present in the sesame germplasm for the different desirable traits such as plant height, branching pattern, leaf shape, number of capsules per axil, number of seeds per capsule, 1000 seed weight, oil content, seed color, resistance to pest and diseases etc., Sesame samples from different agro-ecological

Table 1: Proximate composition of sesame seed

Constituent	Composition %
Moisture	6-7
Proteins	20-28
Oil	48-55
Sugars	14-16
Fiber content	6-8
Minerals	5-7

zones of India were studied by Bhat *et al.* using random amplified polymorphic deoxyribonucleic acid technique. Results showed a high level of genetic diversity, which indicated the nativity of the crop. Rajasthan and the north eastern states showed maximum genetic diversity. The exploitation of the available sesame diversity from these regions would enable improvement in productivity of existing sesame cultivars.

Large sesame collections are present at National Gene Bank at NBPGR, New Delhi with 9630 accessions stored for long term conservation at −20°C in the cold modules and 255 *Sesamum* species maintained at cryobank (NBPGR data, 2013, www.nbpgr.ernet.in). The sesame germplasm includes wild species, landraces and improved varieties and advanced breeding lines However, presence of a large number of uncharacterized accessions is a limitation in effective utilization of genetic diversity. The characterization, documentation and conservation of sesame germplasm for nutritional factors along with other traits of interest is essential for effective conservation and utilization of the sesame genetic resources.

DIVERSITY IN IMPROVED VARIETIES AND WILD SPECIES

Sesame has a wide range of adaptation and a remarkably large number of varieties have been developed suiting to diverse agroclimatic conditions. These varieties include some which are widely adapted and others are location and season specific.[4] Spectrum of varietal diversity is represented by different agroecological regions distributed as - East: Bihar-B-67, Krishna; West Bengal - B-67, Rama; West: Gujarat-Gujarat til l, Purva; North: Haryana - RT-46; Punjab-Punjab til l, TC-289, TC-25, RT-46; Northeast: Assam - Madhavi, Gauri; Andhra Pradesh - Gauri, Madhavi, Rajeshwari; Karnataka- E-8, CO-1; Kerala - Thilothama; Central - Madhya Pradesh - JT-7, TKG-22; Uttar Pradesh – CST (2001) 1, T-12. Rich diversity is present in wild species in the African continent.[5] In India, about five species occur and the Indian material largely includes *Sesamum malabaricum*, *Sesamum radiatum*, *Sesamum alatum*, *Sesamum laciniatum* and *Sesamum prostratum*. *Sesamum indicum* is the only cultivated species representing the sesame germplasm.

Sesame seed nutraceutical components

Sesame seed possess many health promoting effects, some of which have been attributed to a group of compounds called lignans (sesamin, sesamolin, sesaminol and sesamolinol). Sesame seed also contains lignan aglycones in oil and lignan glucosides. Sesame seed is rich in oil, contains high amounts of (83-90%) unsaturated fatty acids, mainly linoleic acid (37-47%), oleic acid (35-43%), palmitic (9-11%) and stearic acid (5-10%) with trace amount of linolenic acid [Table 2].[6] The seeds are a rich source of antioxidants and bioactive compounds including phenolics, phytosterols, phytates, PUFA and short chain peptides. Sesame cake is a rich source of protein, carbohydrate and mineral nutrients. Sesame seeds have special significance for human nutrition on account of its high content of sulfur amino acids and phytosterols.[7] The antioxidative agents (sesamin, sesamolin, sesamol, their glucosylated forms sesaminol glucosides and tocopherol make the oil very stable and therefore it has a long shelf life.[8,9] Among the vitamins in the sesame seed, the presence of vitamin E is very interesting in relation to the effectiveness of sesame seed as a health food.

Antioxidant properties of sesame fractions

Foods of plant origin are known to provide a complex mixture of natural substances with antioxidative effects. Such antioxidant activity appears to be closely related to the prevention of degenerative diseases such as cancer, cardiovascular diseases, atherosclerosis and the process of ageing. Sesame seeds contain a group of phenylpropanoid compounds, namely lignans, an innate non-enzymatic antioxidant defense mechanism against reactive oxygen species which play a vital role in health promotion. Sesame lignans have various pharmacological properties, e.g. antioxidant activity,[9] antiproliferative activity[16] and responsible for enhancing antioxidant activity of vitamin E in lipid peroxidation systems,[10] lowering cholesterol levels,[17] increasing hepatic fatty acid oxidation enzymes[18] and show antihypertensive effects.[19,20] Apart from sesame lignans, sesame seed and oil also contain other important biologically active compounds such as vitamin E (tocopherol homologues), especially γ-tocopherol.[21,22]

Lignans: "distinguished class of phenylpropanoids"

Lignan is a constituent of lignin, a generic name for a compound resulting from two p-hydroxy phenylpropane molecules. It constitutes a group of important plant phenolics characterized by the coupling of two phenylpropanoid (C6-C3) units by a bond between β-positions in the propane side chains. Two major groups of lignans exist in sesame seeds, namely oil soluble lignans and glycosylated water soluble lignans. Sesamin, sesamolin, sesaminol, sesamolinol and pinoresinol are the main oil soluble lignans in sesame [Figure 1]. The major glycosylated lignans are sesaminol triglucoside, pinoresinol triglucoside, sesaminol monoglucoside, pinoresinol monoglucoside and two isomers of pinoresinol diglucoside and sesaminol diglucoside.[11,23,24]

Sesamin and sesamolin have been considered as the major lignans in the sesame seed[25] along with sesaminol which has also been identified as an important lignan in later studies.[26] These components have been reported to possess unique properties, such as helping in lowering blood lipids[27] and arachidonic acid levels,[28] they are also involved in lowering cholesterol levels by inhibiting absorption and synthesis of cholesterol

Table 2: Variation in the contents of functional components in sesame seed and oil

Bioactive components	Name of component	Quantity		Reference
		Sesame seed (mg g^{-1} seed)	Sesame oil (mg g^{-1})	
Lignans	Sesamin	8.80	6.20	Moazzami *et al*. 2006, Hemlatha and Ghafoorunisa 2004[10,11]
	Sesamolin	4.50	2.45	
	Sesamol	1.20	-	
	Sesaminol	1.40	0.01	
Tocopherol	α-tocopherol	-	-	Kamal-Eldin and Appelqvist[12]
	β-tocopherol	-	-	
	γ-tocopherol	800µg g^{-1}	0.68	
	δ-tocopherol	-	-	
Polyunsaturated fatty acids	Palmitic acid (16:1)	9.4%	14.45%	Uzun *et al*.[13]
	Oleic acid (18:1)	39.1%	50.54%	
	Linoleic acid (18:2)	40%	45.50%	
	Linolenic acid (18:3)	0.46%	0.85%	
Phytosterols	β-sitosterol	3.35	2.63	Normen *et al*.[14]
	Campesterol	1.00	1.35	
	Stigmasterol	0.37	0.47	
	Δ^5-avenasterol	-	0.82	
	Sitostanol	-	0.04	
	Campestanol	-	0.02	
	Ergosterol	-	-	
	Total phytosterols	4.72	5.33	
Phytates	Phytic acid	5.18% (defatted sesame meal)		de Boland *et al*.[15]
Minerals	Ca	4.21	-	Hahm *et al*. 2009
	Fe	0.06	-	
	Zn	0.03	-	
	P	4.45	-	
	K	3.85	-	
	Na	0.08	-	
	Mg	2.21	-	
	Cu	0.41	-	
	Mn	0.02	-	

simultaneously in rats,[29] anti-inflammatory function[30] and have immunomodulatory activities [Figure 2].[31] Indian *Sesamum* species have been found to contain high amounts of sesamin (2.45 mg g^{-1} seed) and sesamolin (1.10 mg g^{-1} seed) (unpublished data). Liu *et al*.[32] reported 1520 µmol sesamin of the total lignan content of 2180 µmol 100 g^{-1} seed. Sesamin and sesamolin values for Indian sesame germplasm were higher than that of 65 sesame seed samples harvested in TX, USA, (1.63 mg g^{-1} seed for sesamin and 1.01 mg g^{-1} seed for sesamolin.[11] Moreover, Kim *et al*.[33] reported lower sesamin (2.09 mg/g seed) and sesamolin (1.65 mg g^{-1} seed) contents of 403 sesame landraces of Korea when compared with Indian sesame. Recently, Wang *et al*.[34] reported an average value of 8.54 mg g^{-1} for sesamin and sesamolin contents for core collection from China.

Tocopherols: "Biological quencher of free radicals"

Tocochromanols are amphipathic molecules where the lipophilic isoprenoid side chain is associated to the membrane lipids and the polar chromanol ring is exposed to the membrane surface [Figure 1]. The structural features of tocols govern their metabolic fate and biological activities. All isoforms possess lipid antioxidant activity and α-tocopherol possesses the highest vitamin E activity in mammals.[35,36] Tocopherols are a class of plant phenolics that have important antioxidant and nutritional properties.[37] Being natural antioxidants, they inhibit oil oxidation. They act as biological kidnappers of free radicals and could prevent diseases, besides possessing an important nutritional function for human beings as a source of vitamin E.[38]

The main function of α-tocopherol is that of a radical-chain breaking antioxidant in membranes and lipoproteins, as well as in foods.[39] Due to its antioxidant potential and various other functions at the molecular level, it is found to reduce the risk of cardiovascular diseases and of certain types of cancer.[40] Despite low plasma concentrations, other tocols are still capable of exerting antioxidant and biological activities. Among the tocopherols, α-tocopherol is the predominant form in the photosynthetic tissues such as stems and leaves. γ-tocopherol is the major tocopherol in sesame seeds, whereas α-and δ-tocopherols are present in smaller amounts. It is more potent than α-tocopherol in decreasing platelet aggregation, low density lipid (LDL) oxidation and delaying intra-arterial thrombus formation.[41,42]

Tocopherols have high antioxidant, antitumor and hypocholestrolemic potential. Yoshida *et al*.[43] reported that the amount of γ-tocopherol in sesame ranges from 468.5 to 517.9 mg kg^{-1} lipid while α-and δ-tocopherols are present at low levels. Kamal-Eldin and Appelqvist[44] reported γ-tocopherol to be 490-680 mg kg^{-1} sesame oil. While it was 210-320, 750 and 800 mg kg^{-1} sesame oil, respectively in wild species, *S. alatum*, *Sesamum angustifolium* and *Sesamum latifolium*. In Indian sesame

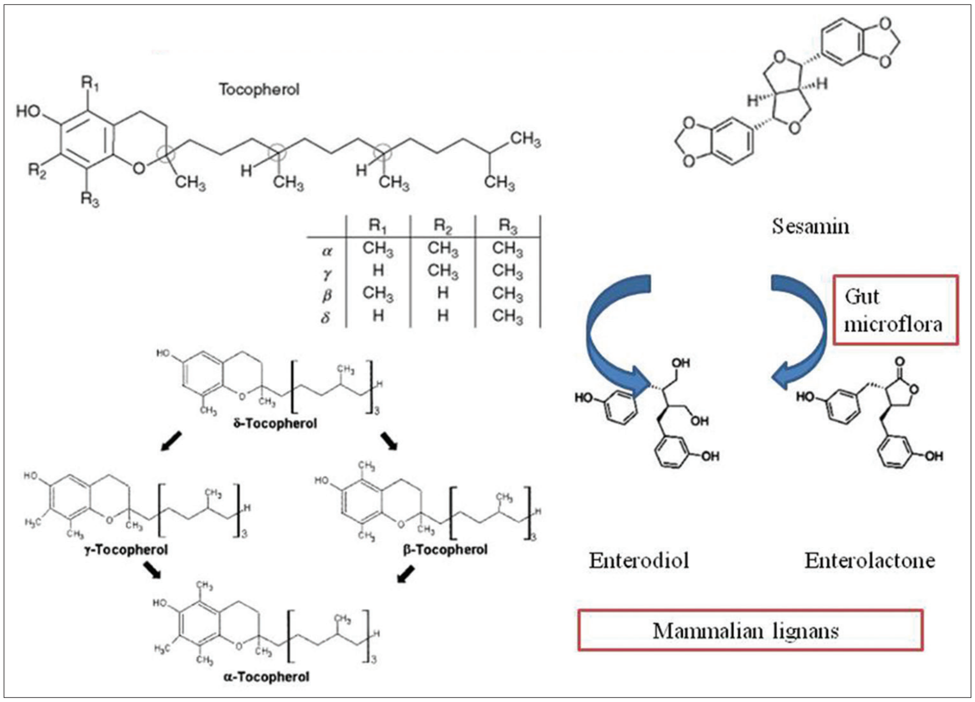

Figure 1: Structures of lignans: Sesamin, sesamolin and tocopherol homologues (αT: α-tocopherol; βT: β-tocopherol; δT: δ-tocopherol; γT: γ-tocopherol)

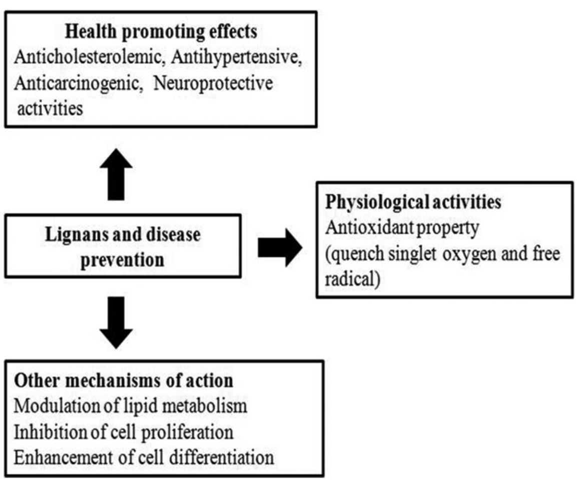

Figure 2: Flowchart depicting physiological and pharmacological activities of lignans

germplasm, the α-and δ-tocopherols are at relatively low concentrations and vary between n.d. −0.91 and n.d. −12.50 μg g^{-1} seed respectively, whereas γ-form represents 95-96% of total tocopherol (0.03-800 μg g^{-1} seed) (unpublished data). The results obtained represent large variation for γ-tocopherol content. Williamson *et al.* in a study on 11 genotypes from USA collection found that the content of α-, δ-and γ-tocopherol content in sesame seeds ranged between 0.034-0.175, 0.44-3.05 and 56.9-99.3 μg g^{-1} seed, respectively.

Phytosterols

Plants possess the bioactive compounds that have a chemical structure very similar to cholesterol and when present in sufficient amounts in the diet reduce cholesterol level in the blood, thereby enhancing the immune response and decrease risk of certain cancers. They are tri-terpenes with a wide spectrum of biological activities in animals and humans, including anti-inflammatory,[45] anti-bacterial,[46] antioxidative[47] and anti-cancerous.[48] Different groups of phytosterols include sitosterol, campesterol, stigmasterol, Δ^5-avenasterol, sitostanol and campestanol.

β-sitosterol is the predominant phytosterol in sesame oil, followed by campesterol and stigmasterol, the content of which ranges from 231.7 to 305.2 mg 100 g^{-1} sesame seed. The beneficial effects of phytosterols are so dramatic that they have been extracted from soybean, corn and pine tree oil and added to processed foods, such as "butter" replacement spreads, which are then labeled as cholesterol lowering "foods." Sesame seeds have been reported to contain the highest (400-413 mg 100 g^{-1}) phytosterol content.[49] They compared the phytosterols in white and brown sesame and found higher phytosterol content in the brown sesame than that of the white seed cultivar.

Phytates

Phytic acid is an important source of plant phosphorous. Its six reactive phosphate groups have a strong chelating ability to complex with proteins in addition to minerals, thereby contributing to anti-nutritional effects.[50] Dietary phytates have attracted much interest because of their role in cancer prevention and hypocholesterolemic effect.[51] The action of phytates is linked with the antioxidant effect by which it binds the excess free iron, thus preventing the formation of free radicals.[52] Sesame seeds are a rich source of phytates and in defatted sesame meal it is 5.18%, compared with 1% in soybean meal and 1.5% in isolated soybean protein.[15] The high content of phytic acid and oxalic acid in sesame seed hinders the use of sesame protein as food.[53]

PUFA

High levels of unsaturated and PUFA increase the quality of oil for human consumption. The PUFA have anti-inflammatory, anti-thrombotic, anti-arrhythmic, hypolipidemic and vasodilatory properties. Moreover, high levels of linoleic acid reduce the blood cholesterol and play a vital role in preventing atherosclerosis.[54] Since the demand for beneficial PUFA has increased drastically, increasing efforts are being made to find plant sources of PUFA that are economical and sustainable. The fatty acids of sesame oil consist mainly of linoleic (35-50%) and oleic (35-50%) acids, with small amounts of palmitic (7-12%) and stearic (3.5-6%) acids and only trace amount of linolenic acids.[12,55] Sesame oil used in combination with soybean oil enhances the nutritive value of the lipid and increases vitamin E activity.[56] Studies on unsaturated fatty acids by various researchers suggest that Indian sesame germplasm has high genetic variability in fatty acid composition.[13] This large variation at inter-and intra-specific level offers interesting future prospects.[57]

Pharmacological benefits of sesame seed and oil

Health benefits

Sesame seed and oil possess immense pharmaceutical applications and have played a prominent role in Chinese and Indian systems of medicine [Table 3]. Sesame oil has burn healing effects,[58] when rubbed on the skin soothes a minor burn or sunburn, as well as helps in the healing process. Sesame oil is ideal massage oil due to its excellent emollient properties. When applied topically, it aids in healing the chronic diseases of the skin. In India, it has been used as an antibacterial mouthwash, to relieve anxiety and insomnia and in the treatment of blurred vision, dizziness and headache.[59] Sesame oil is naturally antibacterial for common skin pathogens such as *Staphylococcus* and *Streptococcus* as well as common skin fungi such as athlete's foot fungus.

Table 3: Nutraceutical, pharmaceutical, industrial and traditional uses of sesame nutritional components and oil

Use	Bioactive components of sesame
Nutraceutical	
Antioxidant and providing hepatoprotection	Lecithin
Cancer preventive	Myristic acid
Tumor prevention, cardioprotective	Fiber and sesame oil
Antioxidant property	Sesamin and sesamolin
Inhibition of cholesterol production	Lecithin and lignans
Skin softener	Sesame oil
Pharmaceutical uses	
Drug vehicle and laxative	Sesame oil
Hypoglycemic activity	Flavonoids
Inhibition of malignant melanoma	Linoleate in triglyceride form
Antibacterial mouthwash	Sesame oil
Industrial role	
Antifungal	Chlorosesamone
Bactericidal and Insecticidal properties	Sesamin and sesamolin
Cosmetics	Myristic acid
Biodiesel	Sesame oil
Traditional uses	
Intestine lubrication	Sesame oil
Constipation	Sesamin
Intestinal worms	Sesamin, Sesamolin

Traditional uses

Since ancient times, sesame seeds are in use for traditional purposes. Sesame seeds are used in Hindu culture as a "symbol of immortality" and its oil is used widely in prayers and rituals performed during death of an individual. "Butter of the Middle East," tahini, a smooth, creamy paste made up of toasted ground hulled sesame seeds is a traditional ingredient in Middle Eastern cooking. A portion of the nutritious seed cake is used as animal feed while the remainder is ground into sesame flour and added to health foods.[60] Southern Indian cuisine depends upon sesame oil for cooking while in China, it was the only cooking oil until quite recently. Sesame seed benefits the body as a whole, especially the liver, kidney, spleen and stomach. Its high oil content not only lubricates the intestines, but nourishes all the internal viscera. It is also known to blacken the hair, especially the black sesame. Hence, it is applied to white hair, habitual constipation and insufficient lactation. Sesame oil is also helpful in treating intestinal worms such as ascaris, tapeworm, etc.

Sesame industrial uses

Several industrial uses have been identified for sesame [Table 3]. African people use sesame flowers to prepare perfumes and cologne.[61] Myristic acid is used as an ingredient in cosmetics. Sesamin has bactericidal and insecticidal activities[62] and also acts as an antioxidant, which can inhibit the absorption and the production of cholesterol in the liver.[63] It is used as a synergist for pyrethrum insecticides.[64] Sesame oil is used as a solvent, oleaginous vehicle for drugs and skin softener, also in manufacturing of margarine and soap. Sesame oil is used in producing margarine, soap making, pharmaceuticals, paints and lubricants.[65] Chlorosesamone obtained from roots of sesame has antifungal activity.[66] Biodiesel production from sesame oil has been reported by Ahmad *et al*.[67] by its transesterification with methanol in the presence of NaOH as a catalyst. They also investigated that the environmental performance of sesame biodiesel was superior to that of mineral diesel. This study supports the production of biodiesel from sesame seed oil as a viable alternative to the diesel fuel.

Sesame seed as functional food: A prospect for developing countries

In order to materialize the potential of sesame seed as functional food, a concerted, multidisciplinary approach involving scientists from diverse fields such as nutrition, agricultural chemicals, food engineering, food technology, molecular biology, biochemistry etc., is imperative. The future of functional foods depends upon the unequivocal demonstration of their efficacy in promoting health. The accurate quantification of bioactive components such as sesamin, sesamolin and tocopherols in sesame seed, their monitoring and enhancing the level in the food chain of human consumption is of utmost importance for domestic and international gains. In addition, it has now been recognized that optimization of bioactive components through conventional plant breeding and agronomic practices along with application of molecular techniques is a viable strategy. Therefore, use of analytical chromatographic techniques in amalgamation with molecular manipulations in sesame seed would enable production of large amounts of functional components in superior sesame genotypes.

Value addition in sesame: An essential initiative

In spite of large benefits of sesame as an oilseed, much attention has not been given to production of value added products, such as sesame oil and meal thereby enhancing its economic value. The following important aspects need to be considered for value addition in this important oilseed.

Development of sesame with low free fatty acids (FAA)

Sesame oil with <2% FAA is considered of good quality. White seeded varieties of sesame from Gujarat (0.5-1.2%), Rajasthan (0.75-1.5%) and Maharashtra (1.0-2.0%) contain low FAA, which are considered to make a good quality oil. The FAA in sesame seeds from Andhra Pradesh, Orissa, Tamil Nadu and Chhattisgarh are very high, ranging from 2.0% to 4.0%. Therefore, investigations for screening or breeding program for identification of types with low FAA need to be initiated. These would enable in the production of high quality oil with long shelf life and will fetch a better price in the market.

Development of sesame with high lignans (sesamin, sesamolin) and tocopherol

Lignans are important antioxidative bioactive components of sesame seeds comprised of sesamin, sesamolin and their derivative glucosides. These are responsible for changing oil quality and improvement of shelf life. Sesame seeds with high lignan and tocopherol content are very important in terms of health promotion and subsequently in prevention of free radical related diseases. Screening of sesame germplasm for identification of varieties with high lignan and tocopherol contents is of utmost importance for enhancing oil quantity and quality.

Development of sesame with low anti-nutritional factors

Sesame seed coat is rich in minerals (22.8 g 100 g^{-1}) including calcium (9.75 g 100 g^{-1}), Phosphorus (4.29 g 100 g^{-1}) and other micronutrients. The presence of oxalic acid (14.3 g 100 g^{-1}) and phytic acid (in traces) in the seed coat renders the calcium and phosphorus into non available form and imparts unpleasant taste. Therefore, the nutritional value and taste of the sesame seed will be improved further and the process of dehulling will be reduced through the development of varieties with low anti-nutritional factors, i.e. oxalic and phytic acids. Thus, large quantities of calcium and phosphorus will be available for human consumption through the process of dehulling which can be made available for human nutrition. Such value added sesame will be preferred and priced higher in western countries.

Modification of antioxidant bioactive components in sesame storage oil

Vegetable oils may sometimes lack the properties best suited for their intended use. For instance, they could have undesirable nutritional attributes such as the presence of anti-nutritional factors, oxalic acid or a high proportion of saturated fatty acids in comparison to the more acceptable unsaturated forms. Such deficient oil would need to be modified to attain the desired properties. Modification of vegetable oils is conventionally done by chemical processes, such as partial hydrogenation, fractionation etc.[68] These processing methods however are expensive and sometimes yield undesirable products in the edible oils. Development of crop varieties producing oils with high quality with better market value presents a better alternative to chemical modification of vegetable oils.

One of the methods to achieve the above target is by domesticating wild plants that accumulate oil with characteristics of interest. However, it takes a long time in breeding for the cultivars to adapt to cultivation and huge efforts are required to domesticate and develop cultivars of high nutritional value. In sesame, attempts are being made to modify the antioxidant bioactive components by means of conventional breeding to meet various consumer demands. Though the technique is successful, conventional breeding relies on naturally occurring variation within a species or genus and is limited to cross compatible taxa.

Current research effort is directed toward creating oils having high levels of nutritional components by genetic engineering. This approach is superior to previous researches owing to its precision and applicability across taxa. By using molecular techniques, it is possible to modify specifically the seed oil quality while keeping the rest of the genetic background of the plant constant. The major lignans and tocopherols should be targeted for genomic modification in sesame. Enhancement of these components would lead to increase in stability and keeping quality of oil. Biotechnology offers the best opportunity for transferring high antioxidant ability and nutritional composition from wild to cultivated species.

Sesame oil constitutes about 45-50% of the seed weight and it has high nutritional value due to the presence of bioactive components. A detailed knowledge of the metabolic pathways involved in the biosynthesis of antioxidative compounds is a prerequisite for genetic engineering of seed bioactive components. Table 4 shows target enzymatic steps that could be modulated by genetic engineering to alter the seed fatty acids, lignan and tocopherol profile leading to accumulation of nutritionally superior oil in sesame. Moreover, down regulation of the gene encoding synthesis of phytic acid would enable low phytic acid production thereby enabling in bioavailability of minerals. Using various modification strategies, it is possible to specifically vary the properties of different bioactive components. Considering that conventional sesame oil is beneficial to human health, it seems appropriate that further

Table 4: Possible targets for modification of sesame oil

Target oil	Advantage	Approach
High sesamin	Increased antioxidant, antiproliferative activity	Over-express Sesamin synthase
High sesamolin	Increased antioxidant, antitumor, antithrombic activity	Over-express Sesamin synthase
High γ-tocopherol	High antioxidant, antitumor and hypocholestrolemic action	Over-express Tocopherol cyclase
High α-tocopherol	Increase anticancerous activity	Over-express γ-tocopherol methyltransferase
High oleate	Increase oil stability, pharmaceuticals, cosmetics, soaps	Down-regulate oleoyl-ACP desaturase
High linoleate or linoleneate	Improve nutraceutical value, cosmetics, paints	Over-express Δ12 and Δ15 desaturases
High β-sitosterol	Increase antioxidative, anticancerous, cholesterol lowering effects	Over-express sterol 24C methyltransferase
Low phytic acid	Anticancer activity, cholesterol lowering effects	Down regulate Myoinositol 1-phosphate synthase

improvement of quality should focus on producing oils with new dietary, cosmetic, pharmaceutical and nutraceutical uses that would embrace the known advantageous properties of the oil.

CONCLUSION

Sesame seed acts as a microcapsule with bioactive components comprising high variability and showing medical importance. Sesame seed is a rich source of biologically active and health promoting phytochemicals such as sesamin, sesamolin, tocopherols, PUFA, phytosterols, phytates and other phenolics. Wide variation in nutritional components (lignans, tocopherols and phytosterols) found in the Indian sesame germplasm collections offer a great potential for sesame breeding. The sesame improvement programs in terms of trait enhancement by sesame breeders would help in selecting genotypes with high nutritive value and production. Moreover, sesame is a promising target oilseed crop for biotechnological applications, in that sesame seed contains a large number of bioactive substances that are important for human health and nutrition. Genetic manipulation in sesame along with other strategies would enable development of varieties with high nutritional and functional value. Thus, endowed with so many qualities and beneficial nutrients, the sesame crop holds tremendous potential for export and over the years it may become one of the most important natural foods having high food value.

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