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Sesame (Sesamum indicum L.): A Review of Nutritional Value, Phytochemical Composition and Breeding Aspects for Improvement

Dr. V. V. Ujjainkar

Professor of Genetics & Plant Breeding
College of Agriculture, Dr. PDKV, Akola 444 104 (MS) INDIA

Abstract

Sesame (*Sesamum indicum* L.), is one of the earliest known oil crops, is a highly adaptable plant that offers substantial nutritional value awarding the place of Queen among group of oilseed crops. Beyond oil extraction, sesame seeds are often utilized into sesame paste, sesame milk, and other culinary products. At present, the ongoing research on sesame is leading to the discovery of more bioactive compounds, which are being applied to effectively advance the sesame processing industry. Modern studies have isolated and identified over 180 phytochemical components from sesame seeds, seed oils, and various plant parts, including lignans, polyphenols, phytosterols, phenols, anthraquinones, cerebrosides, fatty acids, vitamins, proteins, essential amino acids, and sugars. The significant interest among people in tapping into the economic and nutritional potentials of this high-value crop, oil seed breeders focusing on formulating breeding strategies for overall improvement of sesame crop to be used as super food. The research endeavors including exploration of nutri-genetical potentials of available germplasm through morphological, biochemical characterization assisted by modern molecular techniques and their subsequent utilization for trait specific improvement of crop. The Modern tools viz., MAS, Genome Editing, GAB, Haploids, Speed breeding, AI may apply with conventional approaches viz., mutation, hybridization, selection (pureline and mass) which will definitely facilitate the effective selection of elite genotypes and lines that possess novel traits. In this review, the nutritional, phytochemical aspects have been highlighted along with breeding strategies for improvement has been discussed in light of reports on sesame crop.

Keywords: Sesame, *Sesamum indicum*, Phytochemical composition, Nutritional Value, Breeding strategies, Crop Improvement, Conventional breeding and Modern genomic tools

1. Introduction

Sesame (*Sesamum indicum* L.) is recognized as the one of oldest indigenous oilseed crop having the longest history of cultivation in India. Commonly referred to as sesame or gingelly, and known by various names such as *til* (in Hindi, Punjabi, Assamese, Bengali, and Marathi), *tal* (in Gujarati), *nuvvulu* and *manchi nuvvulu* (in Telugu), *ellu* (in Tamil, Malayalam, and Kannada), *tila/pitratarpana* (in Sanskrit), and *rasi* (in Odia) across different regions/states of India. The cultivation of this crop is significantly widespread throughout the country, with over eighty-five of sesame production originating from the states of West Bengal, Madhya Pradesh, Rajasthan, Uttar Pradesh, Gujarat, Andhra Pradesh, and Telangana. Specially, sesame is widely cultivated and appreciated for its aromatic scent and rich flavor. In everyday life, sesame seeds are frequently used to produce a range of food items, such as sesame oil, sesame paste, or as a decorative element for other dishes.

Globally, India holds the top position with an area of 19.47 Lakh hectares and a production of 8.66 Lakh tonnes. The average yield of sesame in India, at 413 kg/ha, is relatively low compared to other countries i.e. of an average of 535 kg/ha. The primary factors contributing to the low productivity of sesame include its cultivation in rainfed conditions on marginal and sub-marginal lands, often under poor management and insufficient inputs designating it as under privileged crop. Nevertheless, advancements in improved varieties and agro-production technologies have been developed to enhance productivity levels of sesame across various agro-ecological contexts in the country. A well-managed sesame crop can achieve yields of 1200 - 1500 kg/ha under irrigated conditions and 800 - 1000 kg/ha under rainfed conditions. In the past years, few thorough reviews have been published regarding the phytochemistry and ethno-pharmacology of sesame. Although the researchers must aware with the nutritional values and its phytochemical composition to plan the scientific experiments for its overall enhancement through conventional and advance breeding strategies. An attempt has made in this paper to discuss these issues in relation to sesame crop viz., specific chemical components in sesame seeds, some pharmacological effects of sesame, or the technical aspects of its production through breeding aspects.

Botany and morphology of Sesame plant:

Sesame, belonging to the genus Sesamum, is a member of the Pedaliaceae family. The genus *Sesamum*, one among the thirteen genera of the family Pedaliaceae, comprises about fourty species, thirty-six in the Index Kewensis. Many occur in Africa (eighteen exclusively), eight occur in the India–Sri Lanka region (five exclusively). The Australian records are probably due to imports by Chinese immigrants in the mid-nineteenth century. *Sesamum indicum*, together with *S. capense* Burn (*S. alatum* Thonn), *S. malabaricum* Nar. and *S. schenkii* Aschers, has the somatic number 2n = 26; *S. laciniatum*, 2n = 28; *S. angolase* and *S. prostratum* 2n = 32; *S. occidentale* and *S. radiatum* Schum & Thonn, 2n = 64 (Hedge, 2012).

Sesame is an erect annual herb that grows 60–150 cm tall. The stem is hollow or has a white pith. The sesame leaves are 3–10 cm long, 2.5–4.0 cm wide, and rectangular or ovate in shape with a slightly hairy surface. They are borne singly or 2–3 together in the leaf axils. The calyx lobes of sesame are 5–8 mm long and 1.6–3.5 mm wide, lanceolate in shape, and have a pilose appearance. The bell-shaped flowers have petal colors ranging from pale yellow to purple. The corolla of sesame is 2.5–3.0 cm long in a tube shape about 1–1.5 cm in diameter. It is white, often with a purplish-red or yellow halo. The four stamens are hidden inside the flower, the ovary is superior, 4-loculed and pilose outside, and flowering occurs in late summer and early autumn. The sesame capsule is rectangular in shape, 2–3 cm in length, and 6–12 mm in diameter, with longitudinal ribs on the surface and microscopic hairs on the epidermis (Akhila et al, 2015, Darr et al, 2019, Gloaguen et al, 2019).

According to the differences in germplasm color, sesame can be classified into white sesame, black sesame, and yellow sesame, with black and white sesame being the more common and widely cultivated dominant species. Black sesame, plants have the strong growth ability, making it suitable in respect of resistance to lodging and drought tolerance, while white sesame is characterized by its high oil content and good quality, having the largest area of planting and distribution. For other variegated varieties such as yellow sesame, the plants are mostly branched. Generally it is observed that the oil content decreases gradually as the color of the germplasm deepens, therefore white seeded varieties are more preferred in oil industry.

Nutritional Value of sesame:

The sesame is termed as "*Queen of oilseeds*" addressing its importance. As in folks story of *Alibaba and fourty thieves*, *Sim-Sim* is a password for treasure cave; sesame is itself the treasure of nutritional properties. The literature of Ayurveda mentions "*Sarvesham taila jaathanaam tila taila prasasyathe Balarthe snehane"* highlights Sesame Oil or "Tila Taila" as the king of all oils, for strengthening and nourishing the skin. However, it may designated as super food in respect of health benefits as given below

a) The sesame oil effectively calms *Vata* and *Kapha*, with a slight increase in *Pitta*.
b) Sesame serves as an excellent laxative when using sesame seeds and oil.
c) Furthermore, sesame oil is a superb moisturizer and softener for the skin. Safe for massaging babies and children, sesame oil aids in strengthening bones, muscles, and joints.
d) Sesame oil also beautifies hair, has a sweet, bitter, and astringent taste, is hot in potency, provides strength, and helps treat imbalances in *Kapha* and *Vata doshas*, as well as conditions like worm infestations, itching, and enhances skin complexion.
e) The black variety of sesame is effective in treating diabetes, hemorrhoids, and edema, while also strengthening teeth.

Sesame seeds exhibits the variation in color from black-brown to white, containing variety of essential nutrients in varying proportions. The structure of sesame seeds consists of 45–65 % oil, which is a remarkable source of plant-based protein, which varies from 19 to 35% per 100 g of seeds, alongside 14 to 20% carbohydrates and 15 to 20% hull material. Although the protein content in sesame seeds is not as high as that of meat, it is on par with or surpasses that of many grains, including rice and wheat. (Ahmed et al, 2020 & Mustafa et al, 2023) Overall, the nutritive value of sesame seeds is very impressive as its richness in essential vitamins, minerals and healthy fat. These small seeds also possess quantifiable levels of oxalic acid, dietary fiber, antioxidants, and minerals including iron, magnesium, and zinc. The fatty acid profile of sesame seeds is mainly composed of unsaturated fatty acids, such as oleic and linoleic acids, alongside lesser quantities of saturated fatty acids, including palmitic and stearic acids.

Table 1: Main nutritional constituents of sesame.(Anonymous, 2022)

Component	Value	Min	Max	Component	Value	Min	Max
Protein (g/100 g)	17.6	17	18	Copper (mg/100 g)	1.58	1.5	4.08
Protein, crude, N × 6.25 (g/100 g)	20.8	3.2	21.3	Iron (mg/100 g)	14.6		

Carbohydrate (g/100 g)	9.85			Magnesium (mg/100 g)	324	318	351
Fat (g/100 g)	49.7			Manganese (mg/100 g)	1.24	1.17	2.46
Sugars (g/100 g)	3	0.29	0.31	Phosphorus (mg/100 g)	605	453	694
Starch (g/100 g)	4			Potassium (mg/100 g)	468		
Fibers (g/100 g)	14.9	11.8	18	Selenium (µg/100 g)	26.5	2.2	51.9
Ash (g/100 g)	4.48	4.45	4.5	Sodium (mg/100 g)	2.31	0.88	11
Fatty acid saturated (g/100 g)	7.09	6.7	7.6	Zinc (mg/100 g)	5.74	5.3	7.75
Fatty acid mono (g100 g)	18.8		18.9	β-Carotene (µg/100 g)	5		
Fatty acid poly (g/100 g)	21.8		21.9	Vitamin E (mg/100 g)	25		
Fatty acid 14:0 (g/100 g)	85	0.048	0.13	Vitamin B1 or thiamin (mg/100 g)	79		
Fatty acid 16:0 (g/100 g)	4.22		4.59	Vitamin B2 or riboflavin (mg/100 g)	25		
Fatty acid 18:0 (g/100 g)	2.78	2.09	2.96	Vitamin B3 or niacin (mg/100 g)	4.52		
Fatty acid 18:1 n-9 cis (g/100 g)	18.7	18.6		Vitamin B5 or pantothenic acid (mg/100 g)	5		
Fatty acid 18:2 9c,12c (n-6) (g/100 g)	21.2	20.9	21.5	Vitamin B6 (mg/100 g)	79		
Fatty acid 18:3 9c, 12c, 15c (n-3) (g/100 g)	26	0.14	0.38	Vitamin B9 or folate (µg/100 g)	97		
Calcium (mg/100 g)	962	714	1150				

Phyto-chemical composition of sesame:

In addition to being rich in nutrients, sesame also contains many important functional components such as sesamin, sesamolin, sesamol, sesaminol, sesamolin phenol, and other lignan-like active ingredients (Pathak et al, 2014). The content of each component in sesame varies depending on the extraction method and external growing conditions, e.g., hot-pressed sesame oil has a higher content of sesamol, sesamin, and total lignans than cold-pressed and refined sesame oil (Khuimphukhieo and Khaengkhan, 2018). The lignan content in sesame can be affected by factors such as strain, genotype, growing location (soil and weather), and growing conditions (irrigation, fertilization, and harvest time) (Xu et al, 2021). A variety of phytochemical compounds have been identified and isolated from sesame seeds, seed oils, and various plant organs, including lignans, polyphenols, phytosterols, phenols, aldehydes, anthraquinones, naphthoquinones, triterpenoids, and other organic compounds. Among them, the lignan components isolated from sesame and their analytical methods are shown in Table 2.

Sesame oil is made up of unsaponifiable components like sesamin, sesamolin, and sterols. Furthermore, sesame seeds serve as a rich source of calcium and contain vital amino acids such as methionine, valine, and tryptophan. Additionally, sesame seeds are rich in bioactive substances including phenolics, vitamins, phytosterols, and polyunsaturated fatty acids (PUFAs), all of which contribute positively to human health.(Agidew et al, 2021 & Wei et al, 2022). Sesame lignans may account for the seed's popularity, including *sesamin, sesamolin,* and *sesamol*. Sesame oil has been shown to have antioxidant and health-promoting benefits due to its high concentration of tocopherol, phytosterol, lignan, and other components (Langyan et al,2022 & Jayraj et al, 2021). Moreover, the protective effects of sesame on heart function, regulation of lipid metabolism, and prevention of mutations and cancer have been demonstrated in numerous studies (Pal et al, 2020 & Singletary, 2022). The bioactive compounds found in sesame based foods are regarded as beneficial elements that aid in disease prevention, which encompasses a variety of compounds, including carotenoids, phenolics, phytosterols, and PUFAs (Langyan et al,2022, Ishfaq et al, 2022 & Wani et al, 2022). These compounds are prominently utilized as an source of antioxidants and serve multiple other purposes, such as inhibiting cholesterol absorption and blocking the effects of bacterial toxins etc., (Pathak et al, 2019, Sallam et al, 2021 and Li et al, 2022). Among the antioxidants and bioactive compounds, sesame may contain elevated levels of PUFAs, lignans, tocopherols, and phytosterols. The high antioxidant concentration in sesame oil, when compared to other edible oils, enhances energy levels and promotes resistance to aging (Ma et al, 2022 & Sallam et al, 2021).

Breeding strategies for sesame improvement:

Sesame improvement is aims for boosting the seed yield and nutritional quality by enhancing plant traits such as non-shattering capsules and disease resistance, while also addressing the challenges posed by low genetic diversity and stresses causing by abiotic factors. At present sesame breeding approaches includes the conventional breeding practices accompanied with the modern genomic tools like marker-assisted selection and genome editing to assimilate desirable traits from existing germplasm and wild relatives. Future strategies will prioritize a multi-faceted approach that includes effective germplasm conservation, the combination of conventional and advanced genomic techniques, the development of climate-smart varieties that can withstand diseases such as phyllody, and the promotion of research and development to improve the uptake of enhanced technologies. Sesame breeding aims chiefly at improving seed retention in the capsule, increasing oil content, ensuring uniform maturity, and enhancing disease resistance. For additional clarity, the subsequent breeding goals merit special emphasis:

a) Ideal plant type i.e. determinate plant type, higher numbers of leaf axils for more capsule bearing/plant, high yield and stability of performance;
b) High oil content, improved fatty acid composition and other quality traits;
c) Low or zero anti-nutritional factors (oxalic and phytic acids) for value addition;
d) Development of CMS lines for ease in hybrid seed production;
e) Resistance to biotic stress: insect pests (leaf eating caterpillar, gall fly) and diseases such as phyllody (virus, mycoplasma), bacterial leaf spot (*Pseudomonas sesami*), powdery mildew, wilt and leaf curl;
f) Semi-indehiscence of capsules;

g) Resistance to abiotic stresses: drought, water-logging and salinity, particularly under the scenario of global climate change

There are few studies on the genetics of sesame as well as on the improvement of genetic variation and its utilization in crop improvement programs. In general, the sesame cultivating community prefer high yielding stable sesame cultivars with inherent resistance to major pests and diseases, good end use quality, and exportable quality viz., white seed color, large seed size and good flavor. The cultivar must be resistant to bacterial blight in high rainfall areas, early maturing in low rainfall areas and resistant/tolerate to phyllody under irrigated condition. Here in this section brief note has been discussed regarding research approaches used by sesame breeder on following improvement aspects (breeding objectives) in this crop through exploring the potential of genetic and genomic resources.

a) Genepool diversity: Maintaining and utilizing diverse genetic resources, including wild relatives, provides access to valuable alleles for traits such as heat tolerance and fatty acid modification. The conservation of Sesame germplasm occurs at several key institutions, such as the Brazilian Gene Bank (BGB, Brazil), the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT, India), the National Bureau of Plant Genetic Resources (NBPGR, India), the National Institute of Agricultural Science and Technology (NIAST, Republic of Korea), the Nigerian National Gene Bank (NNGB), the United States Department of Agriculture—Agricultural Research Service (USDA-ARS, USA), and the Vavilov Institute of Plant Industry (VIR, Russia). ICRISAT is responsible for conserving 1302 accessions of sesame germplasm, which includes wild accessions and those sourced from international germplasm exchanges. Likewise, NBPGR conserves 5288 accessions of sesame germplasm, while the USDA-ARS repository holds 11,116 accessions, VIR has 9221 accessions, NIAST has 3317 accessions, BGB has 1455 accessions, and NNGB has 1039 accessions (Singh et al, 2007). The evaluation and characterization of these accessions for morphological, agronomical, and molecular traits have been conducted, resulting in the identification of unique genotypes that possess high yield, disease resistance, and quality traits.

b) Yield and Oil Quality: Increasing seed yield, oil quantity, and improving fatty acid profiles (e.g., higher oleic acid) are primary goals. From yield point of view, important components traits e.g. number of capsules per plant, seeds/capsule and 1000-seed weight are the important consideration for improvement of productivity. Eight-loculed plants have more seeds per capsule but they are not necessarily the highest yielding cultivars as they bear a comparatively fewer number of capsules. Sesame is a high value high yieldingoil crop. Oil yield can be increased by improving mature seed yield and oil content(>50%). Light seed color cultivars harbor higher oil content than the dark seededcultivars. A balanced fatty acid composition with proportionately higher percent-ages of unsaturated fatty acid (linoleic and oleic acids) as compared to saturatedfatty acid (stearic and palmitic acids) together with higher amounts of antioxidants(sesamol, sesaminol) and tocopherols is needed for high quality export value.

c) Uniformity and Maturity: Achieving synchronized maturity across plants and other desirable plant architecture traits like reduced height contribute to higher yields.

d) Abiotic Stress management: Developing resistance to abiotic stresses viz., drought, water-logging etc., is essential for sustained sesame production.

e) **Biotic stress Management:** Developing tolerance for the biotic stresses prominently diseases and pests are key factors for ensuring the better yield. Sesame is sensitive to bacterial blight, Fusarium wilt (*Fusarium oxysporum* Schlecht. emend. Snyder & Hansen) and charcoal rot (*Macrophomina phaseolina* (Tassi) Goid.) in high rainfall areas and phyllody (caused by Phytoplasma) under irrigated condition (Ojiambo et al. 1999). Similarly,the crop may be drastically affected by major insect pests such as the leaf webber/roller and capsule borer (*Antigastra catalaunalis* Duponchel), sphinx moth (*Acherontia styx* Westwood), aphids (Aphis gossypii Glover) and gall-midge/gall fly(*Asphondylia sesami* Felt). There is a need to develop cultivars with multiple resistance to the above biotic factors

f) **Non-shattering Capsule:** Breeding indehiscent, non-shattering capsules that open only at the tip is crucial for mechanized harvesting and reduces seed loss. Generally, all cultivars are of the shattering type and 99% of the fields are harvested manually, leading to 60–70% yield loss under dry weather. There is a need to reorient breeding strategy to alleviate the high costs of manual harvesting and yield loss due to shattering. Development of new high-yielding cultivars with semi-indehiscent capsules is a possible option to fit mechanized farming.

g) **Climate resilient:** Advancement of current strategies to maintain sesame production under changing climatic conditions. The objective of climate-resilient breeding is to develop crops capable of flourishing even exposed to the difficulties presented by a shifting climate, including rising temperatures, erratic rainfall patterns, and a higher incidence of extreme weather phenomena. This process entails the cultivation of crops that exhibit greater tolerance to these stressors and can sustain or potentially enhance productivity even in unfavorable circumstances.

To achieve above discussed goals in respect of sesame breeding, there are two possible modes for engineering the desired crop as below:

[a] Conventional Breeding Techniques: Sesame breeding through conventional approach involves strategies of hybridization, along with pedigree selection and pure-line selection, aimed at integrating desirable traits like increased yield, better oil quality, and resistance to pests, diseases, and pod shattering. Although this method proves effective, it faces limitations due to the crop's inadequate yields, sensitivity to stress factors, and often restricted genetic base.

Table 3 : Key conventional breeding approaches applicable in sesame

Approach/ Method	**Applicability**
Hybridization and pedigree selection	Desired traits are combined by crossing different parental lines, and subsequent generations are grown and selected based on parental pedigrees.
Pure-line selection	It involves selection of individual plants with superior traits from a population and advancing them as pure lines.
Mass selection	Mass selection is useful for improvement of quality traits like yield and oil content from existing commercial varieties.
Mutation breeding	Involves inducing genetic mutations through agents to create new variations for selection, though it is considered a non-traditional method.

Although, its well known fact that conventional breeding is time consuming and labor intensive exercise. Also to speed up the improvement process in any crop the available modern techniques and advances should be employed for rapid gains

[b] Modern Breeding Techniques: Recent developments in molecular strategies have been harnessed to breed crops with a broad spectrum of economically important traits, facilitating the creation of improved cultivars. These modern approaches address genotyping and high-throughput phenotyping approaches for predictive plant breeding. Modern techniques for breeding sesame include Marker-Assisted Selection (MAS), genome editing (for instance, CRISPR/Cas9), genomics-assisted breeding (GAB), haploid induction, artificial intelligence (AI), and speed breeding.

Table 4: Key Advanced Molecular and Genomic approaches applicable in sesame

Technique	**Applicability**
Marker-Assisted Selection (MAS)	MAS uses molecular markers (like SNPs and SSRs) for identification and selection of desirable genes for traits like yield, oil quality, or disease resistance at an early stage, significantly speeding up the breeding process compared to traditional methods.
Genomics-Assisted Breeding (GAB)	The technique of GAB involves utilization of genomic information, including quantitative trait loci (QTL) mapping, association mapping, and haplotype mapping, to associate specific genetic regions with key traits, facilitating more precise and efficient breeding.
Genome Editing (eg. CRISPR/Cas9)	This technology associated with editing of genome and that allows for precise modifications to the sesame genome, enabling the suppression of undesirable traits or the introduction of beneficial ones to improve traits such as the fatty acid profile and stress tolerance.
Haploid Induction	This technique frequently employed for production of haploid plants, which can be used to quickly create homozygous lines and accelerate the breeding cycle.
Speed Breeding	The technique of speed breeding may be applied by cultivating plants under controlled, optimized conditions (such as specific light and temperature regimes etc.,). The speed breeding permits for multiple crop cycles within a single year, drastically shortening the time to develop new varieties
Artificial Intelligence (AI)	Recent approach of AI can be applied to analyze large genomic and phenotyping datasets to identify key genes and accelerate the selection process in crop improvement.

These advanced strategies are often integrated with traditional breeding methods, such as hybridization and mutation breeding, to accelerate the production of improved sesame varieties that possess desirable characteristics, including increased yield, higher oil content, resistance to pests and diseases, and tolerance to abiotic stresses

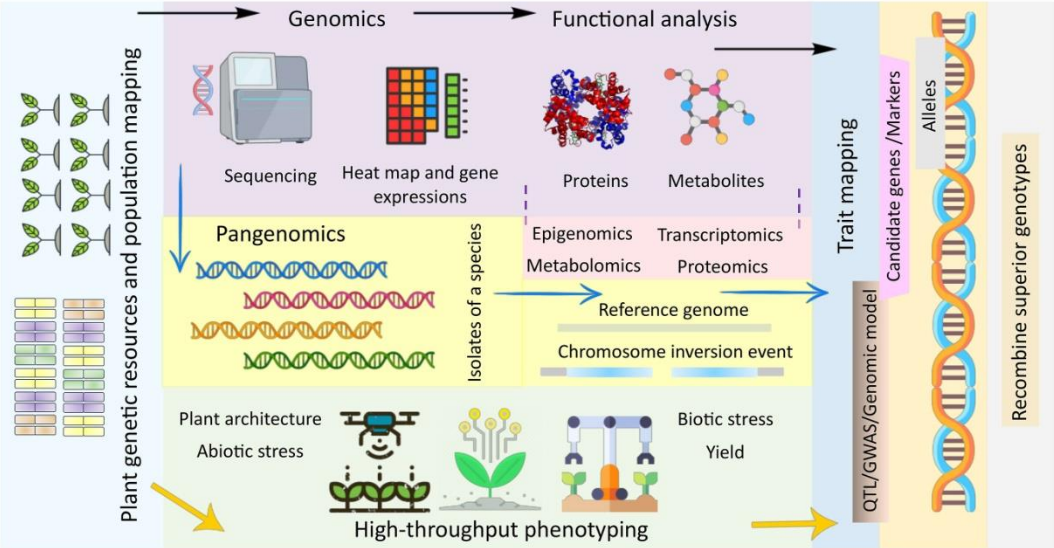
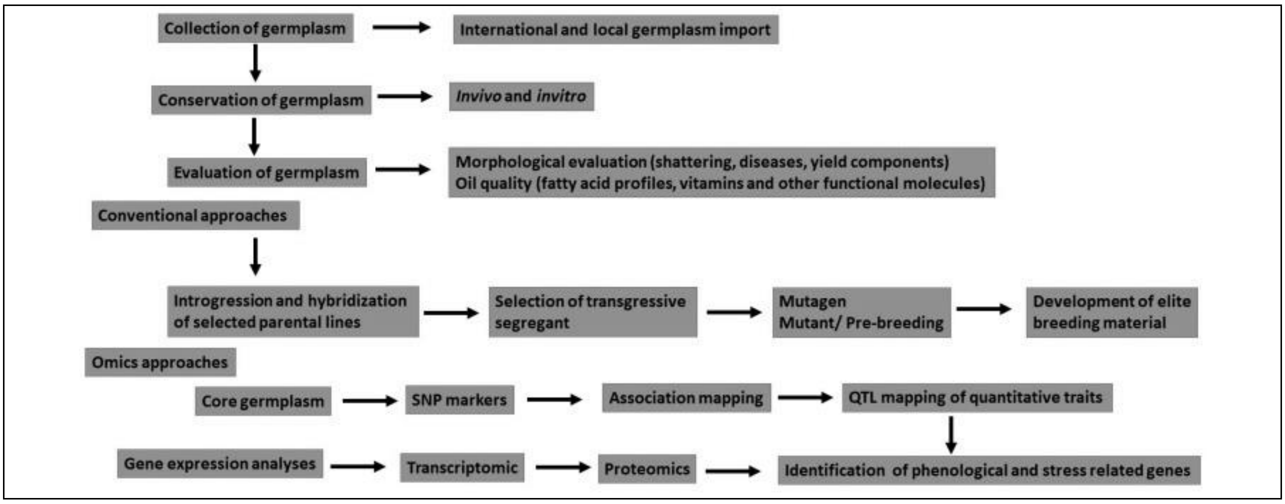


Fig. 1. Overview of modern molecular tools to deliver superior genotypes

The contemporary sequencing platforms use different plant resources to generate genomic variations, which facilitates functional characterization of the genes using different omics approaches. Alternatively, sequencing information is utilized in pangenome development of the plant species through analysing genomes of several plants. Another technique involves the investigation of plant resources through high-throughput tools that provide phenotypic information of the plants through the acquisition of precise phenotypic data by image and sensor technologies. The attained information from the three methods and their combination leads to trait mapping and identification of genotypic information related to the plant phenotypic character. The identified candidate genes and markers related to the favorable trait found from the sequencing and phenotyping data analysis will allow for the recombination of superior plant genotypes.

The rapid emergence of modern biotechnological tools has shown promise for crop breeding. These tools provide a means of introducing genomic variations and chromosomal alterations into plants with high precision and accuracy. It empowers breeders to direct and expedite crop selection in an unparalleled way and allows for limitless possibilities in terms of combining new alleles by removing breeding barriers. A comprehensive summary illustrating the concepts discussed in the text on sesame breeding and conservation is illustrated as below.



Conclusion

Sesame is an important oilseed crop with high value, attributed to its dietary uses, health benefits, and applications in industry. There is great scope for research in economically potent crop of sesame, as still necessary to further increase the yield and quality of sesame and to improve the related traits of sesame. The recent advancements in technology have facilitated substantial progress in crop breeding by researchers. Modern breeding approaches are markedly different from traditional ones, owing to significant changes in both the technical means utilized and the concepts guiding breeding practices. While traditional breeding was primarily focused on achieving high yields, contemporary breeding is oriented towards the specific needs of various stakeholders working in crop. Crop breeding plays a crucial role in improvement programs through the creation of crops tailored to specific environmental conditions, and the preferences of consumers. However, the main uncertainty regarding the application of these methods in plant breeding pertains to the regulatory framework that oversees the commercial products generated. The implementation of high-throughput technologies is essential for navigating regulations and for utilizing modern plant breeding techniques to create new crop cultivars.

References

1. Agidew M.G., Dubale A.A., Atlabachew M., Abebe W. (2021) Fatty acid composition, total phenolic contents and antioxidant activity of white and black sesame seed varieties from different localities of Ethiopia. Chem. Biol. Technol. Agric. 8:1–10.
2. Ahmed I.A.M., AlJuhaimi F., Özcan M.M., Ghafoor K., Şimşek Ş., Babiker E.E., Osman M.A., Gassem M.A., Salih H.A. (2020) Evaluation of chemical properties, amino acid contents and fatty acid compositions of sesame seed provided from different locations. J. Oleo Sci. 69:795–800
3. Akhila, H.; Suhara Beevy, S. (2015) Palynological Characterization of Species of Sesamum (Pedaliaceae) from Kerala: A Systematic Approach. Plant Syst. Evol., 301, 2179–2188.
4. Anonymous. (2022) ANSES. Ciqual Table, nutritional composition of sesame seeds

5. Aziz M. A. and Khalid Masmoudi (2025) Molecular breakthroughs in modern plant breeding techniques., Horticultural Plant J. Vol 11 (1) 15-41
6. Dar, A.A.; Kancharla, P.K.; Chandra, K.; Sodhi, Y.S.; Arumugam, N. (2019) Assessment of Variability in Lignan and Fatty Acid Content in the Germplasm of *Sesamum indicum* L. J. Food Sci. Technol., 56, 976–986.
7. Fasuan T.O., Gbadamosi S.O., Omobuwajo T.O.(2018) Characterization of Protein Isolate from *Sesamum indicum* Seed: In Vitro Protein Digestibility, Amino Acid Profile, and Some Functional Properties. Food Sci. Nutr. 6:1715–1723
8. Geetanjali M. (2024) Unlocking the secrets of Sesame floral biology., GreenariA., Vol. 2 (06) 50-53.
9. Gloaguen, R.M.; Couch, A.; Rowland, D.L.; Bennett, J.; Hochmuth, G.; Langham, D.R.; Brym, Z.T. (2019) Root Life History of Non Dehiscent Sesame (*Sesamum indicum* L.) Cultivars and the Relationship with Canopy Development. Field Crops Res., 241, 107560
10. Hedge D.M. (2012) Chapter 23 – Sesame in Handbook of herbs and spices (Second Edition); Woodhead Publishing., Vol 2, 449-486
11. Ishfaq M., Hu W., Hu Z., Guan Y., Zhang R. (2022) A review of nutritional implications of bioactive compounds of Ginger (*Zingiber officinale* Roscoe), their biological activities and nano-formulations. Ital. J. Food Sci. 34:1–12.
12. Jayaraj P., Narasimhulu C.A., Rajagopalan S., Parthasarathy S., Desikan R. (2020) Sesamol: A powerful functional food ingredient from sesame oil for cardioprotection. Food Funct.,11:1198–1210
13. Kale G.G., V.V.Ujjainkar, E.R.Vaidya and M.W.Marawar (2021): Studies on Genetic Parameters in Sesame (*Sesamum indicum* L.)., E-Conference: “Agricultural Education, Innovation and Research for Future Livelihood - Indian Scenario in 2050” by NAHEP, Dr. PDKV., AKOLA (MS)
14. Kharade M.R., V.V.Ujjainkar and K.C.Bhagat (2016) Evaluation of genetic diversity in groundnut mutants (*Arachis hypogaea* L) using seed protein electrophoresis. Eco. Env. & Cons. 22 (June Suppl.): S83-S87
15. Khuimphukhieo I. and Khaengkhan P. (2018) Combining Ability and Heterosis of Sesamin and Sesamolin Content in Sesame. SABRAO J. Breed. Genet.,50:180–191.
16. Langyan S., Yadava P., Sharma S., Gupta N.C., Bansal R., Yadav R., Kumar A. (2022) Food and nutraceutical functions of Sesame oil: An underutilized crop for nutritional and health benefits. Food Chem.,389:132990
17. Li M., Luo J., Nawaz M.A., Stockmann R., Buckow R., Barrow C., Dunshea F., Suleria H.A.R. (2023) Phytochemistry, Bioaccessibility, and Bioactivities of Sesame Seeds: An Overview. Food Rev. Int.,40:1–27.
18. Lu X., Zhang L., Sun Q., Song G., Huang J. (2019) Extraction, Identification and Structure-Activity Relationship of Antioxidant Peptides from Sesame (*Sesamum indicum* L.) Protein Hydrolysate. Food Res. Int. Ott. Ont.,116:707–716.

19. Ma X., Wang Z., Zheng C., Liu C. (2022) A comprehensive review of bioactive compounds and processing technology of sesame seed. Oil Crop Sci., 7:88–94.
20. Mustafa Y. and Hüseyin G. (2023) Sesame Seed Protein: Amino Acid, Functional, and Physicochemical Profiles. Foods Raw Mater.,11:72–83.
21. Pal D., Chandra P., Sachan N. (2020) Nuts and Seeds in Health and Disease Prevention. Elsevier; Amsterdam, The Netherlands: 2020. Sesame seed in controlling human health and nutrition; pp. 183–210.
22. Pathak N., Bhaduri A., Rai A.K. (2019) Bioactive Molecules in Food. Springer; Berlin/Heidelberg, Germany: 2019. Sesame: Bioactive compounds and health benefits; pp. 181–200.
23. Pathak N., Rai A.K., Kumari R., Bhat K.V. (2014) Value Addition in Sesame: A Perspective on Bioactive Components for Enhancing Utility and Profitability. Pharmacogn. Rev. 8:147–155
24. Ram HH (2011) Sesame. In: Ram HH (ed) Crop breeding and biotechnology. Kalyani Publishers, New Delhi, pp 514–528
25. Ram R, Catlin D, Romero J and Cowley C (1990) Sesame: new approaches for crop improvement. In: Janick J, Simon JE (eds) Advances in new crops. Timber Press, Portland, pp 225–228
26. Sallam K.I., Abd-Elghany S.M., Imre K., Morar A., Herman V., Hussein M.A., Mahros M.A. (2021) Ensuring safety and improving keeping quality of meatballs by addition of sesame oil and sesamol as natural antimicrobial and antioxidant agents. Food Microbiol. ,99:103834.
27. Singh A.K., Srinivasan K., Dhillon B., Mehra K. (2007) Plant Genetic Resources Management in India: A Historical Perspective. In: Singh A.K., Srinivasan K., Saxena S., Dhillon B.S., editors. Hundred Years of Plant Genetic Resources Management in India. NBPGR (ICAR); New Delhi, India. pp. 29–48
28. Singletary K.W.(2022) Sesame: Potential Health Benefits. Nutr. Today.,57:271–287.
29. Sun, L.; Lai, M.; Ghouri, F.; Nawaz, M.A.; Ali, F.; Baloch, F.S.; Nadeem, M.A.; Aasim, M.; Shahid, M.Q. (2024) Modern Plant Breeding Techniques in Crop Improvement and Genetic Diversity: From Molecular Markers and Gene Editing to Artificial Intelligence—A Critical Review. Plants, 13, 2676
30. Teklu, D.H.; Shimelis, H. and Abady, S. (2022) Genetic Improvement in Sesame (*Sesamum indicum* L.): Progress and Outlook: A Review. Agronomy, 12, 2144
31. Tripathy Swapan K., Jayashree Kar and Dibyabharati Sahu. (2021). Advances in sesame (*Sesamum indicum* L.) breeding in Breeding strategies: Industrial and Food crops. Springer Publication., Vol. 6 577-635
32. Ujjainkar V. V. and M. W. Marawar (2020). Genetic Diversity: A tool for assessing potential of genepool., Remarking An Anlisation., 4 (11) 38 – 44
33. Ujjainkar V. V. and V. D. Patil (2020) Marker assisted selection in American cotton genotypes using biochemical and molecular profiling techniques, Int. J. Adv. Res., Ideas and Innovations Tech, Vol. 6 (3) 989 – 993

34. Ujjainkar V.V., E.R.Vaidya, S.M.Shinde and G.G.Kale (2022) Characterization of sesame (*Sesamum indicum* L.) germplasm. Int J Innovative Sci and Res. Technology., Vol 7 (7) 414 – 417
35. Ujjainkar V.V., S.B.Datke and T.H.Rathod (2002) Genetic Divergence studies in sesame (*Sesamum indicum* L.) Annals of Plant Physiology Vol. 16 (2) 18-22
36. Ujjainkar Vaibhav (2025) 'D2 statistics' technique: methodology and applications in plant breeding. International Journal of Research and Review; 12(8): 127-139. DOI: 10.52403/ijrr.20250815
37. Vaibhav Ujjainkar (2025) Significance of the PPV & FR Act In Indian Agriculture: Status Quo and Future Outlook Int. J. Adv. Res. 13(07), 595-604
38. Wang R., Lu X., Sun Q., Gao J., Ma L. and Huang J. (2020) Novel ACE Inhibitory Peptides Derived from Simulated Gastrointestinal Digestion in Vitro of Sesame (*Sesamum indicum* L.) Protein and Molecular Docking Study. Int. J. Mol. Sci. 21:1059
39. Wani S.A., Naik H., Wagay J.A., Ganie N.A., Mulla M.Z., Dar B. (2022) Mentha: A review on its bioactive compounds and potential health benefits. Qual. Assur. Saf. Crops Foods. 2022;14:154–168
40. Wei, P.; Zhao, F.; Wang, Z.; Wang, Q.; Chai, X.; Hou, G.; Meng, Q. (2022) Sesame (*Sesamum indicum* L.): A Comprehensive Review of Nutritional Value, Phytochemical Composition, Health Benefits, Development of Food, and Industrial Applications. Nutrients, 14, 4079.
41. Wu K., Wen-Xiong W.U., Yang M.M., Liu H.Y. and Zhao Y.Z. (2017) QTL Mapping for Oil, Protein and Sesamin Contents in Seeds of White Sesame. ACTA Agron. Sin. 43:1003–1011.
42. Xu F., Zhou R., Dossou S.S.K., Song S. and Wang L. (2021) Fine Mapping of a Major Pleiotropic QTL Associated with Sesamin and Sesamolin Variation in Sesame (*Sesamum indicum* L.) Plants.10:1343.
43. Yermanos D. M. (1980) Sesame. In: Fehr WR, Hadley HH (eds) Hybridization of crop plants. ASA, Madison, pp 549–563
44. Zhang Y, Wang L, Li D et al (2012) Association mapping of sesame (*Sesamum indicum* L.) resistance to macrophomina phaseolina and identification of resistant accessions. Sci Agric Sin 45:2580–2591.

Table 2: Phytochemical components in sesame.

Class of Compound	Phytochemical Components	Organ Studied	Extracting Solvent	Separation Method	Methods of Structural Verification	References
Protein	Albumin, globulin (*α* and *β*), prolamin, glutelin fractions	Seed	NA	Column chromatography	HPLC, UV	Hedge (2012)
Essential amino acid	Alanine, arginine, aspartic acid, cysteine, glutamic acid, glycine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, serine, threonine, tyrosine, valine, tryptophan, proline, *γ*-aminobutyric acid	Leaf, stem, flower, seeds, root	60% MeOH	HPLC or TLC	HPLC or LC-ESI-MS/MS, HRMS, 2D NMR	Wang et al (2020)
Lipid	Latifonin	Flower	95% EtOH	Column chromatography	MS, NMR	Lu et al (2019)
Unsaturated Fatty acid	Oleic acid, linoleic acid, palmitic acid, stearic acid, arachidic acid, linolenic acid, palmitoleic acid	Seeds	EtOH	HPLC	HPLC, GC	Dar et al (2019)
	Lignoceric acid, caproic acid, behenic acid, myristic acid, margaric acid	Seeds	NA	Column chromatography	FT-NIR	Wu et al (2017)
Vitamin	Vitamin A, thiamine, riboflavin, niacin, pantothenic acid, folic acid, ascorbic acid, *α*-tocopherol, *β*-tocopherol, *γ*-tocopherol, δ-tocopherol	Seeds	NA	Column chromatography	HPLC, UV	Hedge (2012)
	Tocotrienol	Seeds	MeOH or EtOH or *n*-hexane and 80% EtOH	2D-TLC	HPTLC, GC	Fusan et al (2018)
Carbohydrates	D-Glucose, D-galactose, D-fructose, raffinose, stachyose, planteose, sesamose	Seeds	NA	Column chromatography	HPLC, UV	Hedge (2012)
Lignan	Sesamin, sesamolin	Aerial organs, seeds	EtOH	HPLC	HPLC, GC	Dar et al (2019)
	Sesamol	Seeds	EtOH	HPLC	HPLC, GC	Dar et al (2019)
	(+)-Episesaminone, (+)-Episesaminol 6-catecho, pinoresinol, (−)-Pinoresinol-*O*-glucoside, (+)-Pinoresinol Di-*O*-*β*-D-glucopyranoside, glucopyranosyl-(1→6)-*β*-D-glucopyranoside, Sesaminol, (+)-	Seeds	MeOH or EtOH or *n*-hexane and 80% EtOH	2D-TLC	HPTLC, GC	Fusan et al (2018)

Class of Compound	Phytochemical Components	Organ Studied	Extracting Solvent	Separation Method	Methods of Structural Verification	References
	Sesaminol 2-*O*-*β*-D-glucoside (+)-Sesaminol diglucoside, (+)-Sesaminol 2-*O*-*β*-D-glucosyl (1→2)-*O*-[*β*-D-glucosyl (1→6)]-*β*-D-glucoside, Sesamolinol, (+)-Sesamolinol 4′-*O*-*β*-D-Glucoside, Sesamolinol 4′-*O*-*β*-D-glucosyl (1→6)-*O*-*β*-D-glucoside, matairesinol, samin, sesangolin, disaminyl ether					

NA = Data not available. HRMS: high resolution mass spectrometer, NMR: nuclear magnetic resonance, TLC: thin layer chromatography, HPTLC: high performance thin layer chromatography, HPLC: high performance liquid chromatography, HR-EI-MS: high-resolution electron ionization mass spectrometry, HR-ESI-MS: high resolution electrospray ionization mass spectrometry, LC-MS: liquid chromatography–mass spectrometry, FT-NIR: Fourier transform-near infrared spectroscopy, ESI-MS: electrospray ionization mass spectrometry, MS: mass spectrometry, IR: infrared spectroscopy, GLC: gas liquid chromatography, GC: gas chromatography.