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COMPLEXITY OF DNA REPAIR MECHANISMS AND EMERGING TRENDS IN SAFEGUARDING GENETIC INTEGRITY

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Abstract *The production and productivity of sesame face significant challenges due to the absence of high-yielding and regionally adapted cultivars, susceptibility to capsule shattering and inadequate seed retention, and exposure to biotic and abiotic stressors. The lack of modern production techniques and insufficient pre- and post-harvest technologies further contribute to these limitations. As a result, existing and future sesame genetic improvement efforts should incorporate features that increase yield and quality, are adapted to the local environment, are machine-harvestable, and have other industrially crucial food and feed properties for various utilities. This can be accomplished by combining traditional breeding techniques with genetic and genomic tools like mutant breeding and breeding assisted by genomics. In this essay, we will examine the research that has been done on sustainable sesame (Sesamum indicum L.) production, as well as the production challenges and prospects for sesame in Myanmar. An essential crop for nutrition and the economy, sesame is treasured for its oil. With greater health consciousness, the demand for sesame on the global market is expanding. Meanwhile, the market for international trade among the producing nations is very competitive. To overcome these obstacles and identify the crucial limiting variables, an integrated strategy is required for sesame production. The integration of these genomic resources will make it possible to boost sesame production through crop protection and production methods, postharvest procedures, crop improvement initiatives, and capacity building. Since improved seed yield, variety release, and deployment with relevant agronomic qualities, as well as oil content and fatty acid compositions, are all important aspects of sesame breeding, it is important to describe these developments in this review. The paper highlights the economic importance of sesame, its production situation, its main production limits, traditional breeding techniques, genomics-assisted breeding, and how these can all be combined to speed up breeding and create cultivars with desirable features for the market.*

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Introduction

Sesame (*Sesamum indicum* L.) is an erect annual plant known as *sesamum*, benniseed, or simsim. It is a diploid with 2n=2X=26 chromosomes, a self-pollinating crop, and a member of the Pedaliaceae family (Kadvani et al., 2020). Archaeological findings suggest that sesame farming can be traced back to native wild populations in South Asia, with evidence indicating its establishment in the region before 2000 B.C (Castillo et al., 2016). Sesame exhibits adaptability to various soil types, although it thrives best in well-drained, fertile soils with a neutral pH and a medium texture, commonly found in sandy loam. Typically categorized as a short-day plant, sesame has the potential to thrive in regions with longer daylight hours (Castillo et al., 2016). Sesame has created genotypes with varying photoperiod needs depending on the amount of light and the length of the day in different geographic locations (Wei et al., 2015). Sesame seeds offer both nutritional and therapeutic benefits because they are a good source of fat, protein, carbs, fiber, and vital minerals. They are used to make bakery goods, high-grade edible oil, and sweets like halva (dessert) and sesame bars.

Sesame is produced for margarine and oil, frequently called the "queen of oil crops," (Pusadkar et al., 2015). The overall oil's fatty acid makeup determines the quality of the oil. Additionally, it serves as an insecticide synergist and is used in pharmaceutical and skin care goods. The seed contains between 50 and 60 percent oil, and because it includes natural antioxidants such as sesamolin, sesamin, and sesame, it is quite stable (Wan et al., 2015). Sesame is one of the oldest cultivated plants in the world, but due in large part to its low yield, production and growth have been constrained. Lack of specific studies on yield structure as a foundation for advancement in sesame breeding is a major cause of sesame's low yields (Tripathy et al., 2019). For sesame to compete with other crops, extensive breeding programs for high-yielding cultivars are required. With a CAGR of 1.7%, global consumption of sesame seeds would increase from USD 6559.0 million in 2018 to USD 7244.9 million by 2024 (Myint et al., 2020). Consumers today tend to favor foods with excellent nutritional values. As a result, sesame seeds are in stronger demand due to their high nutritional value, including vitamins, minerals, fiber, good fats, and protein (Wei et al., 2022). Sesame seed accounts for over 70% of the world's production of oil and meal (Morris, 2002). About 65% and 35% of all food and oil consumed annually, respectively. Figure 1 shows the average sesame productivity of the top 20 sesame-producing nations during the next 20 years (1999–2018) (Myint et al., 2020).

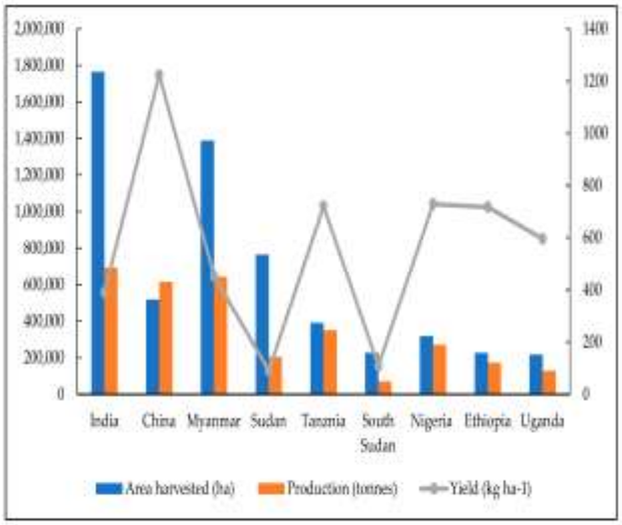

Figure 1: Trend of sesame production values over the past 20 years in the major producing nations (Average 1999–2018) Source: FAOSTAT, 2020, a statistical database maintained by the Food and Agriculture Organization. (Myint et al., 2020).

By 2030, it is anticipated that global consumption of vegetable oils will quadruple, and that of sesame oil may reach 100 million MT (Myint et al., 2020). As a result, there will be a greater demand for genetic research on high-oil crops. Sesame, one of the earliest oilseeds, is commonly grown in tropical and subtropical regions (Pusadkar et al., 2015). Sesame crops are currently subject to several difficulties in the edible oilseed sectors. Despite being one of the top producers and possessing a wide variety of sesame germplasm, Myanmar has many production challenges. Low and inconsistent yields make it difficult to grow sesame, and technology-based farming methods have their limitations (Badji et al., 2022). The sesame crop development program now has access to significant research achievements, genetic resources, and genomic sequence data (Kefale and Wang, 2022). The existing state of the nation, as well as research and development, are required for the growth of the sesame oilseed industry. This paper aims to examine research accomplishments, present trends, and sesame production challenges. It also seeks to suggest the potential for the future and a plan to increase sesame production. A literature search and secondary data are used in its execution (Kefale and Wang, 2022).

Major Constraints on Sustainable Sesame Production

Sesame demonstrates robust growth even in challenging conditions thanks to its inherent resistance to pests and diseases. This resilient crop demands minimal input in terms of fertilizer, water, or debris (Koul et al., 2022). Pesticides are largely unnecessary for sesame cultivation. This crop is predominantly grown in rainfed environments, particularly in arid and semi-arid regions characterized by mild to severe water scarcity stress. However, in some locations, drought and salinity can impede sesame yields (Li et al., 2018). Sesame faces notable susceptibility to drought in all its cultivation zones, especially during the vegetative stages. The semiarid regions, in particular, exhibit limited production potential due to the impact of drought stress. Sesame, however, demonstrates resilience to elevated salinity levels during germination and early growth stages, with observed variations among different sesame genotypes (Li et al., 2018). Sesame cultivation faces challenges in areas characterized by high salt content, waterlogging, or cold temperatures, making it unsustainable in such environments (Myint et al., 2020). Waterlogging significantly hampers plant growth, reduces the number of leaf axils per plant, diminishes seed output, and adversely affects net photosynthesis in sesame. Bacterial diseases such as Cercospora leaf spots, stem and leaf blotch, and leaf spots are prevalent and pose significant threats to sesame plants (ur Rehman et al., 2021). Wilt also proves fatal for susceptible varieties of sesame. Moreover, the crop is prone to serious diseases like blight, charcoal rot, stem anthracnose, mildew, and phyllody, further impacting sesame cultivation (Meena and Ezhilarasi, 2019). Globally, sesame production faces limitations due to the absence of quickly adaptable cultivars, issues with capsule breaking, uneven ripening, challenges in crop stand establishment, suboptimal responses to fertilizers, excessive branching, low harvest index, unpredictable growth habits, and susceptibility to diseases (DANIEL, 2020). Sesame's unpredictable growth pattern and tendency to shatter make harvesting difficult, reduce productivity, and make it difficult to adapt to robotic harvesting. Over 99% of the sesame produced worldwide, most of which is harvested manually, is breaking (Stamatov and Deshev, 2018). When the sesame plants are 50% mature, they are harvested. The greatest troublesome aspect of it is its capsule-shattering tendency, which results in significant seed losses (up to 50%) during harvest. In all phases of postharvest handling, including processing, shipping, storage, packing, and marketing, grain is lost between harvest and consumption. The size of the farm, the quantity of sesame grain produced, the weather, the distance that piles are hauled, the days that piles are stacked, the location of the sesame farm, and the manner of grain transportation were the main determinants of postharvest losses in sesame (Meena and Ezhilarasi, 2019).

Research Achievements through Improved Technologies in Sesame

The global population is projected to increase by 25% over the next 30 years, reaching 10 billion people (Willett et al., 2019). Consequently, there is a pressing need to develop new crops with high yield, enhanced nutrient density, resistance to diseases and pests, and adaptability to climate variations. In the case of sesame, breeding efforts should prioritize traits such as increased yield, higher oil content, uniformity, and resilience to both biotic and abiotic stress factors (Tripathy et al., 2019). Despite its significance for food, health, and industrial applications, genetic development in sesame lags behind that of other oilseed crops. The primary breeding objective is to narrow the wide yield gap, focusing on characteristics influencing yield, such as the quantity of capsules per plant and growth pattern (Tripathy et al., 2019). Langham's groundbreaking discovery of a monogenic homozygous recessive indehiscent mutant (id/id) in 1943 (Myint et al., 2020) marked a crucial development in sesame breeding. The indehiscent variety, having since spread globally, has become a focal point for breeders crossing their sesame lines. Notably, after three decades of extensive research in Bulgaria, four sesame varieties—Victoria, Aida, Valya, and Nevena. Through collaboration between breeders and engineers, this achievement resulted in an average yield of 1354 kg per hectare (Stamatov and Deshev, 2018).

The genus Sesamum encompasses a total of 23 species, among which Sesamum indicum is the most popular and widely cultivated (Wei et al., 2022). A considerable reservoir of genetic material from both cultivated and related wild sesame is currently conserved in various repositories. These include holdings in the United States, South Korea, India, China, and small-scale gene banks in other Asian and African nations. Sesame core collections have been established to facilitate effective research and leverage unique genetic variations. Notably, these collections include 362 Indian accessions, 453 Chinese accessions, and 278 Korean (Teklu et al., 2022). Genetic engineering techniques offer solutions to the limitations of conventional breeding methods, and sesame breeding benefits from various cutting-edge approaches. However, the application of contemporary biotechnology is impeded by the inherent resistance of sesame. Successful sources of somatic embryogenesis in sesame include hypocotyl segments, cotyledons, roots, and the subapical hypocotyl of seedlings (Martínez et al., 2015). Recent advancements have enhanced the regeneration process in sesame, particularly using sesame cotyledons and de-embryonated cotyledons. While genetic changes have been observed in sesame through the use of Agrobacterium, such occurrences are infrequent (Andargie et al., 2021).

The current crop breeding practices are insufficient to meet the continuously growing global population's food and nutritional security demands. To expedite crop genetic advancement, 5G breeding strategies have been proposed. These encompass genome assembly, germplasm characterization, gene function identification, genomic breeding methodologies, and the application of gene editing (Varshney et al., 2020). Genome assembly provides genomic methods and tools essential for molecular breeding and the discovery of traits. To understand the genomic landscape comprehensively, it is imperative to create a gene expression atlas, proteome maps, metabolome maps, and epigenome maps. In the case of sesame, the Sesame Genome Working Group achieved a significant milestone by generating a draft assembly of 293.7 megabases using the Yuzhi11 contemporary cultivar (Myint et al., 2020). The sesame pangenome was recently assembled using two landraces and three contemporary cultivars. This genome spans 554.05 megabases, comprising 258.79 megabases for the core genome and 295.26 megabases for the dispensable genome. The pangenome includes 26,472 orthologous gene clusters, with 15,890 being variety-specific genes, and 58.21% representing core genes. Notably, the study reveals substantial genetic heterogeneity among modern cultivars from China and India. Understanding genetic variability and heritability and conducting correlation studies of plant attributes is crucial for effectively utilizing germplasm in breeding efforts. This knowledge provides valuable insights for optimizing breeding strategies and enhancing the desired traits in sesame (Abbas et al., 2016; Fatima et al., 2023; Iqra et al., 2020; Masood et al., 2015; Tiwari et al., 2019).

National and international genebanks are valuable repositories of diverse alleles essential for crop improvement. DNA markers, owing to their capacity to enhance genetic gain and expedite breeding cycles in numerous crop species, have become effective tools for genetic evolution, marker-assisted breeding, and the acceleration of modern plant breeding (Mazhar et al., 2020; Sarwar et al., 2022; Sarwar et al., 2021; Tripathy et al., 2019). In the context of sesame, various molecular markers, including RAPD (random amplified polymorphic DNA), AFLP (amplified fragment length polymorphism), ISSR (Inter-simple sequence repeats), cDNA-SSR, genome sequence SSR, chloroplast SSR, and high-throughput methods for SNPs (single nucleotide polymorphisms) such as restriction site-associated DNA sequencing (RAD), have been developed and employed. These markers play a crucial role in sesame breeding programs, enabling researchers to understand and manipulate the genetic diversity for improved crop traits (Asif et al., 2020; Shafique et al., 2020; Varshney et al., 2020).

Sesame Genetic Resources and Research Activities

Sesame is one of the many tropical crop species that may be found in Myanmar and has a high diversity rate. In crossbreeding, both imported and conventional cultivars are frequently used. Although variation names vary from place to place, the name of the Myanmar sesame variety is related to the stem, capsule, and seed color. They fall into three general types based on life span: early maturity (60–80 days), medium maturity (80–100 days), and late maturity (100–135 days) (Myint et al., 2020). Traditional and unusual varieties of sesame have been crossing over since 1954. Traditional cultivars are being gathered, chosen, and crossbred to produce high-quality seeds that will be distributed. The genetic diversity study based on morphology has revealed a wide range of variability in stem, leaf, and flower traits and yield and yield component character. Production is influenced by several variables, including the number of days until first blooming, the number of days to 50% flowering, plant height, the number of primary branches and secondary branches per plant, the number of capsules per plant, and the length of the capsules. It was possible to get ten clusters, and a breeding program would profit from them (Kumar et al., 2020).

Constraints and Challenges of Sesame Production

The main difficulty in sesame production is raising output per square foot. FAOSTAT estimates that Myanmar's sesame production (525 kgha) is considerably lower than China's neighbor's is (1 393 kgha). Several abiotic, biotic, technical, and social factors contribute to the discrepancy between the farmer's actual yield and the prospective yield in the sesame production industry. The expected yearly average temperature increase from 1980 to 2005 to the 2020s is between 0.7 and 1.1 °C (Wacal et al., 2021). The temperature and rainfall will shift significantly in the arid regions by the mid-2050s. A short monsoon season lowers sesame yield, while severe rain lowers sesame yield and quality. Numerous reasons contribute to low agricultural output; many correlate with a lack of suitable farm inputs (Sharaby and Butovchenko, 2019). The government distributes approximately 307 MT of sesame seeds, including 89 MT of certified seeds. Attacks from pests and diseases are one of the factors that limit sesame yield. Sesame jassids (*Orosius albicinctus* Distant), sesame leaf rollers (*Antigastra catalaunalis*), leaf hoppers, and aphids were all serious pests in the areas where sesame was grown (LIMA et al., 2020).

Due to the clay and sandy soil characteristics and high risk of erosion and water constraint, land degradation is one of the issues endangering farmers' livelihoods in arid zones and restricting sesame production. Crop yields decreased, cultivation costs rose, and the land that could not be farmed grew for farmers in severely degraded areas. Soil conservation must be done effectively, and extension services must be used to increase farmer understanding through stronger outreach programs (Karnas et al., 2019). Another obstacle to sesame output is poor postharvest handling. A current issue that affects production, drying, and harvesting is a labor shortage. By adding suitable mechanical harvesting equipment, it can be overcome. Oilseeds are susceptible to significant quality losses during storage since they are semi-perishable. Incorrect storage can lead to microbial growth, insect and rodent infestation, and metabolic alterations. The majority of the sesame postharvest losses occurred during storage. It can be reduced by using effective storage technology, modernizing infrastructure, and improving storage procedures (Ahsan et al., 2013; Ali et al., 2014a; Ali et al., 2014b; Teklu et al., 2021). The absence of a market contributes to lower productivity and production in some regions. The majority of farmers prefer to use affordable chemical fertilizers, insecticides, and pesticides that are of high quality. Additionally, they have to deal with uncertainly or poor inputs. Low yield might also be caused by a lack of credit, which prevents you from purchasing the necessary inputs. The many actors in the sesame value chain, including the wholesaler, millers, processors, and exporters, benefited from the increased demand for domestic and foreign trade (Lukurugu et al., 2023).

Breeding Methods and Associated Technologies for Sesame Improvement

Conventional Breeding

The production of new varieties of sesame depends on conventional breeding techniques. New genetic variants in sesame have been produced by conventional breeding. The efficient use of germplasm depends critically on knowledge of the prevalent genetic diversity, degree of heritability, and correlation of agronomic variables. Estimates of heritability quantify the degree of genetic diversity and phenotypic selection-driven evolution. For phenotypic selection to succeed in traditional breeding, great heritability and high genetic progress are prerequisites. The level of association between economic traits determines the effectiveness of selection in sesame breeding (Ali et al., 2013; Ali et al., 2016; Parandi et al., 2023). Highly linked characteristics guarantee higher selection response and yield improvements. Plant height, the number of major and secondary branches, the number of capsules per plant, and the weight of one thousand seeds all have a highly significant positive link with sesame seed yield. Among 139 sesame genotypes gathered from Africa and Asia, Dossa et al. evaluated the amounts of oil, protein, and fatty acids. The authors confirmed Teklu et al.'s findings when they analyzed 100 Ethiopian sesame germplasm sets and found a negative connection between seed oil and oleic acid concentrations. Additionally, a negative association was discovered between the amounts of oleic acid and linoleic acid in sesame genotypes (Nithyapriya et al., 2021).

Mutation Breeding

Mutation breeding is a valuable tool for augmenting genetic diversity and supporting traditional breeding practices. As a result of international development initiatives, 147 sesame mutants with advantageous economic characteristics have been officially registered. Table 2 lists purportedly improved sesame varieties worldwide, resulting from mutation induction and featuring enhanced economic traits. Among the notable examples Senai white 48 and Cairo white 8, two mutant varieties specifically developed and introduced in Egypt (Lima et al., 2023). These varieties exemplify the successful application of mutation breeding techniques to enhance desirable economic features in sesame. In South Korea, Lee and Choi Kang found a mutant cultivar called Seodun to have a greater oleic content and be more resistant to phytophthora blight. The mutant strain ANK-2, which has considerable disease resistance, was produced and distributed in Sri Lanka. One of the low-yield-attributing characteristics of sesame is capsule cracking. Therefore, this major difficulty should be the focus of future mutation breeding initiatives. Disease-resistant and high-oil sesame mutant cultivars were reported in South Korea (Mirzaee et al., 2020).

Variety Name	Trait	Country	Year of Release	Reference
NIAB-Pearl	Higher capsules per plant	Pakistan	2017	(Lima et al., 2023)
NIAB-Sesame 2016	High oil content		2016	
Binatil-3	High yield	Bangladesh	2013	(Noorani et al., 2023)
Cairo white 8	Nonbranching	Egypt	1992	
Senai white 48	Seed color		1992	
Kalika	Short stature	India	1980	
UMA	Uniform maturity		1990	
USHA	Higher yield		1990	
Babil	Earliness	Iraq	1992	(Langham et al., 2021)
Rafiden	Earliness		1992	
Eshtar	Capsule size		1992	
Ahnsan	Disease resistance	South Korea	1985	(Eskandari and Mousavian, 2023)
Suweon	Lodging and disease resistance		1991	
Yangbaek	Higher oil content		1995	
Pungsan	Determinate growth habit and high seed retention		1996	
Seodun	Higher oleic acid content and phytophthora blight tolerance		1997	
ANK-2	Disease resistance	Sri Lanka	1995	(Amorim et al., 2019)

Table 2: Some sesame varieties developed through induced mutation with traits descriptions.

Genomics-Assisted Breeding

Utilizing genomic tools and methodologies is crucial in the context of trait discovery and molecular breeding. Sesame possesses a genome size of 554.05 megabases (Mbp), consisting of a core genome of 258.79 Mbp and a dispensable genome of 295.26 Mbp. These genomic insights provide a foundation for understanding the genetic composition of sesame, facilitating targeted trait identification and molecular. The sesame genome comprises 26,472 orthologous gene clusters, with 15,890 being variety-specific. The complete set of genes, known as the sesame pangenome, represents a vital genomic resource for sesame improvement initiatives and genetic research. This comprehensive collection of genes enables a more in-depth exploration of genetic diversity, facilitating targeted efforts to enhance desirable traits and furthering our understanding of sesame genetics (Abate et al., 2023).

Genetic Diversity Analysis

Molecular markers are extremely trustworthy genetic tools that support phenotypic breeding selection. For genetic analysis, breeding, and conservation, it is essential to understand the genetic diversity and population structure of germplasm collections. Multiple DNA markers have been used to examine the genetic variety of sesame. Various studies have used amplified fragment length polymorphism (AFLP) to evaluate the genetic diversity of sesame accessions worldwide. As a result of their capacity to identify larger levels of polymorphism, higher repeatability, codominance, and extensive genome coverage, SSR markers are frequently utilized in sesame genetic study and breeding (Lv and Wu, 2020). A core collection was chosen because ofgenetic diversity research on 137 Turkish sesame germplasms utilizing morphological features and RAPD markers. The investigation of 24 SSR markers on 121 Ugandan sesame landraces revealed discrepancies between morphological and molecular data. At the National Semi-Arid Resources Research Institute (NaSARRI) in eastern Uganda, 85 test germplasms from various nations were found to have a medium level of genetic differentiation. Additionally, analysis of a global germplasm collection composed primarily of Indian accessions revealed the germplasm to have a significant genetic diversity. The information from phenotypic and molecular markers did not correlate significantly. Using seed oil, fatty acid contents, and SSR markers, the genetic diversity across 100 Ethiopian germplasm collections was evaluated. According to the investigators, the fatty acid profiles and seed oil levels across the test lines showed significant genetic diversity (Gela et al., 2019).

Next-Generation Sequencing

With the development of the NGS technology over the past few years, genetic research on sesame has constantly advanced. Sesame genome assembly and map-based gene cloning now use six high-density molecular genetic maps. Enhancing gene cloning and genomics research in sesame is done utilizing whole-genome re-sequencing and ultra-dense SNP genetic maps. Using the linkage mapping approach and candidate variant screening, two sesame genes, Sidt1 governing inflorescence determinacy and Sicl1 controlling leaf curling and capsule indehiscence, were effectively cloned. In sesame breeding initiatives, the NGS platform can help quickly create genomic tools for genetic advancement, cultivar development, and commercialization (Oloniruha et al., 2021).

Genetic Engineering and Genome Editing

Innovative techniques used in genetic engineering can be used to supplement traditional breeding in sesame. Target gene insertion and the creation of new varieties are two successful attempts at sesame genetic transformation. The scientists obtained up to 42.66% transformation efficiency using the Agrobacterium-mediated transformation approach. At the Oil Crops Research Institute of the Chinese Academy of Agricultural Sciences (OCRI-CAAS) in China, research is underway to transfer candidate genes that influence oil quality attributes and abiotic stress tolerance into elite sesame cultivars. The application of genome editing, also known as targeted gene modification, is a technique used to generate new allelic variants in genomes, including those of crop plants (Teja et al., 2022). Clustered regularly interspaced short palindromic repeats (CRISPR)-based genome editing systems, such as CRISPR/Cas9, CRISPR/Cpf1, base-editing systems, and prime editing systems, hold great promise for genetic improvement programs in crop plants, including sesame. These advanced tools provide precise and efficient means for modifying specific genes, enhancing the potential for developing improved sesame varieties with enhanced oil quality and resilience to abiotic stress (Htet).

Market-Driven Breeding in Sesame

The rate at which farmers and their markets embrace new varieties of crops serves as a barometer for a crop-breeding program's performance. Plant breeders must consider farmers' expertise and preferences when developing and running their breeding projects (Obeidat et al., 2019). According to recent participatory rural appraisal research conducted in Ethiopia, sesame's most significant production restrictions include a lack of access to better seeds, low yield, diseases, low market prices, insect pests, limited market knowledge, and the high cost of improved seeds. On the other hand, the most crucial market-preferred features for sesame in Ethiopia are identified as white seed color, increased seed size, true-to-type seeds, high oil content, and increased 1000-seed weight. Understanding these constraints and preferences is crucial for addressing challenges and improving sesame production and regional marketing (Adhikary et al., 2019).

Conclusion

Due to less funding for research and development than other conventional oilseed crops, breeding advances for sesame seed oil yields and fatty acid composition are not as high. Only a few enhanced sesame cultivars with high yields, oil quantity and quality, early maturity, and disease and insect pest resistance have been created and made available worldwide. Through germplasm analysis, selection, and variety recommendation, conventional breeding has been the main emphasis of soybean improvement. More significantly, several functional genes, QTLs, and molecular markers linked to these traits are currently accessible and can be used in sesame breeding efforts. New generation sesame cultivars that are abiotic and biotic stress-resistant, capsule-breaking resistant, and climate-smart are needed to match the quality standards of the domestic and global markets. As a result, ongoing and future efforts for sesame genetic improvement should incorporate traits that increase yield and quality, local adaptability, machine harvesting, and other crucial characteristics for the industrial sector across various utilities. To achieve this, molecular breeding, genomic-assisted breeding, and genome editing are examples of genomic techniques that can be combined with conventional and mutant breeding procedures. Additionally, there is a need for thriving sesame seed enterprises and public and private sector breeding initiatives. The adoption of enhanced production technologies will be aided by the widespread use of genetic and cutting-edge genomic resources and increasing public and private sector investment in research and development for sustainable production and financial gains from sesame firms.

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Declarations

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All data generated or analyzed during the study are included in the manuscript.

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Conflict of Interest

Regarding conflicts of interest, the authors state that their research was carried out independently without any affiliations or financial ties that could raise concerns about biases.