Sesame Production Constraints and Breeding

Subjects: Biodiversity Conservation
Contributor: Desawi Hdru Teklu, Hussein Shimelis, Seltene Abady

Sesame (*Sesamum indicum* L.; 2n = 2x = 26) belongs to the family Pedaliaceae. It is a predominantly self-pollinating crop.

Keywords: genetic variation ; genomics-assisted breeding ; marker-assisted selection

1. Introduction

Sesame (*Sesamum indicum* L.; 2n = 2x = 26) belongs to the family Pedaliaceae. It is a predominantly self-pollinating crop [1]. Sesame cultivation dates back some 5500 years ago in the Harappa valley of India [2]. Sesame seed oil and derived products serve the food, feed, and cosmetics industry globally. Sesame has higher seed oil content ranging from 40% to 60% when compared to soybean (~20%), rapeseed (~40%), sunflower (~45%), and groundnut (45–56%) [3][4][5][6][7]. Sesame oil comprises about 85% unsaturated and 15% saturated fatty acids [6]. The unsaturated fatty acids include linoleic acid (~46%) and oleic acid (~38%), while the saturated fatty acids are palmitic acid (~12%) and stearic acid (~4%) [6][8][9]. The higher quantity of unsaturated fatty acids present in sesame oil has human health benefits believed to minimize the risks of cardiovascular diseases, cancer, brain, and liver damage [10][11].

Sesame is widely traded in local, regional, and international markets [12]. A global total of 2.4 million tons of sesame grain was traded in 2020 with a monetary value of 3.2 trillion USD [13]. Likewise, sesame consumption is steadily increasing due to high demands related to its unique nutritional values such as higher contents of vitamins (e.g., A and E), minerals, fiber, desirable fatty acids, carbohydrate (~13.5%), and protein (~24%) [12]. Furthermore, population pressure, urbanization, and the changing lifestyle have increased the global demand for sesame products [12].

About 70% of the world's sesame seed is processed to produce food oil, while the seedcake left after oil processing is used to prepare livestock meals [12]. The global annual human consumption of sesame is about 65% and 35% in the form of processed food oil and grain, respectively [14]. In 2020, world sesame grain production was 7.25 million tons [13]. Sudan is the largest sesame grain-producing country with 1.52 million tons per annum, followed by China (0.89 million tons), Myanmar (0.74 million tons), the United Republic of Tanzania (0.71 million tons), India (0.65 million tons), Nigeria (0.49 million tons), Burkina Faso (0.27 million tons), and Ethiopia (0.26 million tons) [13].

The actual mean seed yield of sesame in sub-Saharan Africa is <0.6 ton·ha^{-1}, which is far below the attainable yield of the crop, reaching up to 4.00 tons·ha^{-1} [13]. Relatively higher sesame seed yield productivity is reported in Lebanon (3.29 tons·ha^{-1}), Jordan (2.38 tons·ha^{-1}), Israel (2.04 tons·ha^{-1}), China (1.62 tons·ha^{-1}), Tajikistan (1.59 tons·ha^{-1}), and Uzbekistan (1.52 tons·ha^{-1}) [13]. The low yield level in sub-Saharan Africa is attributable to the use of unimproved traditional varieties or landraces. Moreover, sesame yields are hindered by the indeterminate growth habit of some varieties, capsule shattering, and excessive seed loss pre- and post-harvest [12][15][16][17]. Nearly all the global sesame varieties are prone to capsule shattering, and they are not suitable for machine harvesting [12][18][19]. Langham and Wiemers [18] reported a pre-harvest yield loss of 50% in some sesame varieties due to capsule shattering. Hence, manual sesame harvesting is the method of choice globally, which significantly increases the production and market costs of the produce [12][18][19].

Ethiopia is the center of genetic diversity of sesame [20][21]. The Ethiopian Biodiversity Institute (EBI) maintains about 5000 accessions of sesame germplasm collections [22]. The production and productivity of the crop in East Africa, including Ethiopia, are severely constrained by the lack of high-yielding and locally adapted varieties, susceptibility to capsule shattering and poor seed retention, the prevalence of several biotic and abiotic stresses, and a lack of modern production and pre- and post-harvest technologies [8]. In the region, sesame production relies on unimproved traditional varieties or landraces [22]. The landrace varieties are highly preferred by growers, consumers, and markets due to unique aroma and taste. These attributes make the traditional varieties attractive to growers, breeders, and local, regional, and international markets. Hence, landrace varieties are an excellent source of genetic variation for sesame pre-breeding and breeding programs globally.

2. Constraints to Sesame Production

The major constraints to sesame production and productivity are a lack of high-yielding and locally adapted varieties, capsule shattering and seed loss, uneven maturity, biotic stresses (insect pests and diseases), abiotic stresses (e.g., drought, waterlogging, salinity, and frost), the use of traditional production technologies, and poor pre- and post-harvest infrastructure [8][15][17][23][24][25][26][27][28][29].

Field insect pests cause a yield loss of 25% in sesame [30]. The major insect pests of sesame crop are webworm (*Antigastra catalaunalis)*, gall midge (*Asphondylia sesame)*, and seed bug (*Elasmolomus sordidus)* [31]. The seed bug is both a field and a storage insect pest that causes up to 50% yield loss at storage [32]. Moreover, most sesame varieties are attacked by diseases caused by bacteria (e.g., blight caused by *Xanthomonas campestris* pv. *sesame*), fungi (e.g., charcoal rot caused by *Macrophomina phaseolina*, stem anthracnose (*Colletotrichum* spp.), mildew (*Erysiphe cichoracearum*), *Fusarium* wilt caused by *Fusarium oxysporum* f.sp. sesame (Fos), and root rot (*Rhizoctonia solani*)), and viruses (e.g., phyllody, *Orosius albicinctus*) [12].

Among the fungal diseases, charcoal rot is the most devastating disease of sesame caused by soil-borne necrotrophic fungus *Macrophomina phaseolina* (Tassi) Goid [33]. This fungus causes pre- and post-emergence damage in more than 500 plant families, including sesame. Furthermore, *Fusarium* wilt is one of the most economically important soil-borne diseases of sesame globally causing 15–30% 1yield loss [34][35]. For instance, root rot caused by *Rhizoctonia solani* is one of the most damaging fungal diseases in Egypt [36][37]. Drought stress is the main yield-limiting constraint in sesame during the vegetative and flowering growth stages [12][38][39][40]. Yousif et al. [41] and Tripathy et al. [28] reported that sesame is sensitive to waterlogging, salinity, and low-temperature conditions. Waterlogging leads to reduced plant growth, leaf axils per plant, biomass, net photosynthesis, and seed yield [42][43].

Cultivation of sesame using varieties with indeterminate growth habits and that are susceptible to capsule shattering leads to yield penalty [8][12][15][17][24][25][26][27]. Globally, 99% of sesame varieties are susceptible to capsule shattering [12][18][19]. Langham and Wiemers [18] reported a 50% pre-harvest yield loss owing to capsule shattering and seed loss.

Sesame seed loss is common during pre-harvest (e.g., field crop stand) and post-harvest (e.g., harvesting, stacking, drying, threshing, transporting, storage, seed cleaning, and packaging) [44]. Pre- and post-harvest losses are the confounding factors of reduced yield loss and high market price in sesame production.

Lack of access to post-harvest infrastructure and low and variable market prices during harvest are among the critical challenges in sesame value chains [12][17][24]. For instance, in Ethiopia, a 100 kg of sesame grain is traded at 1000–3000 ETB (about 22.3–67 USD) during the harvest period (October to December), while the price is at 3000–3500 ETB (about 67–78 USD) during the off-season (January to September) [17].

3. Sesame Breeding

The main goals in sesame breeding programs include high seed yield, seed oil quantity and quality, capsule shattering resistance, high seed retention rate, uniform maturity, and tolerance to biotic and abiotic stresses. However, breeding gains in sesame are low and stagnant compared to other oilseed crops such as groundnut and sunflower [45]. Selection for improved seed yield and yield components remains the key breeding strategy. The main yield-related traits include early and uniform maturity, reduced plant height, higher number of capsules per plant, number of branches per plant, number of seeds per capsule, and heavier 1000-seed weight. Thus far, most sesame breeding programs have largely focused on germplasm characterization and recommendation using the conventional breeding methods. There is a need to complement phenotyping with other modern breeding strategies such as identifying and discovering new genes, genomic-assisted breeding, and gene editing, which are described below.

Progress and Achievements in Sesame Genetic Improvement

In the past 20 years, sesame research and development have benefited from conventional breeding methods, including pure line and mass selection, hybridization and mutation breeding. This has led to the development of improved sesame varieties. In the last 40 years, more than 200 improved sesame varieties with high yields, oil quantity and quality, early maturity, and resistance to diseases and insect pests were developed and released globally.

Genetic and genomic techniques such as genomics-assisted breeding and genome editing have been markedly used in oil crop research such as in groundnut and rapeseed crops. There has been rapid development of genetic tools, particularly molecular markers, and their application in genetic diversity studies, marker-assisted breeding, chloroplast genome sequencing, haplotype mapping, database development, association mapping, genome-wide association studies (GWAS), gene discovery and functional studies, genetic mapping, and genomics-assisted breeding [45][46][47]. Nevertheless, these genomic resources have been widely used in most sesame genetic improvement programs.

Modern sesame genotypes reported with agronomic and other valuable traits are summarized in **Table 1**. India and China have each developed more than 50 improved cultivars over the last 40 years [48]. A total of 32 improved sesame varieties have been developed and released by the Ethiopian Institute of Agricultural Research (EIAR) through mass selection from among the local germplasm collections since 1976 [49]. Among the EIAR's released varieties, Humera-1 and Setit-1 are widely grown by farmers for their early maturity, better yield response (about 1 ton/ha), and broad adaptability [17]. However, the yield response of these varieties is below the reportedly attainable yields of the crop. Some 29 sesame varieties were released in Myanmar in the past 42 years. These varieties were bred for early maturity, white seed color, high yield, and seed oil content [12]. In Myanmar, the following varieties were released: Ju-Ni-Poke, Me-Daw-Let-The, Gwa-Taya, and Gwa-KyawNet. The varieties reportedly had stable yields. Ju-Ni-Poke, Shark-Kale, Hnan-Ni 25/160, Yoe-Sein, Boat-Hmway, Kye-Ma-Shoung, Selin-Boat-Taung, Magway-Ni 50/2, and Nyaung-Aing had relatively higher seed oil content (≥ 55%) [12]. In Bulgaria, four sesame varieties, namely, Victoria, Aida, Valya, and Nevena, were successfully developed for amenable to mechanized harvesting with a mean grain yield of 1.35 tons·ha^{-1} through a research collaboration between plant breeders and agricultural engineers over the last 30 years [50]. In Kenya, sesame cultivars such as SIK 031 and SIK 013 showed resistance to the white leaf spot disease, whereas SIK 031 and SPS 045 showed resistance to angular leaf spot disease [51]. The two varieties were released by the department of crop science, the University of Nairobi [52].

Table 1. Modern sesame varieties reported globally with desirable agronomic and seed oil traits.

Variety	Pedigree	Trait	Country	Year of Release	References
Sin-Yadana 4	**-**	**Good export quality**	**China**	**1994**	[12]
Ju-Ni-Poke	**-**	**Stable yield and high oil content**	**Myanmar**	**1994**	[12]
Me-Daw-Let-The	**-**	**Stable yield and high oil content**		**1994**	
Gwa-Taya	**-**	**Stable yield**		**1994**	
Gwa-Kyaw-Net	**-**	**Stable yield**		**1994**	
Humera-1	**ACC.038 sel.1**	**Early maturity, better yield and broad adaptability**	**Ethiopia**	**2010**	[17]
Setit-1	**Col sel p#1**	**Early maturity, better yield and oil content and broad adaptability**		**2010**	
Dangur	**E.W.013.(8)**	**High oil content**	**Ethiopia**	**2015**	[49]
BaHaNecho	**W-109/WSS/ (Acc-EW-012(5)**	**Better yield and oil content**		**2016**	
BaHaZeyit	**W- 119/WSM/ (Acc-EW-023(1)**	**Better yield and oil content**		**2016**	
Setit-2	**J-03**	**Early maturity, better yield, and broad adaptability**		**2016**	
Setit-3	**HuARC-4**	**Early maturity, better yield and oil content, and broad adaptability**		**2017**	
Waliin	**BG-004-1**	**Better yield and oil content**		**2017**	
Gida Ayana	**Ass-acc-29**	**Late maturity, better yield and oil content, and broad adaptability**		**2018**	
Hagalo	**EW002 × Obsa22-1**	**Late maturity, better yield, resistance to bacterial blight, and broad adaptability**		**2019**	
Yale	**EW002 × Dicho 5-3**	**Late maturity, better yield and oil content, resistance to bacterial blight, and broad adaptability**		**2019**	

Variety	Pedigree	Trait	Country	Year of Release	References
RAMA	'Khosla' local	Medium seed size and brown seed color		1989	
OSC-593	-	White seed color	India	1995	[53]
TKG-352	-	White seed color		1995	
TMV 1	-	Erect, fairly bushy with moderate branching, 4-loculed, red brown to black seeds, and better oil content		1939	
TMV 2	Nagpur white × Sattur	Open, moderate branching, 6–8-loculed, cylindrical big sized capsules, and dark brown to black seeds Suitable for cold weather conditions and better oil content		1942	
TMV 3	South Arcot variety × Malabar Variety	Bushy with profuse branching, 4-loculed, dark brown to black seeds, and better oil content		1943	
KRR 1	-	Bushy with profuse branching, 4-loculed, brown seeds, and better oil content		1967	[54]
KRR 2	Karur local × Bombay white	Bushy with profuse branching, 4-loculed, better oil content, and white seeds		1970	
TMV 4	-	Bushy with profuse branching, 4-loculed, brown seeds, and better oil content		1977	
TMV 5	-	Erect with moderate branching, 4-loculed, brown seeds, and better oil content		1978	
TMV 6	-	Erect with moderate branching, 4-loculed, brown seeds, and better oil content		1980	
CO 1	(TMV 3 × Si 1878) × Si 1878	Bushy plant, 4-loculed, black warty seeds, and better oil content		1983	
Paiyur 1	Si2511 × Si 2314	Resistance to powdery mildew, 4-loculed, bushy, suitable for irrigated condition, black seeds, and better oil content		1990	
SVPR 1	-	White seeds, 4-loculed, high yield, suitable for irrigated conditions, and better oil content		1992	
VRI 1	-	Early maturity, 4-loculed, and better oil content		1995	
VRISV2	US9003 × TMV6	Moderate resistance to shoot webber, 4-loculed, and higher oil content		2005	
TMV (Sv) 7		High yield, 4-loculed, tolerance to root rot disease, lustrous brown testa, and higher oil content		2009	
VRI 3	SVPR 1 × TKG 87	Moderate resistance to phyllody and root rot diseases, white seed, and higher oil content		2017	

MoA = Minstry of Agriculture; - = data not available.

References

1. Ashri, A. Sesame breeding. In Plant Breeding Reviews; Janick, J., Ed.; John Wiley: Oxford, UK, 2010; Volume 16.
2. Bedigian, D.; Harlan, J. Evidence for cultivation of sesame in the ancient world. Econ. Bot. 1986, 40, 137–154.
3. De la Vega, A.J.; Hall, A.J. Effect of planting date, genotype, and their interactions on sunflower yield: II. Components o f oil yield. Crop Sci. 2002, 42, 1202–1210.
4. Zheljazkov, V.D.; Vick, B.A.; Ebelhar, M.W.; Buehring, N.; Baldwin, B.S.; Astatkie, T.; Mille, J.F. Yield, oil content, and co mposition of sunflower grown at multiple locations in Mississippi. Agron. J. 2008, 100, 635–639.
5. Wei, W.; Zhang, Y.; Lv, H.; Li, D.; Wang, L.; Zhang, X. Association analysis for quality traits in a diverse panel of Chines e sesame (Sesamum indicum L.) germplasm. J. Integr. Plant Biol. 2013, 55, 745–758.

6. Dossa, K.; Wei, X.; Niang, M.; Liu, P.; Zhang, Y.; Wang, L.; Liao, B.; Cissé, N.; Zhang, X.; Diouf, D. Near-infrared reflect ance spectroscopy reveals wide variation in major components of sesame seeds from Africa and Asia. Crop J. 2018, 6, 202–206.
7. Gulluoglu, L.; Arioglu, H.; Bakal, H.; Onat, B.; Kurt, C. The Effect of Harvesting on Some Agronomic and Quality Charac teristics of Peanut Grown in the Mediterranean Region of Turkey. Turk. J. Field Crop 2016, 21, 224–232.
8. Were, B.A.; Onkware, A.O.; Gudu, S.; Welander, M.; Carlsson, A.S. Seed oil content and fatty acid composition in East African sesame (Sesamum indicum L.) accessions evaluated over 3 years. Field Crops Res. 2006, 97, 254–260.
9. Anastasi, U.; Sortino, O.; Tuttobene, R. Agronomic performance and grain quality of sesame (Sesamum indicum L.) lan draces and improved varieties grown in a Mediterranean environment. Genet. Resour. Crop Evol. 2017, 64, 127–137.
10. Yen, G.C. Influence of seed roasting process on the changes in composition and quality of sesame (Sesame indicum L.) oil. J. Sci. Food Agric. 1990, 50, 563–570.
11. Yol, E.; Toker, R.; Golukcu, M.; Uzun, B. Oil Content and fatty acid Characteristics in mediterranean sesame core collec tion. Crop Sci. 2015, 55, 2177–2185.
12. Myint, D.; Gilani, S.A.; Kawase, M.; Watanabe, K.N. Sustainable Sesame (Sesamum indicum L.) Production through Im proved Technology: An Overview of Production, Challenges, and Opportunities in Myanmar. Sustainability 2020, 12, 35 15.
13. FAOSTAT. The Food and Agriculture Organization Corporate Statistical Database (FAOSTAT), Rome, Italy. 2020. Availa ble online: http://www.fao.org/faostat/en/#data/QC (accessed on 16 March 2022).
14. Morris, J.B. Food, industrial, nutraceutical, and pharmaceutical uses of sesame genetic resources. In Trends in News C rops and New Uses; Janick, J., Whipkey, A., Eds.; ASHS Press: Alexandria, Egypt, 2002; pp. 153–156.
15. Abdellatef, E.; Sirelkhatem, R.; Ahmed, M.M.; Radwan, K.H.; Khalafalla, M.M. Study of genetic diversity in Sudanese s esame (Sesamum indicum L.) germplasm using random amplified polymorphic DNA (RAPD) markers. Afr. J. Biotechno l. 2008, 24, 4423–4427.
16. Uzun, B.; Çagirgan, M.I. Identification of molecular markers linked to determinate growth habit in sesame. Euphytica 20 09, 166, 379–384.
17. Teklu, D.H.; Shimelis, H.; Tesfaye, A.; Abady, S. Appraisal of the sesame production opportunities and constraints, and f armer-preferred varieties and traits, in Eastern and Southwestern Ethiopia. Sustainability 2021, 13, 11202.
18. Langham, D.R.; Wiemers, T. Progress in mechanizing sesame in the US through breeding. In Trends in New Crops and New Uses; Janick, J., Whipkey, A., Eds.; ASHS Press: Alexandria, Egypt, 2002; pp. 157–173.
19. Khidir, M.O. Natural cross-fertilization in sesame under Sundan conditions. Exp. Agric. 1972, 8, 55–59.
20. Bedigian, D. Origin, diversity, exploration and collection of sesame. Sesame: Status and Improvement. In Proceedings of the Expert Consultation, Rome, Italy, 8–12 December 1980; FAO Plant Production and Protection Paper: Rome, Ital y, 1981; Volume 29, pp. 164–169.
21. Seegeler, C.J. Oil Seeds in Ethiopia: Their Taxonomy and Agricultural Significance; Centre for Agricultural Publication a nd Documentation: Wageningen, The Netherlands, 1983.
22. Teklu, D.H.; Shimelis, H.; Tesfaye, A.; Mashilo, J.; Zhang, X.; Zhang, Y.; Dossa, K.; Shayanowako, A.I.T. Genetic variabi lity and population structure of Ethiopian sesame (Sesamum indicum L.) germplasm assessed through phenotypic trait s and simple sequence repeats markers. Plants 2021, 10, 1129.
23. Were, B.A.; Lee, M.; Stymne, S. Variation in seed oil content and fatty acid composition of Sesamum indicum L. and its wild relatives in Kenya. Swed. Seed Assoc. 2001, 4, 178–183.
24. Dossa, K.; Konteye, M.; Niang, M.; Doumbia, Y.; Cissé, N. Enhancing sesame production in West Africa’s Sahel: A com prehensive insight into the cultivation of this untapped crop in Senegal and Mali. Agric. Food Secur. 2017, 6, 68.
25. Nyongesa, B.O.; Were, B.A.; Gudu, S.; Dangasuk, O.G.; Onkware, A.O. Genetic diversity in cultivated sesame (Sesam um indicum L.) and related wild species in East Africa. J. Crop Sci. Biotechnol. 2013, 16, 9–15.
26. Woldesenbet, D.T.; Tesfaye, K.; Bekele, E. Genetic diversity of sesame germplasm collection (Sesamum indicum L.): I mplication for conservation, improvement and use. Int. J. Biotechnol. Mol. Biol. Res. 2015, 6, 7–18.
27. Anyanga, W.O.; Hohl, K.H.; Burg, A.; Gaubitzer, S.; Rubaihayo, P.R.; Vollmann, J.; Gibson, P.T.; Fluch, S.; Sehr, E.M. G enetic variability and population structure of global collection of sesame (Sesamum indicum L.) germplasm assessed th rough phenotypic traits and simple sequence repeats markers for Uganda. J. Agric. Sci. 2017, 9, 13–14.
28. Tripathy, S.K.; Kar, J.; Sahu, D. Advances in Sesame (Sesamum indicum L.) Breeding. In Advances in Plant Breeding Strategies: Industrial and Food Crops; Al-Khayri, J.M., Jain, S.M., Johnson, D.V., Eds.; Springer: Cham, Switzerland, 2 019; pp. 577–635.

29. Yol, E.; Uzun, B. Inheritance of indehiscent capsule character, heritability and genetic advance analyses in the segregat ion generations of dehiscent x indehiscent capsules in sesame. Tarim Bilim. Derg. 2019, 25, 79–85.

30. Weiss, E.A. Sesame. Oilseed Crops, 2nd ed.; Blackwell Science: London, UK, 2000.

31. Gebregergis, Z.; Dereje, A.; Fitwy, I. Assessment of incidence of sesame webworm (Antigastra catalaunalis (Duponche l)) in Western Tigray, North Ethiopia. J. Agric. Ecol. Res. Int. 2016, 9, 1–9.

32. Ministry of Agriculture (MoA). Crop extension Package and Manual; MOA: Addis Ababa, Ethiopia, 2018; pp. 126–132.

33. Thiyagu, K.; Kandasamy, G.; Manivannan, N.; Muralidharan, V.; Manoranjitham, S.K. Identification of resistant genotyp es to root rot disease (Macrophomina phaseolina) of sesame (Sesamum indicum L). Agric. Sci. Digest. 2007, 27, 34–3 7.

34. Li, D.; Wang, L.; Zhang, Y.; Lv, H.; Qi, X.; Wei, W.; Zhang, X. Pathogenic variation and molecular characterization of Fu sarium species isolated from wilted sesame in China. Afr. J. Microbiol. Res. 2012, 6, 149–154.

35. Wei, X.; Zhu, X.; Yu, J.; Wang, L.; Zhang, Y.; Li, D. Identification of sesame genomic variations from genome compariso n of landrace and variety. Front. Plant Sci. 2016, 7, 1169.

36. El-Barougy, E.S. Pathological Studies on Sesame (Sesamum indicum L.) Plant in Egypt. Master's Thesis, Agriculture a nd Botany Department, Faculty of Agriculture, Seuz Canal University, Ismailia, Egypt, 1990; p. 145.

37. El-Shakhess, S.A.M. Inheritance of some economic characters and disease reaction in some sesame (Sesamum indic um L.). Ph. D. Thesis, Agronomy Department, Faculty of Agriculture, Cario University, Cario, Egypt, 1998; p. 135.

38. Boureima, S.; Oukarroum, A.; Diouf, M.; Cisse, N.; Van Damme, P. Screening for drought tolerance in mutant germplas m of sesame (Sesamum indicum) probing by chlorophyll A inflorescence. Environ. Exp. Bot. 2012, 81, 37–43.

39. Kadkhodaie, A.; Zahedi, M.; Razmjoo, J.; Pessarakli, M. Changes in some anti-oxidative enzymes and physiological ind ices among sesame genotypes (Sesamum indicum L.) in response to soil water deficits under field conditions. Acta Phy siol. Plant 2014, 36, 641–650.

40. Aye, M.; Khaing, T.T.; Hom, N.H. Morphological characterization and genetic divergence in myanmar sesame (Sesamu m indicum L.) germplasm. Int. J. Curr. Adv. Res. 2018, 6, 297–307.

41. Yousif, H.Y.; Bingham, F.T.; Yermason, D.M. Growth, mineral composition, and seed oil of sesame (Sesamum indicum L.) as affected by NaCl. Soil Sci. Soc. Am. J. 1972, 36, 450–453.

42. Uçan, K.; Kıllı, F.; Gençoglan, C.; Merdun, H. Effect of irrigation frequency and amount on water use efficiency and yiel d of sesame (Sesamum indicum L.) under field conditions. Field Crops Res. 2007, 101, 249–258.

43. Sun, J.; Zhang, X.R.; Zhang, Y.X.; Wang, L.H.; Huang, B. Effects of waterlogging on leaf protective enzyme activities a nd seed yield of sesame at different growth stages. Chin. J. Appl. Environ. 2009, 15, 790–795.

44. Gebretsadik, D.; Haji, J.; Tegegne, B. Sesame post-harvest loss from small-scale producers in Kafta Humera District, E thiopia. J. Dev. Agric. Econ. 2019, 11, 33–42.

45. Dossa, K.; Diouf, D.; Cissé, N. Genome-Wide investigation of Hsf genes in Sesame reveals their segmental duplication expansion and their active role in drought stress response. Front. Plant Sci. 2016, 7, 1522.

46. Dixit, A.; Jin, M.H.; Chung, J.W.; Yu, J.W.; Chung, H.K.; Ma, K.H. Development of polymorphic microsatellite markers in sesame (Sesamum indicum L.). Mol. Ecol. Resour. 2005, 5, 736–738.

47. Wang, L.; Zhang, Y.; Qi, X.; Gao, Y.; Zhang, X. Development and characterization of 59 polymorphic cDNA-SSR marker s for the edible oil crop Sesamum indicum L. (Pedaliaceae). Am. J. Bot. 2012, 99, 394–398.

48. Hodgkin, T.; Qingyuan, G.; Xiurong, Z.; Ying-zhong, Z.; Xiang-yun, F.; Gautam, P.L.; Mahajan, R.; Bisht, I.S.; Loknatha n, T.R.; Mathur, P.N.; et al. Developing sesame core collections in China and India. In Core Collections for Today and T omorrow; International Plant Genetic Resources Institute: Rome, Italy, 1999.

49. Ministry of Agriculture (MoA). Plant variety release. Protection and seed quality control directorate. In Crop Variety Regi ster; MoA: Addis Ababa, Ethiopia, 2019; Volume 22, p. 330.

50. Stamatov, S.; Velcheva, N.; Deshev, M. Introduced sesame accessions as donors of useful qualities for breeding of Intr oduced sesame accessions as donors of useful qualities for breeding of mechanized harvesting cultivars. Bulg. J. Agri c. Sci. 2018, 24, 820–824.

51. Nyanapah, J.O.; Ayiecho, P.O.; Nyabundi, J.O. Evaluation of sesame cultivars for resistance to Cercospora leaf spot. E ast Afr. Agric. J. 1995, 60, 115–121.

52. Ayiecho, P.O.; Nyabundi, J.O. Yield Improvement of Kenyan Sesame Varieties Using Induced Mutations; 1st year repor t to IAEA; Department of Crop Science, University of Nairobi: Nairobi, Kenya, 1994.

53. Pandey, S.K.; Das, A.; Rai, P.; Dasgupta, T. Morphological and genetic diversity assessment of sesame (Sesamum indicum L.) accessions differing in origin. Physiol. Mol. Biol. Plants. 2015, 21, 519–529.
54. Chellamuthu, M.; Subramanian, S.; Swaminathan, M. Genetic potential and possible improvement of Sesamum indicum L. IntechOpen 2020, 11, 1–18.