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Review

Unveiling herbicide tolerance in major oilseed crops

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ABSTRACT

Herbicide tolerance in oilseed crops has revolutionized modern agriculture and offered effective weed management solutions while enhancing crop productivity. This comprehensive review explores various facets of herbicide tolerance, from its underlying mechanisms and historical evolution to its economic, environmental, and regulatory implications. We delve into the genetic basis of herbicide tolerance, elucidating the mechanisms that confer resistance in oilseed crops. The historical development of herbicide-tolerant varieties, from glyphosate-tolerant soybeans to novel traits in canola and sunflowers, reflects the evolving relationship between scientific innovation and industry dynamics. Economic analyses underscore the significant cost savings and yield improvements associated with herbicide tolerance while emphasizing the importance of sustainable weed management practices. Environmental considerations, including the impact on non-target organisms and biodiversity conservation, are evaluated alongside the regulatory frameworks governing the safe and responsible adoption of herbicide-tolerant varieties. Emerging trends in genetic engineering, biotechnology, and regulatory oversight offer promising avenues for future innovation and sustainability. To conclude, herbicide tolerance in oilseed crops represents a valuable tool for modern agriculture, contributing to global food security while necessitating careful stewardship and responsible management practices.

Keywords: Acetohydroxyacid synthase, Genome editing, Herbicide tolerance, Oilseed crops, Superweeds

Herbicides are pivotal in modern agriculture, effectively controlling weeds that compete with crops for vital resources. With a significant global increase in herbicide usage, as reported by the Food and Agriculture Organization (FAO), agricultural practices have intensified to meet the rising food demands. Weed management poses a significant challenge to crop productivity and sustainability. Integrating herbicide tolerance into crop plants has become crucial for contemporary weed control strategies, enhancing weed management effectiveness. However, the increasing resistance of weeds to selective herbicides underscores the need for reevaluating chemical weed control methods. Strategies include exploring novel herbicide target sites, synthesizing potent compounds, and restructuring crop plant genetics. These methods are costly and time-consuming, potentially exacerbating environmental chemical burdens (Beckie, 2020). Leveraging biotechnological techniques to genetically engineer the crops, and enhance selectivity to effective broad-spectrum herbicides offers a viable alternative. This review aims to address contemporary challenges in herbicidal weed control, their mechanisms of action (MOA), crop-specific herbicide resistances, identification of herbicide tolerance genes, conventional and molecular breeding approaches, economic and environmental considerations of using herbicides, emerging trends in oilseed-herbicide interactions, and few case studies on herbicide-tolerant oil crops.

Historical Development of Herbicide-Tolerance

At the advent of agriculture, man had to spend a considerable amount of energy to remove weeds from cultivable lands and bring them to good condition to ensure optimum growth of the desired crop. The historical development of herbicide tolerance spans several to Romans using salt in 164 B.C., English farmers in the 16th century used salt selectively. In the 1900s, researchers like Bolley, Schultz, and Bonnett explored inorganic compounds and copper salts. Initially studied by Went and Thimann in 1937, plant growth regulators led to the discovery of 2,4-D by Pokorny in 1941, marking the chemical era in herbicide development. Templeman and Sexton found phenoxyacetic acids selectively toxic to dicotyledonous plants. Commercial use of 2,4-D began in the U.S.A. in 1947. Today, farmers utilize 2,4-D as a selective herbicide against broadleaf dicots, sparing monocots. DNOC, a contact herbicide, was used in France in 1993 for selective weed control, increasing food production during World War II. This success spurred ongoing herbicide research (Cremlyn, 1991;

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Green *et al.,* 1987; Klingman *et al.,* 1975; Lowery *et al.,* 1987; Rao, 2000). The first documented case of herbicide tolerance emerged in the United States during the 1950s, with field bindweed displaying resistance to 2,4-D. Subsequent instances, such as common groundsel resistance to triazine herbicides in the 1970s, underscored the growing concern. By the 1980s, the proliferation of resistant biotypes escalated both domestically and globally, with over 65 weed species exhibiting resistance to various herbicide families. Crops that are herbicide tolerant withstand particular broad-spectrum herbicides that destroy nearby weeds without harming the crop that has been planted. The first commercially available herbicide-tolerant crop was Monsanto's Roundup Ready soybean, introduced in 1996. This crop was engineered to tolerate glyphosate, the active ingredient in the herbicide Roundup, allowing farmers to spray glyphosate to control weeds without harming the crop. Following the success of Roundup Ready soybeans, other crops such as maize, cotton, canola, and alfalfa were also engineered for herbicide tolerance. These crops were developed by various biotechnology companies using similar genetic engineering techniques. Over time, developers have introduced crops tolerant to multiple herbicides, providing farmers with more options for weed control. For example, Dow AgroSciences (now Corteva Agriscience) developed Enlist crops, which are resistant to glyphosate as well as 2,4-D, an older herbicide (Qaim, 2009).

Currently, the tolerant glyphosate varieties of soybean are mostly cultivated in the U.S. However, the U.S. Department of Agriculture (USDA) is currently in the process of deregulating other new varieties of crops made resistant to 2,4-D and other herbicides. Notably, herbicide resistance has been more pronounced in certain modes of action, particularly ALS inhibitors and photosystem II inhibitors.

The surge in glyphosate-resistant crops has resulted in amplified herbicide application, the emergence of herbicide-resistant weeds, known as "superweeds," and various environmental and human health consequences. The adoption of herbicide-resistant crops represents an effective strategy for weed control with benefits including diminished crop phytotoxicity from herbicide application (Rogers *et al.,* 2024), broadening the range of herbicidal effectiveness (Glick, 2001), and reducing weed management costs (Shaner, 2000). Consequently, development of herbicide-resistant crop as a paramount approach to curbing weed proliferation and substantially enhancing crop productivity (Green, 2012).

Classification of herbicides

Herbicides, chemicals inhibiting plant growth, are classified in numerous ways: by crop (e.g., a soybean herbicide), by their application time (e.g., PRE or POST to the crop or weeds), by their chemical family (e.g., sulfonylurea, dinitroanilines), by their path of mobility in the plant (e.g., translocation by phloem, xylem, or both), and by the mechanism of action (MOA) (e.g., photosystem II inhibitors, ALS inhibitors). MOA classification defines how herbicides affect weed growth, guiding resistance management. Among over 200 active ingredients globally, only 29 primary MOAs exist, with some herbicides' MOAs remaining unknown.

Mechanisms of action of herbicides

Herbicides belonging to the same class of site of action will cause comparable symptoms in the vulnerable plants (Sherwani *et al.,* 2015). Understanding crop management and effective use of herbicides requires knowledge of their method of action. The first enzyme, protein, or biochemical step impacted in the plant after application is indicated by the classification based on mode of action. (Duke, 1990). The most commonly used herbicides and their mode of action are given in the following table (Sherwani *et al.,* 2015).

The main mechanisms of action of herbicides according to the Weed Science Society of America (WSSA) are:

ACCase inhibitors: ACCase inhibitors: Acetyl coenzyme inhibition in the meristems of grass plants, a carboxylase called ACCase influences lipid metabolism, which in turn impacts the synthesis of cell membranes.

ALS inhibitors: The enzyme acetolactate synthase (ALS), also called acetohydroxyacid synthase (AHAS), inhibits branching-chain amino acid synthesis (valine, leucine, and isoleucine) in meristematic tissues.

EPSPS inhibitors: When the enolpyruvylshikimate 3-phosphate synthase enzyme (EPSPS) is inhibited, tryptophan, phenylalanine, and tyrosine synthesis is disrupted.

Synthetic auxins: They influence multiple processes, including morphogenesis, cell development, differentiation, and division, by acting as plant hormone equivalents.

Photosystem-II inhibitors: These chemicals hinder photosynthetic process's electron transport from water to NADPH2+. This leads to an excess of oxidation processes, which kills the plant.

Table 1 Chronology of events in the herbicide commercialization of soybean (Nandula *et al.,* 2007)

Resistance against	Trait Gene	Trait Designation	First Sales	Trade Name
Glyphosate	cp4 epsps	GTS 40-3-2	1996	Roundup Ready®
Glyphosate	cp4 epsps	MON89788	2009	Roundup Ready® 2 Yield
Glufosinate	pat	A2704-12	2009	LibertyLink System®
Dicamba	dmo	MON87708	2017	Roundup Ready 2 Xtend®
2,4-D	tfdA	DHT2	2019	Enlist™ Weed Control System

Table 2 Herbicide classification as per Herbicide Resistance Action Committee (HRAC)

Mode of action	Chemical family	Active ingredient
Inhibition of acetyl CoA carboxylase (ACCase)	Aryloxyphenoxy propionate Cyclohexanedione	Fenoxaprop, Fluazifop, Quizalofop, Clethodim, Sethoxydim
Inhibition of acetolactate synthase (ALS)	Sulfonylurea	Chlorimuron, chlosulfuron, Foramsulfuron, Halosulfuron, Iodosulfuron, Nicosulfuron, Primisulfuron, Prosulfuron, Rimsulfuron, Sulfometuron, Thifensulfuron, Tribenuron.
	Imidazolinone Trizolopyrimidine	Imazamox, Imazapyr,Imazaquin, Imazethapyr, Flumetsulam,Cloransulam.
Inhibition of microtubule assembly	Dinitroaniline	Benefin, Ethalfluralin, Pendimethalin, Trifluralin
Inhibition of indoleacetic acid transport	Phenoxy	2,4-D, MCPA, MCPP
	Benzoic acid	Dicamba
	Carboxylic acid	Clopyralid, Fluroxypyr,Picloram, Triclopyr
	Semicarbazone	Diflufenzopyr
Inhibition of photosynthesis at Photosystem II Site A	Triazine	Atrazine, Ametryn, Prometon,Simazine
	Triazinone	Hexazinone, Metribuzin
	Uracil	Bromacil, Terbacil
Inhibition of photosynthesis at Photosystem II Site B	Nitrile	Bromoxynil
	Benzothiadiazole	Bentazon
Inhibition of photosynthesis at Photosystem II site A – different binding behavior	Urea	Diuron, Linuron, Tebuthiuron
Photosystem I – electron diversion	Bipyridilium	Paraquat, Diquat
Inhibition of EPSP synthase	None accepted	Glyphosate
Inhibition of glutamine synthetase	None accepted	Glufosinate
Inhibition of lipid biosynthesis – not ACCase inhibition	Thiocarbamate	Butylate, EPTC
Bleaching: inhibition of DOXY synthase	Isoxazolidinone	Clomazone
Bleaching: inhibition of 4- HPPD	Isoxazole	Isoxaflutole
	Triketone	Mesotrione, Sulcotrione
	Pyrazolone	Topramezone
Inhibition of protoporphyrinogen oxidase (Protox or PPO)	Diphenyl ether	Acifluorfen, Fomesafen, Lactofen
	N-Phenylphthalimide	Flumiclorac, Flumioxazin
	Aryl triazinone	Sulfentrazone, Carfentrazone
Inhibition of synthase of very–long–chain fatty acids (VLCFA)	Chloroacetamide	Acetochlor, Alachlor, Metochlor, metolachlor, Dimethenamid
	Oxyacetamide	Flufenace

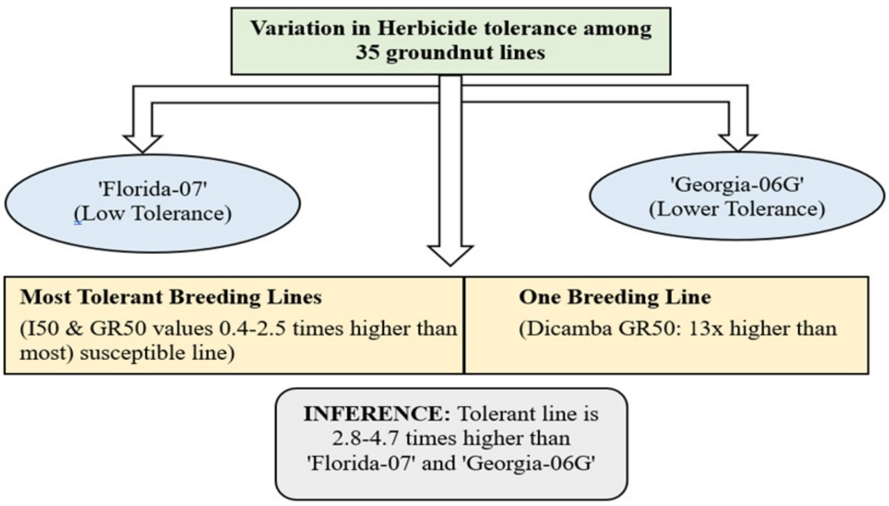
Source: (Choudhury *et al*., 2016)

Table 3 Classification of herbicides based on the mode of action

Mode of action	Examples
Amino Acid Synthesis Inhibitors	Imazethapyr, Glyphosate
Lipid synthesis Inhibitors	Cyclohexanediones
Seedling Growth Inhibitors	Pendimethalin, Alachlor
Photosynthesis Inhibitors	Atrazine, Metribuzin
Cell membrane Disruptors	Paraquat
Growth Regulators	2,4-D, 2,4,5-T, Dicamba
Pigment synthesis Inhibitor	Bromoxynil

Table 4 Genetic Basis of herbicide tolerance in sunflower (Miller and Al-Khatib, 2002a)

Technology	Genetic Basis	Development Process	Superiority over Other Traits	References
Imisun	Additive control by two genes: Ahasl1-1 and a modifier/enhancer factor	Discovered in wild sunflowers in Kansas, USA in 1996. Hybrid varieties developed from donor materials.	Requires expression of both target and non-target components for commercial tolerance.	Al-Khatib *et al.,* 1998; Jocić *et al.,* 2004; Tan *et al.,* 2005; Miller & Al-Khatib, 2002a; Bruniard & Miller, 2001; Sala & Bulos, 2012b; Trucillo Silva *et al.,* 2010
Clearfield Plus	Partially dominant nuclear allele Ahasl1-3	Developed using imazapyr selection and seed mutagenesis. offers exceptional resistance to herbicides.	Displays lower inhibition of AHAS enzyme by IMI, leading to better biomass accumulation and stability.	Sala *et al.,* 2012; Sala *et al.,* 2012a, 2012d, 2012c, 2012b; Sala *et al.,* 2012; Sala *et al.,* 2008a, 2008b; Sala and Bulos, 2012a, 2012b)
Sures	Mutation P197L at Ahasl1 locus	Developed from wild sunflower populations in the USA. Tolerance allele introgressed via forward crossing and selection with tribenuron.	Crop injury differences due to modifier genes. Increased range of available herbicides.	Al-Khatib *et al.,* 1998; Miller and Al-Khatib, 2002a; Kolkman *et al.,* 2004; Miller and Zollinger, 2004, Jocić *et al.,* 2004
ExpressSun	EMS mutagenesis over HA89 line	Developed and commercialized. Provides similar tolerance to Sures sunflowers.	Tolerance achieved through mutagenesis. Expands herbicide options in sunflower cultivation.	Gabard & Huby, 2015; Streit, 2012



I50 - herbicide concentration required to inhibit 50% of enzyme activity *in vitro* GR50 - growth reduction by 50%

Fig. 1. Postemergence herbicide tolerance variation in peanut germplasm

Table 5 Molecular characterization and detection of a spontaneous mutation conferring imidazolinone resistance in rapeseed

Aspect	Description
Herbicide Resistance Trait	Development of an imazethapyr-resistant rapeseed (M9) from a naturally occurring mutant plant
Biochemical Basis	*In vitro* AHAS activity assay revealed that AHAS enzyme from M9 conferred specific resistance to IMIs
Molecular Basis	Identification of a single-point mutation (Ser653Asp) in the BnAHAS1 gene, leading to an amino acid substitution at the herbicide-binding site
Molecular Marker Development	Development of an allele-specific PCR marker for the BnAHAS1 mutant sequence, which co-segregated with IMI resistance in F2, BC1, and BC2 populations
Utilization in Hybrid Rapeseed	Development of CMS restorer line 10M169 to demonstrate resistance, leading to increases in seed purity and yield
Seed Purity Enhancement	Utilization of herbicide-resistant trait to eliminate false hybrids in hybrid rapeseed production, resulting in increases in seed purity and yield
Potential Release of Resistant Cultivars	The molecular mechanism and marker described lay the groundwork for the release of IMI-resistant rapeseed cultivars

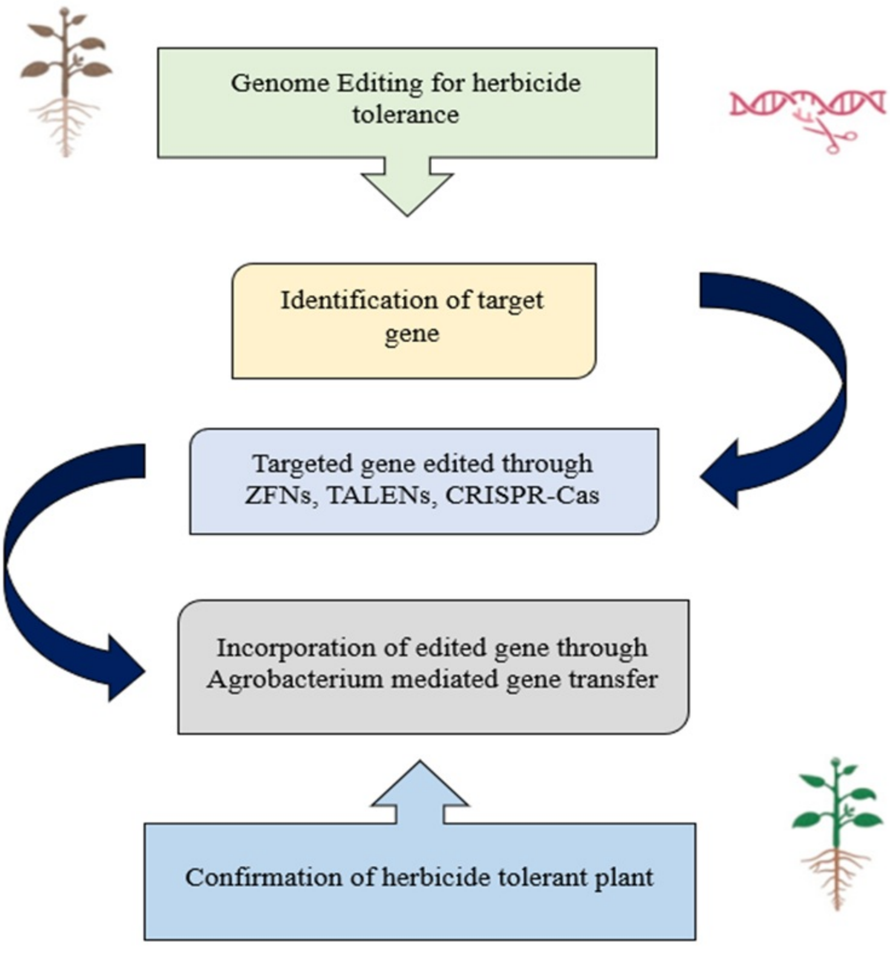


Fig. 2. Application of genome editing in imparting HT genes

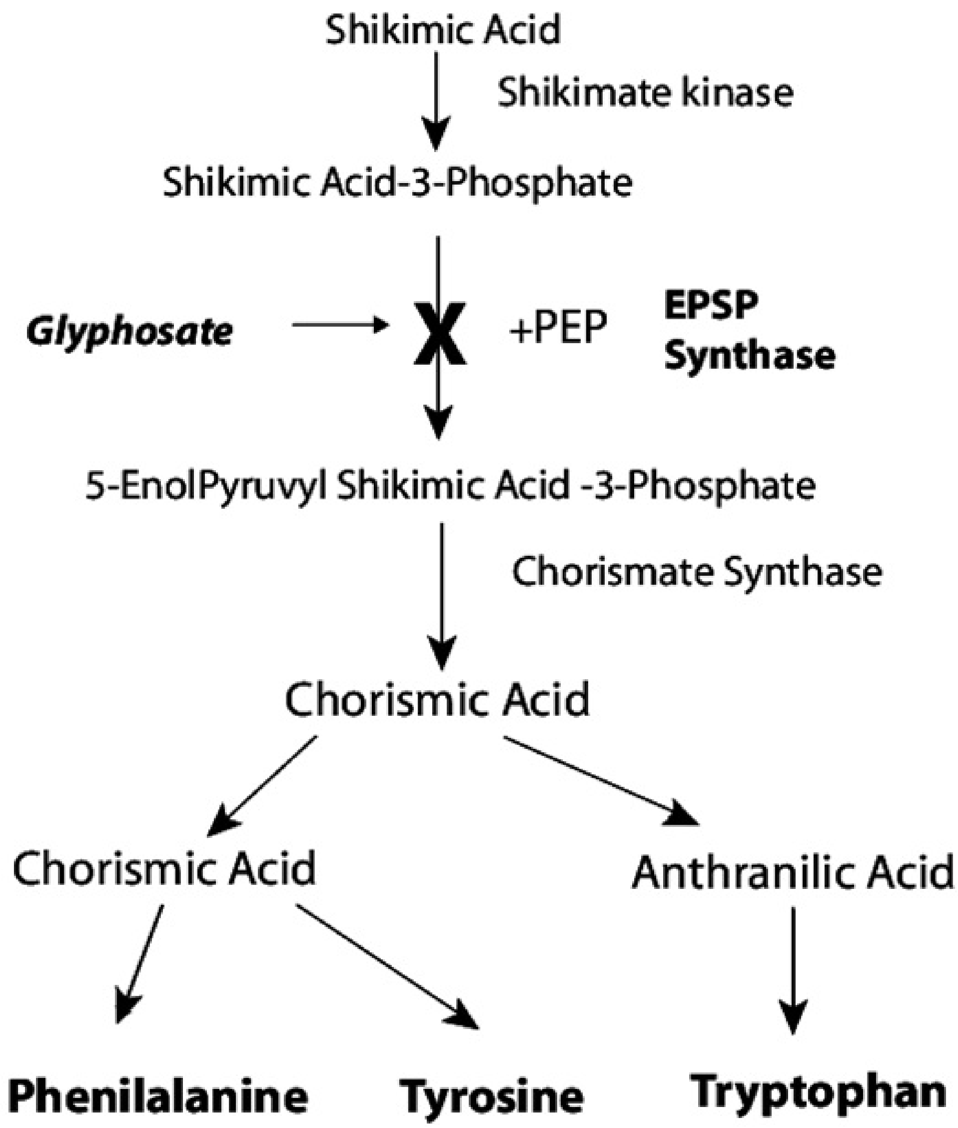


Fig. 3. Glyphosate mode of action (Dill, 2005)

Photosystem-I inhibitors: They cause an immediate electron discharge onto oxygen by taking electrons out of the regular route via FeS, Fdx, and NADP. Plant death results from the cell's intolerance of this excess reactive oxygen species production.

Discovering the gametocidal properties of most sulfonylureas and imidazolinones in addition to ALS-inhibiting herbicides. They provide an environment-friendly male sterility in hybrid seed production. However, certain herbicides like florasulam, flumetsulam, penoxsulam, and bispyribac-sodium, though ALS inhibitors, directly don't induce male sterility, but affect other vital microspore development processes.

Mitosis inhibitors (Benzamide, Dinitroaniline, etc.), glutamine synthetase inhibitors (Gluphosinate), carotenoid inhibitors (amides, anilidex, etc.), protoporphyrinogen oxidases inhibitors (diphenyl ethers, oxadiazoles), etc. are some more mechanisms of herbicide mode of action. (Prakash *et al.,* 2020).

Evolutionary Insights into Herbicide Resistance

Strong selection pressures brought about by the widespread use of synthetic herbicides over the previous 70 years have led to the evolution of herbicide resistance in a wide range of weed species. Herbicide-resistant crop cultivation is an efficient way to manage weeds and lessen crop phytotoxicity caused by herbicide use (Duke, 1990), widen the range of herbicidal effects (Ghanizadeh *et al.,* 2019), and reduce the cost of weeding (Hu *et al.,* 2015). Therefore, the best way to stop weed growth and boost crop output significantly is to produce herbicide-resistant crops (Dill, 2005).

Herbicide-resistant crop improvement was previously aided by classical mutagenesis breeding, albeit this method is labour- and time-intensive. Over the past few decades, transgenic techniques have been successfully applied for crop enhancement since they became available (Batard *et al.,* 1998). Furthermore, there has been a significant rise in transgenic crops resistant to herbicides (Cabello-Hurtado *et al.,* 1998). However, the usage and promotion of genetically modified products are prohibited due to the transfer of alien genes, and the broad use of this strategy is likewise constrained (Robineau *et al.,* 1998).

Target-site resistance (TSR) and non-target-site resistance (NTSR) are two types of herbicide resistance mechanisms. Herbicide binding is usually affected by TSR through mutations in genes encoding herbicide target proteins, either in the active site itself or in close proximity. Enhanced herbicide sequestration or metabolic breakdown, as well as decreased herbicide absorption or translocation, are all components of NTSR processes. Complex gene families like glutathione S-transferases and cytochromes P450 are frequently involved in these processes. TSR and NTSR processes can be combined by specific weeds to increase resistance levels. The variety of resistance mechanisms that weed populations have evolved to withstand strong selection pressures is reflected in their adaptability. The development of herbicides, herbicide-resistant crops, and resistance management techniques are all influenced by our understanding of these mechanisms of action (Gaines *et al.,* 2020).

The evolution of herbicide resistance in weeds is influenced by factors such as, mutation, selection, inheritance, mating system, and gene flow. Spontaneous mutations are the primary source of genetic variation, potentially leading to resistant mutants in susceptible populations. Repeated herbicide treatments with the same mode of action can accelerate resistance evolution. Dominantly inherited mutations spread faster than recessive ones in random mating populations. Gene flow, via pollen or seed dispersal from resistant populations, can introduce resistance alleles to susceptible plants in the nearby fields. Effective resistance management strategies involve reducing herbicide selection pressure and limiting the migration of resistant seeds. (Jasieniuk and Maxwell, 1994)

Genetic Basis of Herbicide Tolerance

Herbicide resistance/tolerance is a genetically controlled mechanism. Within a population, individuals can acquire herbicide resistance (HR) through different processes, all of which are controlled by genetics. Herbicide resistance includes the following: reduced uptake and translocation, improved metabolism and degradation, healing of herbicide-induced damage, sequestration of the herbicide within the plant cell, and conformational alterations to the target site for herbicide action. The innate capacity of a species to endure and procreate following herbicide treatment is known as herbicide tolerance. (Prather *et al.,* 2000).

Herbicide resistance typically arises after prolonged, exclusive use of specific herbicides over consecutive years without rotation. Triazine resistance has been observed in various settings including corn fields, orchards, vineyards, groves, tree plantations, roadsides, and railroad rights-of-way. In species where resistant biotypes or varieties emerge, resistance is typically inherited through one or occasionally two major nuclear genes. Mutations leading to resistance often trigger multiple effects across different biochemical pathways. Maternal inheritance of resistance provides a valuable clue hinting at the potential presence of multiple binding sites. Pleiotropic effects accompanying triazine resistance may include various biochemical changes, though some may appear secondary (Kumar *et al.,* 2022).

Herbicide-tolerant crops enable targeted weed control through tailored herbicide applications, developed via genetic variability exploitation or genetic modification. Various crops, including maize, wheat, rice, sunflower, soybean, and chickpea, exhibit significant genetic variation for herbicide tolerance. The mechanisms of tolerance include altered enzyme binding sites, enhanced herbicide metabolism, molecule sequestration, and target protein overexpression. Mutations such as SNPs or insertions/deletions confer tolerance, like the AHAS1 gene mutation in sunflower. Transgenic approaches, incorporating resistance genes from diverse sources, contribute to herbicide tolerance. However, superweeds, resulting from gene transfer through natural outcrossing, pose challenges in herbicide-tolerant crop management (Prakash *et al.,* 2020).

Identification and Characterization of Herbicide Tolerance Genes in Major Oilseeds

Rapeseed holds significant importance as an oil crop in China, yet its production faces challenges due to ineffective weed management strategies stemming from a lack of herbicide-resistance genes. This problem was solved by using seed mutagenesis to create the rapeseed line M342, which is resistant to herbicides that inhibit Acetohydroxyacid synthase (AHAS). Due to AHAS insensitivity, M342 displays cross-resistance to sulfonylureas (SUs) and imidazolinones (IMIs). This dominant characteristic is inherited from a single nuclear-encoded gene (HU *et al.,* 2017).

Helianthus tuberosus was used to clone one of the first P450 genes for HT, which metabolizes a variety of xenobiotics and herbicides with great efficiency (Batard *et al.,* 1998) (Cabello-Hurtado *et al.,* 1998). Additionally, (Robineau *et al.,* 1998) reported of a mutant P450 gene with elevated HT levels in sunflower. The manifestation of a genetically endowed mechanism that confers resistance to herbicides from distinct chemical classes is known as cross-tolerance in sunflower (Hall *et al.,* 1994). The degree of cross-tolerance that sunflower HT characteristics exhibited to AHAS inhibitor herbicides varied significantly. For example, Ahasl1-1 confers tolerance to imazamox and imazethapyr, but not to pyrithiobac, cloransulam-methyl, or high dosages of imidazolinones. It also confers a modest tolerance to thifensulfuron and chlorimuron (Sala *et al.*, 2012, Al-Khatib *et al.,* 1998, Bruniard & Miller, 2001, White *et al.,* 2002). Plants carrying the Sures trait show tolerance to tribenuron) (Sala *et al.,* 2008), metsulfuron, and chlorsulfuron,but complete susceptibility to imazapyr, imazapic, and imazamox (White *et al.,* 2002).

Although identifying genes responsible for herbicide tolerance does not currently replace herbicide use entirely, these genes can be utilized in developing alternate alleles that help in producing potentially reduced herbicide dosage. Examples of such resistant gene refinement include EPSP synthase in soybean, cotton, and maize (Dietz-Pfeilstetter & Zwerger, 2009), AHAS1 gene in sunflower (Funke *et al.,* 2006), MCPA genes in Raphanus (Bulos *et al.,* 2013), and opaque2 gene in maize (Jugulam *et al.,* 2014).

Table 5 outlines the comprehensive process and outcomes of developing imazethapyr-resistant rapeseed (M9) and utilizing this trait in hybrid rapeseed production. (HU *et al.,* 2017) identified the BnAHAS1 gene providing resistance to IMI herbicides through biochemical and molecular analyses. The development of an allele-specific PCR marker facilitated the detection of this mutation, aiding in the selection of IMI-resistant plants in breeding populations. Additionally, using the herbicide-resistant trait in hybrid rapeseed production led to significant improvements in seed purity and yield. Overall, these findings lay the groundwork for the potential release of IMI-resistant rapeseed cultivars, offering promising prospects for enhanced agricultural productivity and sustainability.

Genetic Variation and Inheritance Patterns

Depending on the resistance gene or mechanism, different weed species exhibit varied inheritance patterns. Most cases of resistance due to target-enzyme mechanisms follow a single nuclear gene inheritance pattern. In weeds resistant to triazine, maternal inheritance has been noted. Interestingly, resistance resulting from overexpression of the target enzyme does not necessarily follow the model of single-gene inheritance. Complete dominance, semi-dominance, and recessive for overexpression and mutation processes are the three types of allelic dominance. On the other hand, the inheritance pattern of non-target site resistance is more intricate and necessitates independent research. Comprehending inheritance patterns is essential for controlling the dynamics of herbicide resistance in weed populations, supporting the creation of forecasting models and creative tactics to stop the spread of resistance genes (Ghanizadeh *et al.,* 2019)

Evaluation of herbicide tolerance in peanut breeding lines is crucial for grower acceptance of new cultivars. However, there is limited knowledge about herbicide tolerance variability in peanut germplasm. The findings of a variation study (Leon and Tillman, 2015) revealed different mechanisms as illustrated in the following figure. This flowchart (Figure 1) visually represents the variation in herbicide tolerance among groundnut lines, highlighting the lower tolerance levels of'Florida-07' and 'Georgia-06G'. Significantly higher tolerance levels were observed in the most tolerant breeding lines and one specific breeding line with exceptionally high dicamba GR50 values. The most tolerant lines were consistently tolerant to herbicides with distinct modes of action, indicating that mechanisms other than target-site mutations are more likely to cause tolerance. These findings demonstrated how important it would be for peanut breeding programs to screen breeding lines for resistance to important herbicides and create a database of herbicide tolerance. Given that half of the breeding lines showed lesser tolerance than the market cultivars, this information can be used to design new crosses that minimize the chance of producing cultivars with low herbicide tolerance.

The significance of this study is the importance of screening breeding lines for herbicide tolerance to enhance cultivar development in peanut breeding programs. (Beckie, 2014)

Conventional breeding approaches

Herbicide tolerance can be introduced into crops using three basic approaches:

- overexpression of the herbicide target enzyme,
- detoxification of the herbicide, and
- expression of an herbicide insensitive target enzyme.

Combinations of these three basic approaches can also be used by adopting any standard breeding methods (Dill, 2005). Conventional breeding methods offer cost-effective, adaptable solutions with less regulatory burden when compared to non-conventional approaches like transgenic and gene editing methods, which face stringent regulations and limited consumer acceptance (Trucillo Silva *et al.,* 2010). Developing Herbicide Tolerant/Resistant Crops involves various methods successfully applied for improvement (Bradford *et al.,* 2005). One such method is screening for natural variations in germplasm lines sourced from diverse origins. The other method involves utilizing available genes within the gene pool or genes found in wild relatives of the crop species. Additionally, random mutagenesis can be employed to induce variation for herbicide tolerance.

i. Wild genotypes: The idea of using wild relatives and animals to produce herbicides Superweed emergence led to the emergence of tolerance (Taran *et al.,* 2010), caused by increased herbicide application in fields. Selection pressure among related weed species, including crop wild relatives acting as weeds, has led to herbicide failures. Screening wild relatives via similar procedures as germplasm materials is feasible. Gene flow among crop wild relatives and crops, as well as among wild relatives, is common (Bain *et al.,* 2017). Herbicide-resistant weeds and crop volunteers can quickly accumulate if persistent herbicide applications with the same mode of action are made after resistance genes are found in related weed species or crop volunteers (Song *et al.,* 2003).

ii. Germplasm: Germplasm screening involves subjecting plant materials to varying herbicide doses, evaluating parameters like plant stand, yield differences, leaf damage, floral development, days to flowering/maturity, harvest index, photosynthetic ability, and Normalized Difference Vegetation Index (NDVI) (Chaturvedi *et al.,* 2014; Kishore *et al.,* 1992)(Gaur *et al.,* 2013; Prakash *et al.,* 2020). Promising lines undergo rigorous multi-location, multi-year evaluations. Selected lines are then utilized in developing herbicide-tolerant cultivars through diverse breeding methods.

iii. Mutation: Mutations serve as a valuable source of herbicide tolerance in crops lacking sufficient variability in their germplasm (Bernasconi *et al.,* 1995; Délye *et al.,* 2013). Physical and chemical mutagenesis techniques effectively induce mutations, facilitating the development of herbicide-tolerant lines (Batterman & Leemans, 1988; Parker *et al.,* 1990). Screening mutants for herbicide tolerance follows the same protocols as germplasm screening. As lines identified as resistant to herbicides can be disseminated immediately (Sala & Bulos, 2012) or integrated into breeding programs for further enhancement (Mou, 2011).

iv. Incorporation of herbicide-tolerant traits into elite varieties: To grant commercial resilience to herbicides, various herbicide-tolerance alleles exhibit different inheritance requirements: some alleles are effective in a heterozygous state, others necessitate a homozygous condition, while some must be combined with another tolerance gene. These alleles, which confer herbicide tolerance, are incompletely dominant and generally do not affect other traits, except for the triazine-tolerant mutation, which is maternally inherited and associated with several agricultural characteristics. Incorporating the herbicide-tolerant trait into elite crop varieties involves crossing the elite variety with a donor possessing the desired trait.

Molecular Breeding Approaches:

Plant breeding, vital for food security, has evolved through artificial selection, hybridization, and molecular breeding, now advancing into precision design breeding. Molecular breeding, involving marker-assisted selection and transgenic techniques, enhances breeding efficiency. Recent advancements in high-throughput sequencing facilitate genetic analysis. Molecular-assisted breeding enhances oilseed traits like oil content and oleic acid levels. Integrating omics approaches and emerging technologies like metagenomics fuels further breeding progress. Precision design breeding, necessitated by climate challenges, relies on accurate genotype-phenotype associations. Despite sequencing technology cost and speed, improving and, integrating diverse datasets remain a challenge

Experiments utilizing acquired genes have elevated soybean oil content, boosted soybean oleic acid levels, and decreased linolenic acid content. In 2010, (Pham *et al.,* 2010) discovered three polymorphisms in the FAD2-1B allele, resulting in missense mutations that increased oleic acid content. They also demonstrated the production of high-oleic-acid soybeans by combining mutant FAD2-1A and FAD2-1B genes. To further diminish linolenic acid content, one or two mutated FAD3 genes were introduced into the high-oleic-acid background (Hagely *et al.,* 2021).

Molecular-assisted breeding recently led to the development of a high-oleic-, low-linolenic-acid soybean variety with elevated vitamin E content. These advancements aim to produce high-quality soybeans with health-enhancing properties (Pham *et al.,* 2010, 2012). Additionally, molecular-assisted breeding has enhanced carbohydrate profiles (Hagely *et al.,* 2021), reduced pod-shattering (Miranda *et al.,* 2019), improved yield and latitude adaptability (Kou *et al.,* 2022; Lu *et al.,* 2017; Zhao *et al.,* 2016) and elevated seed oil and protein content (Wang *et al.,* 2020 , Kou *et al.,* 2022; Miranda *et al.,* 2019; Pham *et al.,* 2012; Zhao *et al.,* 2016) in soybean breeding. Combining established Molecular Assisted Selection (MAS) with emerging Accelerated Single Seed Descent (aSSD) techniques has further streamlined the breeding process in soybean (Croser *et al.,* 2021). Integrating these platforms with conventional breeding programs poses challenges, requiring trust in quality assurance practices and adequate platform capacity. MAS facilitates rapid and cost-effective screening of plants, reducing reliance on herbicide bioassays. Integrating molecular markers with other trait markers accelerates trait stacking. In a case study on herbicide-tolerant chickpeas, MAS shortened the breeding cycle, facilitating continuous introgression of desirable traits into elite lines. Implementing marker assays at the F2 generation reduced aSSD lines by 75%, while MAS of perlite screen survivors ensured progression of only homozygous tolerant progeny, optimizing breeding resources.

GWAS and GS, leveraging extensive marker data across diverse genotypes, offer promising avenues to tackle complex traits in sunflower. However, GWAS remains cost-prohibitive and inaccessible to many researchers and breeders. Efforts have begun to refine prediction models for hybrid performance based on GWAS and GS data, yet further enhancements are needed, particularly in accounting for dominance and epistasis alongside additive effects. Tailored GS strategies must be devised considering species-specific factors such as reproductive system, generation time, genome structure, harvested organs, and breeding objectives. Empirical GS studies in plants have demonstrated its potential efficacy, suggesting successful performance even with fewer markers and modest population sizes (Bonnafous *et al.,* 2016; Mangin *et al.,* 2017; Nakaya & Isobe, 2012)

Genetic Engineering Techniques

Originally, traditional plant breeding and transgenic technologies served as the foundation for developing herbicide-tolerant crops. Emerging genome technologies such as CRISPR (clustered regularly interspaced short palindromic repeat), TALENs (transcription activator-like effector nucleases), and ZFNs (zinc-finger nucleases) have given us a new avenue for crop improvement through precise manipulation of endogenous genes in plant genomes. Among them, CRISPR technologies-which are straightforward, user-friendly, and extremely effective-such as nuclease systems, base editors, and prime editors show promise for developing novel crop germplasms resistant to herbicides (Gosavi *et al.,* 2022).

Novel methodologies for imparting herbicide resistance to plants continue to evolve, with CRISPR/Cas9-mediated gene editing techniques emerging as a promising avenue for crop improvement. The recent breakthroughs were in leveraging CRISPR/Cas9 technology to develop herbicide-resistant plants, focusing on the targeted modification of endogenous genes such as acetolactate synthase (ALS), 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS), cellulose synthase A catalytic subunit 3 (CESA3), and splicing factor 3B subunit 1 (SF3B1). Additionally, the potential candidate genes for generating herbicide-resistant plants through the induction of loss-of-function mutations using the CRISPR/Cas9 system have emerged. These advancements hold significant promise for enhancing crop resilience to herbicides while minimizing off-target effects and environmental impacts (Han & Kim, 2019)

Given this, genome editing appears to be a clever tactic to develop crops that will be resilient to various abiotic stresses in the future, as it permits accurate manipulation of different gene loci in comparatively less time, thereby reducing the expense of crop-improvement initiatives (Schaart *et al.,* 2016). This flowchart provides an overview of the steps involved in genome editing for herbicide tolerance.

Economic Impact of Herbicide Tolerance on Oilseed Crop Production

Cost-Benefit Analysis: Assessing the economic viability of adopting herbicide-tolerant oilseed crops compared to conventional varieties involves evaluating factors like seed costs, herbicide expenses, labor requirements, and yield benefits. Transgene detection in the conventional produce at the field level increases external costs based on the area size and spatial detail. Conversely, if transgene presence is averaged across all fields due to grain blending, external costs are determined solely by the relative size of the source area. This model seamlessly integrates into economic evaluations of policies regulating the adoption of genetically modified herbicide-tolerant oilseed rape (GM HT OSR). (Ceddia *et al.,* 2007).

Yield Gains and Production Efficiency: Analysing the yield advantages associated with herbicide-tolerant varieties and their impact on overall crop production efficiency, including increased yields per acre and reduced production risks.

Weed Management Costs: Includes evaluating the cost savings achieved through reduced reliance on alternative weed control methods, such as mechanical cultivation, hand weeding, or multiple herbicide applications.

Input Savings: Quantifying the savings in herbicide usage and associated inputs (e.g., fuel, equipment) resulting from the adoption of herbicide-tolerant crops, and their implications for overall production costs.

Farmer Profitability: Examining the profitability of herbicide-tolerant oilseed crops for farmers, considering factors such as gross margins, net returns, and return on investment (ROI) compared to conventional cropping systems.

Market Dynamics: Investigating the market forces driving the adoption of herbicide-tolerant varieties, including seed prices, herbicide availability, and market demand for sustainably produced crops.

Environmental Externalities: Assessing the economic value of environmental benefits associated with herbicide tolerance, such as reduced soil erosion, water conservation, and biodiversity preservation, and their implications for long-term sustainability.

Risk Management: Analysing the role of herbicide tolerance in mitigating production risks related to weed competition, weather variability, pest pressure, and market fluctuations, and its impact on farm resilience and risk management strategies. With the introduction of HR crops, the promise of less herbicide use was accomplished, but it did not endure; to control glyphosate- and intergroup-HR weeds in HR maize, soybean, and cotton, herbicide use eventually increased. With the impending release of new multiple- or stacked-trait HR crops, growers have the chance to apply more varied cropping methods and weed control techniques and make the correct decision this time (Beckie, 2014).

Adoption Trends: Tracking the adoption rates of herbicide-tolerant oilseed crops over time and across different regions, and identifying factors influencing farmer decisions to adopt or reject this technology. These days, the development of novel strategies for efficiently delivering herbicides into fields is receiving increased attention from the scientific and industrial sectors. Keeping this in mind, the paradigm shift from a strong reliance on herbicide to a more integrated system involving a wide variety of technologies and cultural practices has led to the adoption of both old and new technologies for weed management (Peerzada *et al.,* 2019).

Policy Implications: Discussing the economic implications of regulatory policies, intellectual property rights, and market access agreements affecting the adoption and diffusion of herbicide-tolerant varieties, and their influence on industry dynamics and farmer decision-making.

Environmental Considerations and Sustainability of Herbicide-Tolerant Systems

In some regions of the world, increased herbicide use is regarded as dangerous, even though the effects on the environment or human health are rarely discussed in detail. However, the public has become concerned about the consequences of pesticide use, such as groundwater pollution and pesticide residues in food crops. Herbicide use in herbicide-resistant cultivars (HRCs) appears to be related to two main factors. The farmer may be able to raise doses to achieve better weed control without endangering the crop if the crop has a high degree of crop tolerance. The other reason is that farmers need to mix herbicides with different modes of action or raise dosages to maintain an adequate level of weed control due to issues with weeds that are tolerant or resistant as well as volunteers. These are a few more environmental issues.

Impact on Non-Target Organisms: Assessing the potential effects of herbicide-tolerant systems on non-target organisms, including beneficial insects, pollinators, soil microbes, and aquatic fauna. While it is challenging to evaluate, it is widely acknowledged that both glyphosate and glufosinate have minimal effects on soil microorganisms. Additionally, these herbicides pose low toxicity risks to humans and animals. Due to their rapid decomposition in soil and their absorption by organic colloids, glyphosate and glufosinate have reduced potential for leaching, thus decreasing the risk of groundwater contamination(Danson *et al.,* 2006).

Soil Health and Microbial Communities: Examining the influence of herbicide-tolerant systems on soil health parameters, such as microbial diversity, nutrient cycling, and soil structure, and their long-term implications for soil sustainability.

Weed Resistance Management: Discuss strategies for managing herbicide-resistant weeds in herbicide-tolerant systems, including the adoption of integrated weed management (IWM) approaches, diversified cropping systems, and herbicide rotation strategies.

Pesticide Use and Residue Levels: Analysing the trends in pesticide usage, including herbicides and associated adjuvants, in herbicide-tolerant systems and assessing their potential impacts on human health, wildlife, and ecosystems.

Biodiversity Conservation: Evaluating the effects of herbicide-tolerant systems on plant biodiversity, including weed flora composition, weed seed banks, and the conservation of native plant species and habitats.

Water Quality and Aquatic Ecosystems: Investigating the potential for herbicide runoff and leaching from herbicide-tolerant systems to affect water quality, aquatic habitats, and non-target aquatic organisms, including fish and amphibians.

Ecological Resilience: Assessing the resilience of agroecosystems under herbicide-tolerant systems to environmental stressors, such as climate variability, pest outbreaks, and extreme weather events, and their capacity to maintain ecosystem functions and services.

Gene Flow and Transgene Escape: Examining the risks of gene flow and transgene escape from herbicide-tolerant crops to wild or weedy relatives, and the potential ecological and agronomic consequences of such events. A study demonstrated the potential for unintended gene flow between different transgenic herbicide-resistant oilseed rape cultivars, highlighting the importance of managing volunteer plants with multiple herbicide resistance. Despite reduced outcrossing frequencies with increased isolation distance, seed-mediated gene flow via harvesting machinery poses a significant challenge for containment efforts. suggest a title (Dietz-Pfeilstetter & Zwerger, 2009).

Social and Ethical Considerations: Addressing social and ethical concerns related to the adoption of herbicide-tolerant systems, including farmer autonomy, consumer preferences, land tenure issues, and the socio-economic impacts on farming communities.

Regulatory Frameworks and Policy Implications: Discuss the regulatory frameworks governing the use of herbicide-tolerant crops and associated herbicides, including risk assessment protocols, labelling requirements, and public participation in decision-making processes.

Glyphosate action on oilseeds

Glyphosate exerts its herbicidal effects by inhibiting the activity of an enzyme called EPSP synthase, which plays a crucial role in the synthesis of aromatic amino acids through the shikimic acid pathway. These amino acids, including phenylalanine, tryptophan, and tyrosine, are essential building blocks for proteins involved in various plant growth processes. Additionally, glyphosate disrupts the synthesis of nonaromatic amino acids through alternative mechanisms, leading to the accumulation of shikimate, a substrate of EPSP synthase. Consequently, the inhibition of EPSP synthase hampers the production of amino acids and proteins necessary for plant growth, resulting in various toxic effects. This mode of action is not specific to particular plant species, rendering glyphosate toxic to most plants upon contact with foliage (Rogers *et al.,* 2024)

Transgenic canola engineered for glyphosate tolerance via mutated EPSPS and synthetic GOX gene showed enhanced resistance. Bioinformatics analyzed the synthetic GOX gene's structure and mRNA. Subsequent transformation confirmed transgene presence, copy numbers, and expression via PCR, Southern blotting, and RT-PCR. Glyphosate bioassays demonstrated transgenic canola's survival at 1.5 mM, whereas non-transformed plants perished at 0.5 mM glyphosate (Hadi *et al.,* 2012).

Experiments evaluated glyphosate resistance in soybean and canola, focusing on dose responses and glyphosate metabolism. Glyphosate-resistant soybean showed 49-fold resistance compared to non-resistant, with no significant differences in glyphosate metabolism. Chlorophyll reduction varied among resistant soybean varieties. Glyphosate-resistant canola exhibited 47-fold resistance, with no chlorophyll or shoot fresh weight reduction. Glyphosate metabolism differed between soybean and canola. The presence of a bacterial glyphosate oxidoreductase gene in resistant canola-aided glyphosate breakdown. Exogenous AMPA caused similar injury in both resistant and non-resistant canola. AMPA from glyphosate breakdown might have been metabolized before causing injury (Nandula *et al.,* 2007).

Engineering Glyphosate Resistance

Glyphosate is a potent herbicide inhibiting the enzyme EPSP synthase, crucial in the biosynthesis of amino acids and other compounds in plants. The recent emergence of glyphosate-resistant weeds has challenged its efficacy. Three genetic engineering strategies aimed to develop glyphosate-resistant crops: EPSP synthase overproduction, metabolic detoxification gene introduction, and altered EPSP synthase enzyme. Modification of EPSP synthase structure dominated research, aiming to render it functional yet insensitive to glyphosate. Initial studies introduced a modified EPSP synthase gene from Salmonella typhimurium into tobacco, resulting in decreased glyphosate affinity. Subsequent research focused on Gly101 to Ala101 substitution in petunia EPSP synthase, yielding moderate glyphosate tolerance.

Identification of a naturally occurring glyphosate-tolerant EPSP synthase gene (cp4) from Agrobacterium sp. strain CP4 provided promising results in various crop plants. Glyphosate resistance via metabolic detoxification pathways involving glyphosate oxidoreductase (GOX) genes from microbes was explored. Two detoxification pathways, involving oxidative cleavage or carbon-phosphorus lyase, were identified. Cloning of the GOX gene from Pseudomonas sp. strain LBr enabled its use alongside the cp4 gene to confer glyphosate resistance in various commercial crops.

This approach formed the foundation of Roundup-Ready crops, including soybeans, corn, canola, and cotton. Glyphosate oxidoreductase works alongside the cp4 gene to metabolize glyphosate into non-toxic components. The development of glyphosate-resistant crops has significantly impacted weed management practices in agriculture.

Research in genetic engineering strategies for glyphosate resistance continues to evolve to address emerging challenges in weed control. These advancements underscore the importance of biotechnological approaches in enhancing crop resilience and agricultural sustainability.

Case study on herbicide tolerance of few oilseed crops

Clearfield® technology based on Imisun sunflowers

The development of the first commercial Herbicide Tolerant (HT) trait in sunflowers, known as 'Imisun,' began in 1996 when IMI-tolerant wild sunflowers were discovered in a Kansas field (Sala, Bulos, Altieri, & Ramos, 2012a). Crossbreeding these tolerant plants with cultivated sunflower lines resulted in the emergence of IMI-tolerant populations and lines (Joci *et al.,* 2004; Miller & Al-Khatib, 2002a; Sala, Bulos, Altieri, & Ramos, 2012a). The inheritance of Imisun involves the additive control of two genes, with one being the partial genotypes showing synergistic effects of IMI and malathion, indicating the involvement of various physiological mechanisms in non-target site tolerance. To achieve commercial levels of IMI tolerance in Imisun sunflower hybrids, both target and non-target components of tolerance must be expressed (Miller & Al-Khatib, 2002b). However, it's important to note that linkage drags from the wild parent around the resistant gene have been associated with a decrease in seed oil percentage (Sala, Bulos, Altieri, & Ramos, 2012c).

Roundup Ready Canola (Glyphosate Tolerance)

Roundup Ready Canola, also known as glyphosate dominant allele Ahasl1-1 and the other acting as a modifier or enhancer factor (Al-Khatib *et al.,* 1998; Tan *et al.,* 2005). Heterozygous Imisun inbred lines exhibit variability for IMI tolerance, with certain -tolerant canola, which represents a significant advancement in agricultural biotechnology. Engineered through genetic modification, this variety of canola is designed to withstand applications of the herbicide glyphosate, commonly marketed as Roundup. The introduction of Roundup Ready Canola has revolutionized weed management practices, offering farmers a highly effective and convenient solution for weed control. Glyphosate inhibits the enzyme EPSPS, essential for the synthesis of aromatic amino acids in plants. By integrating a modified EPSPS gene into the canola genome, Roundup Ready Canola exhibits reduced sensitivity to glyphosate, allowing for selective weed control while sparing the crop. This trait has greatly streamlined farming operations, simplifying weed management and reducing the need for labor-intensive methods such as mechanical cultivation or multiple herbicide applications. Furthermore, the adoption of Roundup Ready Canola has led to enhanced crop yields and improved profitability for farmers, as it enables more efficient weed suppression and promotes healthier crop growth. Despite concerns over herbicide-resistant weeds and potential ecological impacts, Roundup Ready Canola continues to be widely cultivated, contributing to the sustainability and productivity of modern agricultural systems. Ongoing research and development efforts aim to further optimize the performance and sustainability of glyphosate-tolerant canola varieties in the face of evolving agricultural challenges.

Future Directions and Challenges

One research gap in herbicide tolerance of oilseeds is the need for further exploration and development of novel herbicide-tolerant traits in oilseed crops beyond the current dominant traits. While herbicide tolerance has been successfully introduced in some oilseed crops, such as soybeans and canola, there are still many oilseed species with limited or no herbicide tolerance traits available. Additionally, existing herbicide tolerance traits may face challenges such as the development of herbicide-resistant weeds, environmental concerns, or limitations in efficacy against certain weed species. Therefore, there is a need for research aimed at identifying and characterizing new herbicide tolerance mechanisms in various oilseed crops, as well as evaluating their effectiveness, environmental impacts, and potential for resistance development. Additionally, research focusing on improving the durability and sustainability of herbicide tolerance traits in oilseeds through innovative breeding strategies, genetic engineering techniques, and integrated weed management approaches would also address this research gap.

In conclusion, herbicide tolerance in oilseed crops epitomizes the intersection of scientific ingenuity, agronomic efficiency, and environmental consciousness. It showcases the adaptability of plants to genetic manipulation, offering tailored solutions to weed management while mitigating environmental impacts. The historical journey from glyphosate-tolerant soybeans to novel traits in canola and sunflowers reflects a dynamic balance between innovation and industry dynamics. Economic benefits, including cost savings and enhanced profitability, underscore the importance of sustainable weed management practices and regulatory oversight. Collaboration among stakeholders is essential for navigating regulatory landscapes and promoting safe adoption. Future prospects, including gene editing and synthetic biology, offer promising avenues for precision agriculture, guided by principles of sustainability and responsibility. In sum, herbicide tolerance in oilseed crops is integral to modern agriculture, enhancing productivity while safeguarding environmental integrity and global food security.

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Review

Different approaches for genetic improvement of sesame (*Sesamum indicum* L.) for enhancing yield in India: A Review

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ABSTRACT

Sesame (*Sesamum indicum* L., 2n=2x=26) is an important oilseed crop from family Pedaliaceae, grown widely in Asia and Africa. Polyunsaturated fatty acids (PUFA), proteins, lignans (sesamin and sesamolin), and tocopherol all are present in high concentrations in sesame seed oil. The sesame crop is termed as queen of oilseeds because of its high oil quality and presence of lignans which prevent rancidity. Unavailability of stable genotypes with high yield, presence of wild traits like non-shattering capsule, indeterminate growth habit and asynchronous capsule ripening are the major constraints in sesame. To overcome these yield limiting conditions, integrated breeding approach like conventional plant breeding along with non-conventional methods such as mutation breeding, marker assisted breeding, transgenic technology and genome editing are to be followed. In recent time, Marker Assisted Selection with detailed information on genomic resources has new challenges to strengthen the approach for betterment of sesame productivity genome editing techniques can also help in improving different desirable characters. The review highlights several scientific research works conducted for sesame genetic improvement including both traditional and modern thoughts.

Keywords: Conventional, Oilseed, Qualitative, Quantitative, Sesame

Sesame (*Sesamum indicum* L.), also known as gingelly or til, is a significant oilseed crop from the Pedaliaceae family, it is extensively cultivated in tropical and subtropical parts of Asia, Africa, and South America. Sesame is referred to as the "Queen of Oilseeds" because of the remarkable properties of the oil and meal with antioxidants including sesamolin, sesamin, sesamol, and sesaminol (Vijayarajan *et al.,* 2007; Prathyusha *et al.,* 2023) and its high percentage of oil content. Sesame seed contains elevated oil percentage (46-50%) with 20% proteins lignans (sesamin and sesamolin), 83-90% polyunsaturated fatty acids (PUFA), phytosterols, phytates, tocopherol, and minerals. The highest concentration of antioxidants is found in sesame oil, which also contains a number of fatty acids, including oleic acid (43%), linoleic acid (35%), palmitic acid (11%), and stearic acid (7%), as well as trace amounts of linolenic acid (Ashri, 1998; Kamal-Eldin *et al.,* 1995). In addition to being eaten as a raw food, seeds are also utilised to make a variety of food products, including halva, pinni, tahini, and other baked goods and confections. One of the healthiest vegetable cooking oils, sesame oil can help lower blood cholesterol and high blood pressure while also helping to avoid atherosclerosis, heart disease, and cancer. Sesame is widely grown on more than 11.74 million ha of land worldwide, with a yield of 512.30 kg/ha and an annual production of 6 million tonnes (FAOSTAT, 2018). In terms of sesame production (746000 tonnes) and area under sesame cultivation (1730000 ha), India came in third place overall in 2018. About 70% of the sesame seeds produced in India are grown in West Bengal, Rajasthan, Madhya Pradesh, and Gujarat. It is also grown in various other states, including Andhra Pradesh, Uttar Pradesh, Bihar, Odissa, Telangana, Karnataka, and Tamil Nadu. Sesame's vertical expansion can help India's enormous oilseed output deficiency (Kumar *et al.,* 2020). An upward tendency is evident for future productions in order to capitalise on the rising demand for sesame on the global market and to close the gap in India's oilseed production. India, however, imported a record high volume of 70000-80000 MT of sesame seeds in the year 2018.

The primary causes of sesame's low productivity are the lack of stable genotypes with high yields for a variety of environmental conditions. It is mostly grown in rainfed situations on marginal and sub-marginal soils under subpar conditions with inadequate management and few inputs. The overall production becomes stagnate as a result of seed shattering, an indeterminate growth habit, asynchronous capsule ripening, vulnerability to pests and diseases, etc. Making decisions on the best ways to increase sesame productivity is also crucial. It is necessary to develop high yielding varieties with higher oil content, better cultivation techniques that boost harvest index and yield, varieties resistant to biotic and abiotic stresses, synchronous maturity,

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non-shattering cultivars for mechanical harvesting, and varieties with genetic purity of up to 99-99.5% purity.

According to the materials used in the various studies, the genetics of traits like capsule number, capsule length, 1000-seed weight, and branch number per plant are highly correlated to seed yield and controlled by both additive and non-additive genetic effects with predominant control of either of the genetic components (Kumar *et al*., 2020). Environment always plays an important role in (General Combining ability) gca x environment and (Specific Combining ability) sca x environment interaction suggesting the experiment must be done under different environmental conditions to have precise estimates and identification of good general and specific combiners (Das and Dagupta, 1999; Das, 2005). Indehiscent vs dehiscent capsules are essential under mechanized cultivation; indehiscent capsule helps to increase productivity as found in USA. But in country like India where still manual method of cultivation is more popular, indehiscent capsule will result in difficulty in harvesting. Indehiscence capsule (id) is controlled by single recessive gene. Langham and Rodriguez (1945) reported that the capsules in the original id/id lines were so hard to open that they required a hammer. The id allele produced pleiotropic effects that included cupped leaves, twisted stems, short seed pods, semi-sterility, and low yield.

The seed coat of a healthy sesame seed ranges in colour from black to white through a number of intermediate colours, including dark brown, brown, light brown, beige, and cream. In comparison to black-seeded sesame, white sesame seeds have higher ratios of oil, protein, and moisture (Kanu, 2011). Despite rising demand for white seeded sesame, India has a dearth of high yielding white seeded sesame cultivars with high oil content. Although digenic control described by earlier studies (Falusi, 2007 and Zhang *et al.,* 2013) showed that two primary genes with additive-dominant-epistatic effects together with polygenes were responsible for influencing the seed coat colour trait, the genetics of seed coat colour is still not conclusive. But, Pandey *et al.* (2013) reported a tetragenic model with additive-dominant-epistatic effect corroborated with different seed colour combinations. It is thought that cultivars having a high density of capsules per leaf axil have more capsules per plant, which could lead to a higher seed production (Pharm *et al.,* 2010; Kumar *et al.,* 2022; Akhtar, 2005). Tetra-carpellate types have a more grain yield per plant in compare to bi- and tri-carpellate types as well as greater expression of capsules per plant, seeds in a capsule, oil content, and biomass yield per plan (Monpara *et al.,* 2019; Prathuysha *et al.,* 2020). This is evident from a comparison of bi-, tri-, and tetra-carpellate types for yield and yield contributing characters.

Breeding approaches in sesame

There are two approaches for sesame breeding conventional and non-conventional breeding. In conventional breeding, mainly two process hybridization and selection are considered but under selection; mass selection and pureline selection. In pureline, there are single seed descent method, bulk method, pedigree method, and backcross. In non-conventional breeding, recombinant DNA technology, molecular approach tissue culture, mutation breeding etc.

Conventional plant breeding is the practice of developing new cultivars or improving current ones while adhering to the genetic diversity of the species. Characterising and preserving naturally occurring diversity in a crop are an essential component of breeding, and morphological basis is a method to estimate genetic differences between sesame genotypes that may be examined in accordance with DUS standards of sesame (Singh *et al.,* 2017; Ranjithkumar and Bisen, 2017). One of the useful breeding strategies is hybridization, which aims to improve the genetic variety of elite cultivars. The traditional approach has some drawbacks; a long-term programme is an ongoing, taxing endeavor that calls on compatibility, patience, and persistence. Only plants that are sexually compatible with one another can breed. Numerous detrimental effects on yield potential are transferred when plants are crossed together with the desired characteristic. Hybrid varieties have had a significant impact on agricultural production over the past few decades using this method of crop modification.

Plant cultivars are created or enhanced by non-traditional methods such as molecular approaches, tissue culture, and plant genome manipulation through mutation. Mutation breeding is also one of the major approaches that is helpful in improving sesamum crop. In order to supplement traditional breeding programmes, it is useful in increasing genetic variation. Sesame breeding has benefited greatly from induced mutagenesis. In India, the variety Usha was developed through chemical mutagenesis and released for its increased yield. Variety Kalika for short stature and variety Uma for synchronous maturity.

The increased understanding of DNA over the past 50 years has accelerated the science of molecular breeding. Molecular markers are extremely trustworthy genetic instruments that are used together with phenotypic selection in breeding. For the purposes of genetic analysis, breeding, and conservation, knowledge of the genetic diversity and population structure of germplasm collections is essential. Numerous markers have already been used to identify genetic diversity in the sesamum crop. Major genetic areas corresponding to a desired quantitative characteristic in a population are identified using quantitative trait locus (QTL) analysis. Molecular breeding, broadly defined, as the process of applying genetic engineering at the DNA molecular level to plants in order to improve desired features. The prime aim of molecular breeding is to develop those plant varieties that have desirable characters based on the modification of DNA with particular genes and save a lot of time in the breeding process. There are two types of molecular markers: dominant marker and co-dominant marker. In dominant marker further divided into RAPD (Random Amplified Polymorphic DNA) and AFLD (Amplified Fragment Length Polymorphism) whereas Co-dominant markers classified as SSR (Simple Sequence Repeat), EST-SSR (Expressed Sequence Tag), SNP (Single Nucleotide Polymorphism) and RFLP (Restricted Fragment Length Polymorphism).

For genetic diversity research, the creation of genetic maps, and marker-assisted selection (MAS), RAPD is a popular technique since it is straightforward, quick, and somewhat inexpensive; sequence information is not necessary. Whereas when the structure of the genome is unclear, AFLP is a technique used to detect polymorphisms in DNA. Sesame genetic diversity has been successfully studied using AFLP markers by Uzun *et al.* (2003), Laurentin and Karlovsky (2007), and Ali *et al.* (2007). SSR markers are co-dominant, reproducible, incredibly polymorphic, and highly informative due to both the number and frequency of identified alleles. The molecular techniques of SSR Dixit *et al.* (2005); Spandana *et al.* (2012); Wang *et al.* (2012); Yepuri *et al.* (2013); Wei *et al.* (2014); Pandey *et al.* (2015); Dossa *et al.* (2016); Bhattachajee *et al.* (2019): Kumar *et al.* (2022) have been used to evaluate the genetic diversity in sesame of different origin. The expressed sequences that give rise to EST-SSRs are made from cDNAs, which are short DNA molecules reverse-transcribed from the cellular mRNA population. For the study of genetic diversity, comparative genomics, and genome annotation, it is helpful. Sesame EST-SSRs have been reported by Zhang *et al.* (2007), Wei *et al.* (2011), and Bhattacharyaa *et al.* (2014) to assess the genetic diversity in sesame of various origins.

SNPs are single nucleotide polymorphisms that exist in individual genetic sequences. SNPs are the most prevalent, exhibit significant inter-species variation, and are valuable for quickly identifying crop cultivars and creating ultra-high-density genetic maps. However, they are expensive to generate, need prior sequencing information, and are still restricted in sesame. RFLP is a difference in homologous DNA sequences that can be identified by the presence of fragments of different lengths after digestion of the DNA samples with a particular restriction endonucleases. RFLP, as a co-dominant molecular marker, is specific to a single clone/restriction enzyme combination. Research on transcriptomes and genomes has been transformed by next-generation sequencing (NGS). Tools in sequencing are useful for identifying, confirming, and evaluating genetic markers across a range of populations. The cost and efficiency of genotyping in a number of model and agricultural plants have been greatly improved using quantitative trait locus (QTL) NGS technologies. In the past few years, with the advancement of NGS technology, sesame genetic research has made steady progress.

Genetic engineering methods encompass a range of cutting-edge strategies that can supplement traditional breeding in sesame. Transforming characteristics genetically might be a perfect way to introduce some useful genes, like resistance to capsule shattering, into elite cultivars of sesame. Sesame genetic transformation has shown some success with target gene insertion and new variety production.

Genome editing, also known as targeted gene modification, is a technique for generating new allelic variants in the genomes, including crop plants. The clustered regularly interspaced short palindromic repeats (CRISPR)-based genome editing systems, such as CRISPR/Cas9, CRISPR/Cpf1, base-editing system, and prime editing system, have brought promise for genetic improvement programs of crop plants, including sesame.

Tissue culture is the cultivation of plant cells, tissues or organs in artificial medium. An entire plant might regrow from a single cell under the appropriate conditions. Explants are the plant parts that are employed in plant tissue culture. The first in vitro multiplication and regeneration of sesame using tissue culture were reported by George *et al.* (1987 and 1989). Asad *et al.* (2020) have performed *in vitro* shoots multiplication from sesame nodal explants.

A DNA fragment from a donor cell or organism is isolated and inserted into the DNA of another cell or organism using recombinant DNA technology. In order to confer desired features, researchers can use this to introduce a new gene into an organism. Yadav *et al.* (2010) also reported that Agrobacterium tumefaciens-mediated genetic transformation of sesame has occurred. It is also a method of sesame improvement; it occurs when a DNA gene is changed or damaged in such a way as to alter the genetic message carried by that gene. Occasionally, through mutation, superior traits spontaneously arise. However, the rate of spontaneous mutation is extremely slow. Researchers found that by exposing plants to radiation such as X-rays and gamma rays as well as chemicals that cause mutations, such as sodium azide and ethyl methane sulphonate, colchicine, they could significantly increase the frequency of these changes. In sesame, mutation breeding is very successful efforts around the world today. Conventional methods of breeding with induced mutation followed by genotype screening for desirable traits become crucial proved by Wongyai *et al.* (2001); Uzun *et al.* (2009), Begum and Dasgupta (2011) and Boureima *et al.* (2012).

Huge genomic resources have been developed in the "Omics" era with the completion of the nuclear and chloroplast genome sequencing as well as the publication of diverse transcriptome data (Dossa *et al.,* 2017). Genome sequencing of sesame has begun recently by Sesame Genome Working Group (SGWG) in China (Zhang *et al.,* 2013) using a Chinese domestic cultivar Yuzhi 11. Yi and Kim (2012) evaluated the complete chloroplast genome of S. indicum by using GS-FLX pyro sequencing method. Wang *et al.* (2014) reported a high-quality genome sequence from an elite Chinese cultivar Zhongzhi13 using the Illumina Hiseq 2000 platform. Vaja and Golakiya (2016) analysed Whole Genome Sequencing (WGS) of GT-10 cultivar of sesame by using SOLiD 5500xl genome analyzer and Ion torrent sequencing system to generate sesame draft genome. The Indian cultivar "Swetha" had its genome sequenced by an Indian team from the NBPGR.

Exploitation of modern techniques for sesame improvement

For economically significant agricultural crops, such as cereal, oilseeds, vegetables, and ornamental plants, the MAS programme has been a frequently used technique in commercial crop breeding and product development. Similar to this, marker-assisted sesame variety characterization for conservation and improvement has been tested (Woldesenbet *et al.,* 2015). An extremely low seed production (300-400 kg/ha) is caused by the wild characteristics of cultivated sesame, such as seed shattering, an indeterminate growth habit, and asynchronous capsule ripening. Uzun and Çagirgan (2009) reported the molecular studies and tagging of the dt gene regulating determinate growth habit, first time in sesame on the use of ISSR for linkage analysis. Four quantitative trait loci (QTLs) for seed coat colour were discovered by Zhang *et al.* (2013). These QTLs were QTL1-1, QTL11-1, QTL11-2, and QTL13-1, dispersed among three linkage groups (LG 1, LG 11, and LG 13), with heritability ranging from 59.33% to 69.89%. A total of 24 markers for protein and 19 markers for oil content were published by Li *et al.* (2014), and 19 markers were linked to both features. According to an allele effect study, the allele linked to a high oil content was always linked to a low protein content and vice versa. The newly SSR-based genetic map and fourteen quantitative trait loci (QTL) for sesame charcoal rot disease resistance were detected by Wang *et al.* (2017). Sovetgul *et al.* (2020) detected four QTLs on Chr10. The gene with a strong link between the phenotype variation of Phytophthora disease resistance and gene expression levels is represented by the blue bar. A total of 44 SNPs on Chr10 were also found to be associated with Phytophthora blight. Sesame crop has major destruction with number of diseases like Phyllody, fusarium wilt, root and stem rot. Phyllody is one of the major diseases for sesame crop caused by phytoplasma, which causes economic damages. Few tolerant types have been reported by, Argane and T-85 from Ethiopia (Taye *et al.,* 2019), NS 98002-04, NS98003-04, NS99005-01 and NS01004-04 from Pakistan (Akhtar *et al.,* 2013).

Recently, Gar *et al.* (2020) discovered QTLs for shattering resistance capsules. Which protect the capsule from shattering and hence reduce grain loss.

Table 1 Area, Production and yield of sesame in selected countries

Countries	Area (‘000 ha)	Yield (kg/ha)	Production (‘000 MT/ha)	Percentage of world production
India	1730	431	746	12.40
China	311	1393	433	7.20
Myanmar	1463	525	769	12.78
Sudan	3480	282	981	9.33
Tanzania	800	701	561	14.56
South Sudan	618	334	207	3.43
Nigeria	539	1063	573	9.52
Ethiopia	415	726	301	5.01
Uganda	210	667	140	2.33

Source: Food and Agriculture Organization Statistical Databases (FAOSTAT, 2020)

Table 2 List of Sesame varieties their Centre of origin, year of release and parentage in India

Name of genotypes	Centre of origin	Year of release	Parentage
Varieties developed by selection method			
Savitri	West Bengal (PORS)	2008	Selection from germplasm SWB32
Rama	West Bengal (PORS)	1989	Selection from 'Khosla' local
Tilottama	West Bengal (PORS)	1984	Selection from local germplasm Jinardi Ducca2
GT-10	ARS, GAU, (Gujarat)	2002	Selection from TNAU17
SWB-32-10-1	Behrampur	2008	Selection from SWB-32
TMV-6	TNAU, Coimbatore	1978	Selection from local material of AP
TMV-4	TNAU, Coimbatore	1984	Selection from variety Sattur
VRI(SV)-1	TNAU, Coimbatore	1997	Pureline selection from Thirukattupalli
AMRIT	OUAT, Bhubaneshwar	2007	Selection from XU-2 X Krishna
TSS-6	TNAU, Coimbatore (TN)	1990	Selection from Rajapalayam
VRI(Sv)-1			Thirukattupalli
T-12	CSAUAT, Kanpur, UP	1962	Selection
T-13	CSAUAT, Kanpur, UP	1967	Selection
C-50	ARS, SKRAU, Rajasthan	1967	Selection
RT-46	ARS, SKRAU, Rajasthan	1989	T-12 x Punjab Til-1
T-85	OUAT, Bhubaneshwar	1962	Selection from Kopergoan5-9
Vinayak (Sel-14)	OUAT, Bhubaneshwar	1971	Selection from Mathasahi local
Purva-1	GAU, Junagadh (Gujarat)	1969	Selection from local
GT-1	RAS, GAU, Amreli, (Gujarat)	1978	Selection from MT-67-52
GT-10	RAS, GAU, Amreli, (Gujarat)	2002	Selection from TNAU-1
N-32	JNKVV, Jabalpur, MP	1969	Selection from Local Chattarpur Dist.
JT-7	JNKVV, Jabalpur, MP	1978	Selection fromNP-6x Punjab Til
Jawahar Til-11	ZARS, Powarkheda (MP)	2006	Bichua local
Jawahar Til-12	ZARS, Powarkheda (MP)	2010	Mohgaon-local 2
N-8	Dr. PDKV, Nagpur	1983	Selection from local Bori Til
Tilottama (B-67)	Govt. of WB, Berhampur (WB)	1981	Selection from Jinardi Ducca-2
Savitri (SWB-32-10-1)	Govt. of WB, Berhampur (WB)	2008	Selection from SWB-32
HT-1	CCSHAU, Hisar, Haryana	1977	Selection from NP-6
Gouri	RARS, ANGRAU, Jagtial (AP)	1977	Selection from local germplasm
Rajeshwari	RARS, ANGRAU, Jagtial (AP)	1987	Selection from N-62-39
E-8	UAS, Dharwad (Karnatka)	1987	Selection from Northern Karnataka
DS-1	UAS, Dharwad (Karnatka	1996	Gulbarga local x JT-68-135
Punjab TIl-1	RRS, PAU, Gurdaspur	1965	Selection from local
Kayamkulam-1	RRS, KAU, Kayamkulam, Kerala	1972	Selection from local
Soma	RRS, KAU, Kayamkulam, Kerala	1984	Selection from Type-38
Surya	RRS, KAU, Kayamkulam, Kerala	1985	Selection from Type-42-1
Thilak	RRS, KAU, Kayamkulam, Kerala	1993	Selection from North Kerala,
Sabour Til-1	BAU, Sabour	2023	Selection from Bihar
Varieties developed by hybridization			
CUHY-57 (Pragnya)	West Bengal (CU)	identified by CVRC, 2018	Uma x TKG 352
JLT 408	Maharashtra	2010	Padma x Yuzhi-8
RT-351	Mandore, Rajasthan	2010	NIC 8409 x RT 127
TKG22	JNKVV, Tikamgarh, MP	1995	HT6 x JLT3

Table 2 (contd...)

Name of genotypes	Centre of origin	Year of release	Parentage
RT-54	ARS, SKRAU	1992	A6-5 x BS 6-1
Gujarat TIL-2	ARS, GAU (Gujarat)	1995	Gujarat Til-1 x TC-25
TMV-7		2009	Si250 x Es22
VRI-2	RRS, Virdhachalam, TNAU	2005	Vs-9003x TMV-6
VRI-3	RRS, Virdhachalam, TNAU	2018	SVPR 1x TKG 87
T-4	CSAUAT, Kanpur, UP	1959	T-10 x T-3
T-78	CSAUAT, Kanpur, UP	1993	NP-6 x T-4
Sekhar	CSAUAT, Kanpur, UP	2001	T-4 X T-12
Pragati	CSAUAT, Kanpur, UP	2002	JLT-26x RT-127
RT-54	ARS, SKRAU, Rajasthan	1991	A 6-5x BS 6-1
RT-103	ARS, SKRAU, Rajasthan	1993	C- 7 X A6-5
RT-125	ARS, SKRAU, Rajasthan	1993	Type-13x RT-1
RT-127	ARS, SKRAU, Rajasthan	2000	SI- 3500 x Patan-64
RT-346	ARS, SKRAU, Rajasthan	2008	RT-127 x HT-24
RT-351	ARS, SKRAU, Rajasthan	2010	NIC8409 x RT-127
Kanak`(BS6-1)	OUAT, Bhubaneswar	1978	Vinayak x T-4
Subhra	OUAT, Bhubaneshwar	2012	TKG22x Uma
Smarak	OUAT, Bhubaneshwar	2012	Ajit-131x TKG-22
GT-2	ARS, GAU, Amreli (Gujarat)	1994	G.Til x TC-25
GT-3	ARS, GAU, Amreli (Gujarat)	2006	GT-1 x AHT-85
GT-4	ARS, GAU, Amreli (Gujarat)	2010	GT-1x RT -125
GJT-5	ARS, GAU, Amreli (Gujarat)	2015	AT-90 x AT-104
G Til-6	ARS, GAU, Amreli (Gujarat)	2018	AT-117 x GT-2
JT-21(TKG-21)	ZARS, JNKVV, Tikamgarh (MP)	1992	Punjab Til-1x TC-25
TKG-22	ZARS, JNKVV, Tikamgarh (MP)	1994	HT-6X JLT-3
TKG-55	ZARS, JNKVV, Tikamgarh (MP)	1998	TC-25x TNAU-10
JTS-8	ZARS, JNKVV, Tikamgarh (MP)	2000	OMT-10 x TC-289
TKG-306	ZARS, JNKVV, Tikamgarh (MP)	2004	CST-785 x TKG-22
TKG 308	ZARS, JNKVV, Tikamgarh (MP)	2008	JLT-26 x JLT-7
Jawahar Til-14	ZARS, Powarkheda (MP)	2010	JLCS-58 x RT-288
Phule Til-1	ORS, MPKV, Jalgaon	1978	D-7-11x N-58-2
Tapi (JLT-7)	ORS, MPKV, Jalgaon	1987	N-58-2x C-50
Padma (JLT-26)	ORS, MPKV, Jalgaon	1990	Phule Til-1x N32
AKT-64	Dr. PDKV, Nagpur	1996	N-128 x C-50
AKT-101	Dr. PDKV, Nagpur	2001	N-62-10x R-19
PKV-NT-11	Dr. PDKV, Nagpur	2009	JLT-9x LT-4
JLT-408(JLS-9848-2)	ORS, MPKV, Jalgaon	2012	Padma x Yuzhi-8
HT-9713 HT-2)	CCSHAU, Hisar	2008	HT-1 x HT-15
YLM-11 (Varaha	ARS, ANGRAU, Yellamanchilli	1992	Vinayakx Kanak
YLM-17(Gautama)	ARS, ANGRAU, Yellamanchilli	1992	Vinayak x Kanak
Swetha Til	RARS, ANGRAU, Yellamanchilli	1996	E-8x IS-113
Hima (JCS-9426)	RARS, ANGRAU, Yellamanchilli	1998	No. 5039x AT-
Chandana (JCS-94)	RARS, ANGRAU, Yellamanchilli	2002	T-85x L-5107
DS-5	UAS, Dharwad	2012	OSC-906 x AT-124
TC-25	RRS, PAU, Ludhiana	1977	EC-7x TS-24-1

Table 2 (contd...)

Name of genotypes	Centre of origin	Year of release	Parentage
TC-289	RRS, PAU, Ludhiana	1985	Punjab Til-1x EC-4619
Punjab Ti No. -2	PAU, Ludhiana (Punjab)	2008	MT-32x RT-54
Thilothama	RRS, KAU, Kayakulam (Kerala)	1981	PT-58-35x Kayamkulam-1
Thilathara	RRS, KAU, Kayamkulam, Kerala	1997	CsT-785xB-4
Thilarani	RRS, KAU, Kayamkulam, Kerala	2002	Thilakx Kayakulam-1
Krishna	RAU, Dholi, Bihar	1985	M-3-2x Venezuela-17/4
Tilhan Tec ICH-6	IIOR, Hyderabad	2023	N-32 X IC-205312
Varieties developed by mutation			
Suprava (CUMS17)	West Bengal (CU)	Notified by CVRC ,2019	mutant of IC 625735
Prachi	Odisha (OUAT)	2004	Mutant of B67
Nirmala	OUAT, Odisha	2003	Mutant of B-67
UMA	OUAT, Bhubaneshwar	1999	Mutant of Kanak
DSS-9	UAS, Dharwad	_	Mutant of Phule Til-1 x E-8
Kalika	OUAT, Bhubaneshwar	1978	Mutant of Vinayak (EMS-0.1%)
Usha	OUAT, Bhubaneshwar	1989	Mutant of Kanak (Arsenic 10%)
UMA	OUAT, Bhubaneshwar	1989	Mutant of Kanak
Prachi	OUAT, Bhubaneshwar	2002	Mutant of Tilotamma
Nirmala	OUAT, Bhubaneshwar	2002	Mutant of Tilotamma
Suprava	IAS, University of Calcutta, WB	2017	Mutant of IC-21706
DSS-9	UAS, Dharwad (Karnatka)	2009	Mutant of Phule Til-1x E-8

Source: IIOR, Rajendranagar, Hyderabad & PC (Sesame & Niger) Unit, Jabalpur, Madhya Pradesh

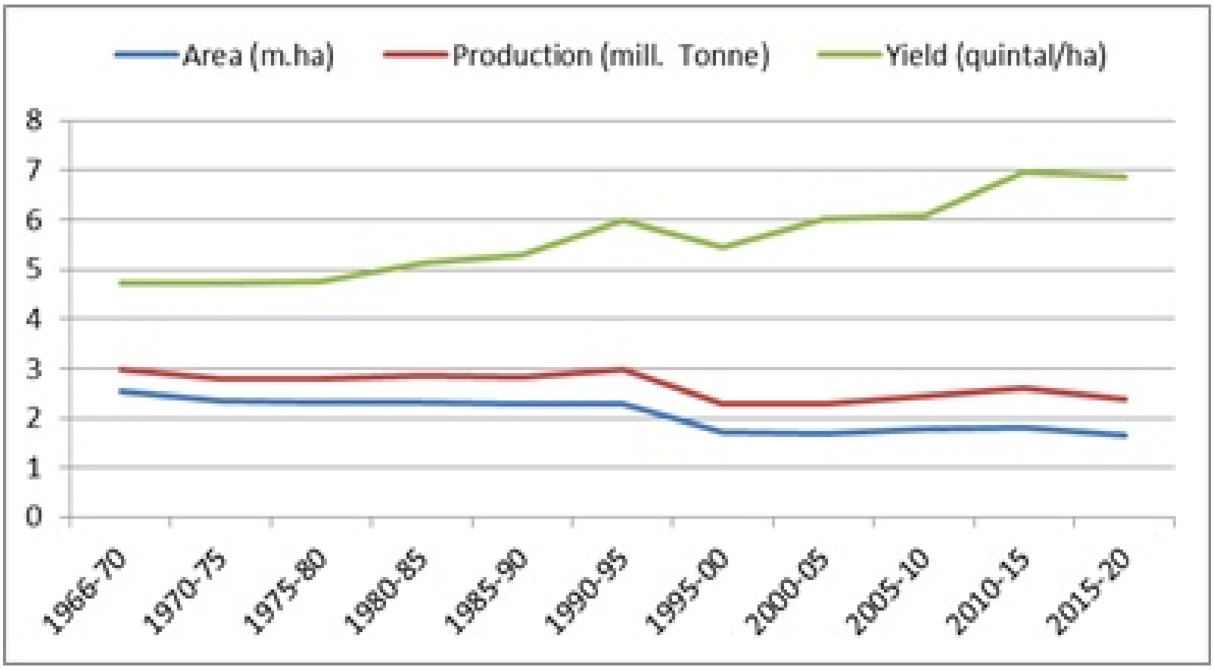

Fig. 1. All India Area Production and Yield of Sesamum (Year on X axis)

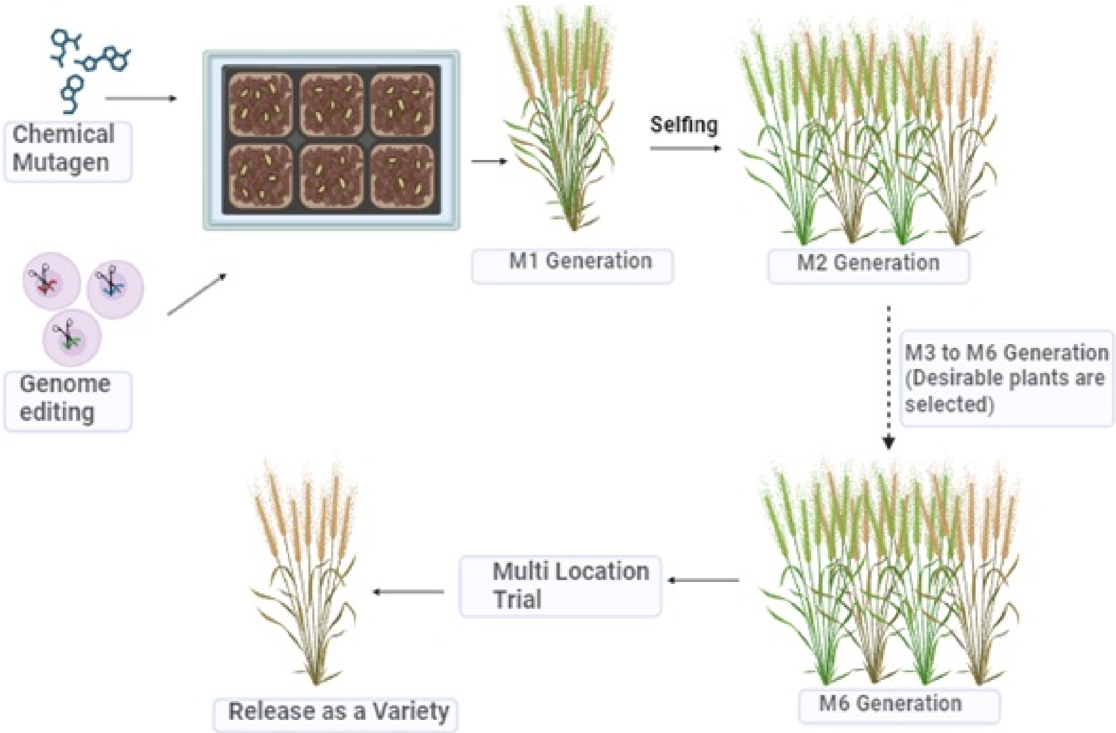

Fig. 2. Release of desirable variety with mutation and genome editing

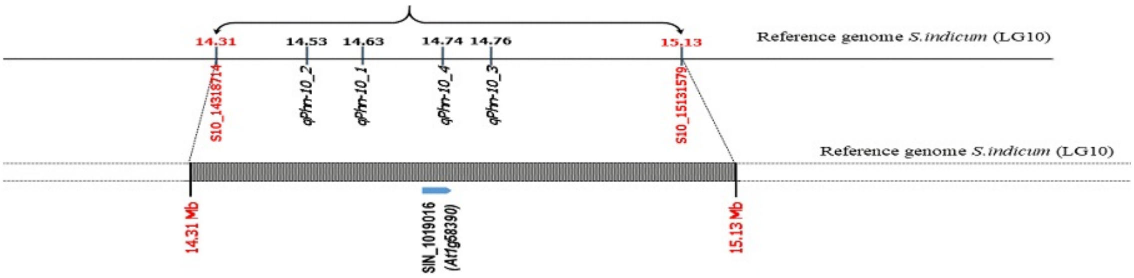

Fig. 3. QTL for phytophthora disease resistance

Fig. 4. QTL for shattering resistance capsules

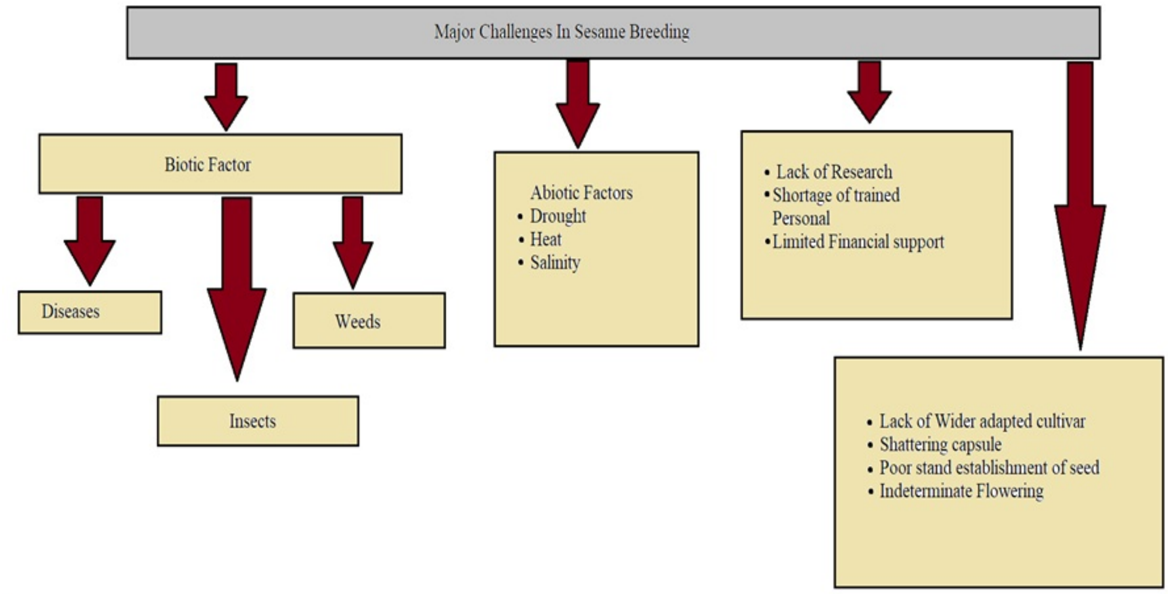

Fig. 5. Major constraints in sesame production

Major challenges in sesame breeding

Sesame is very important since it can endure harsh climatic situations that other crops cannot (MoAR *et al.,* 2015). The average sesame yield in India is relatively low. Other than this, the main causes of decreased sesame yields, including an indeterminate flowering habit, mature capsules shattering, various pests, heat, and drought, have been identified as the main difficulties for sesame improvement. No any of Consultative Group on International Agricultural Research (CGIAR) centers (Daniel, 2017) is dealing on this crop.

Major opportunities of sesame breeding in India

Going with conventional and molecular breeding approach can helps in increasing the crop production. Conventional approach should run parallel with molecular approach for sesame enhancement. QTL mapping on different characters can be helpful in the construction of markers, which help in early generation selection of desirable crop. Confirming different genes, its expression and its location can give a lot of opportunities like gene editing, development of gene-based markers etc. which helps a breeder to find those varieties which can solve the problems related to sesame production. Mutation breeding also helpful in creation of variability which can be utilized by conventional breeding.

There are intense challenges in sesame production. Challenges are driving force which motivates breeder to develop new cultivars and improved technology. It can be executed by broadening the genetic base of breeding material. It's time to start incorporating information from other sources, such as promising genetic material and wild resources, in order to increase a certain yield component's tolerance to different stresses. Sesame enhancement has generally concentrated on traditional breeding strategies, including germplasm characterization, selection, and variety recommendation. More significantly, a number of molecular markers, QTLs, and functional genes linked to these traits are currently accessible and can be used in sesame breeding initiatives. There is need to develop new-generation, climate-smart, abiotic and biotic stress-resistant, capsule shattering-resistant sesame varieties that meet the quality requirements of the local and international markets. Therefore, current and future sesame genetic improvement programs should integrate yield- and quality-promoting traits, local adaptation, machine harvesting, and other industrially essential attributes for multiple utilities. This can be achieved by integrating the conventional and mutation breeding methods and genomic techniques such as molecular breeding, genomic-assisted breeding, and genome editing. Long term planning in plant breeding program must have some extended goal and it must start from (i) Germplasm collection including landraces, wild plants and evaluation under multiple environments to identify potentiality of accessions. (ii) Crossing program between diverse parents (iii) Attempt must be done for marker assisted selection. The trait with the greatest potential to both boost sesame yield and make it suitable for mechanical harvesting is one that decreases seed shattering. Sesame is typically grown under rain fed conditions with severe environmental changes, whether in developed or underdeveloped countries. Drought is frequently the most significant factor decreasing yields under these situations. So, it is necessary to create sesame varieties that can withstand drought. Sesame has a low harvest index, or the proportion of energy consumed to create the seeds out of all the above-ground biomass, when compared to other crops. The harvest index can be raised by improvements in photosynthesis efficiency, the quantity of photosynthetic products directed at seeds, and light reception.

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Review

Biology and management strategies of sesame pests: A comprehensive review

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ABSTRACT

Sesame (*Sesamum indicum* L.), a historical oilseed crop cultivated for over 3,000 years, thrives primarily in tropical and subtropical regions of Asia, Africa, and South America. Renowned for its high-quality oil and diverse nutritional content, sesame is deeply rooted in agricultural traditions, especially in India. Despite its significant economic value, sesame cultivation faces considerable challenges, particularly from insect pests, which can severely impact both yield and quality. This review examines the key insect pests affecting sesame, including the sesame webworm or leaf webber/roller and capsule borer (*Antigastra catalaunalis*), leaf hopper (*Orosius albicinctus*), mirid bug (*Crytopeltis tenuis*), whitefly (*Bemisia tabaci*), hawk moth (*Acherontia styx*), Bihar hairy caterpillar (*Spilosoma obliqua*), and sesame gall fly (*Asphondylia sesami*). Each pest's biology, damage symptoms, and management strategies are discussed, highlighting the necessity of integrated pest management (IPM) approaches. Effective management includes cultural, biological, and chemical methods, with an emphasis on eco-friendly practices such as the use of neem and castor extracts. The review underscores the critical need for tailored pest management strategies to mitigate the impact of these pests and ensure sustainable sesame production, considering the evolving pest dynamics driven by climatic changes.

Keywords: Eco-friendly pest management, Insect pests, Integrated pest management, *Sesamum indicum*

Sesame (*Sesamum indicum* L.) is a time-honored oilseed crop, cultivated for over 3,000 years. It is usually cultivated in tropical and subtropical regions of Asia, Africa and South America (Anil *et al.,* 2010). In India, sesame is deeply rooted in agricultural traditions, known for its high-quality oil. It is grown mainly for its seeds which contain approximately 50% oil, 25% protein and 25% other nutrients like calcium, iron, magnesium, phosphorus fibre etc. (Panday *et al.,* 2021; Prathyusha *et al.,* 2023). Sesame is called the "Queen of Oilseed" crop because of its excellent qualities of seed, oil and meal (Dossa and Dossa, 2017). In India, at present sesame occupies an area of about 15.23 lakh ha with an annual production of 8.02 lakh tones and average productivity of 527 kg/ha (Directorate of Economics and Statistics, New Delhi (2022-23). Sesame seed is used for a wide array of edible products in a raw or roasted form and also for industrial uses such as soaps, lubricants, an ingredient in cosmetics; pharmaceutical uses and animal feed (Bedigian *et al.,* 2010). Globally, sesame holds a prominent position, with countries like India, Sudan, Myanmar, China, and Tanzania being major producers. Tanzania has notably emerged as a leading producer, surpassing India in sesame seed production. The nutritional richness of sesame seeds is well-recognized, with lignans found in sesame seeds exhibiting remarkable antioxidant effects on the human body. Sesame oil is particularly valued for its heart-healthy properties, being considered cholesterol-free and beneficial for heart ailments (NCBI). India, with its vast sesame cultivation area, faces challenges in productivity due to rainfed cultivation in marginal lands under poor management conditions. However, advancements in improved varieties and agricultural technologies are enhancing productivity levels, with well-managed sesame crops capable of yielding significantly under both irrigated and rainfed conditions. It is grown in rainfed as well as irrigated land. In Indian condition the sesame growing season are given in table.

One of the major constraints in sesame production is the immense damage by insect pests leading to the deterioration of both quality and quantity (Bhura *et al.,* 2020; Boopathi *et al.,* 2023). The management of insect pests in sesame cultivation in Africa, has garnered significant attention due to its impact on crop productivity investigating the effectiveness of bio-pesticide formulations in controlling dominant insect pests in sesame fields. The study found that strategically applying plant materials under varying climatic conditions can suppress key pests and enhance sesame yields (Ahmed *et al.,* 2014; Dilipsundar. 2019). A comprehensive review of the major insect pests affecting sesame production, focusing on their biology, damage characteristics, and management strategies (Desawi and

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Desawi, 2021) are discussed below. A total 67 insect pests have been recorded to damage the sesame crop from germination to maturity (Panday *et al.,* 2021). The important insect species attacking to sesame crop *viz.,* sesame webworm, *Antigastra catalaunalis* (Dup.), leaf hopper, *Orosius albicinctus* (Distant), whitefly, *Bemisia tabaci* (Genn.); Mirid bug, *Crytopeltis tenuis* (Reuter); hawk moth, *Acherontia styx* (Westwood); Bihar hairy caterpillar, *Spilosoma obliqua* (Wlk.), and sesame gall fly, *Asphondylia sesami* (Felt.) (Alok *et al.,* 2024). Climate change transforms sesame-insect dynamics. Mirid bugs, once insignificant, gain prominence due to intensified cultivation in diverse seasons (Mishra *et al.,* 2015). A study reported the increasing incidence of mirid bugs in sesame fields, causing substantial yield losses (Patel *et al.,* 2019). Incidence of mirid bugs are very prominent now a days in sesame, *Crytopeltis tenuis* is one of the most common species of mirid bug seen in sesame (Bhura *et al.,* 2020). The comprehensive review of pest management in Ethiopia, mentioned the economic importance of sesame pests, including species like sesame webworms, seed bugs, gall flies, and meal moths (Desawi and Desawi, 2021). The need for improved pest management strategies to mitigate the impact of these pests on sesame production and ensure sustainable crop yields is crucial. A study identified the mirid bug species *Crytopeltis tenuis* as a common pest affecting sesame crops in Egypt. *N. tenuis* feeds on sesame leaves, stems, and capsules, causing significant damage and yield losses. By incorporating the mirid bug, particularly *C. tenuis,* into the list of major sesame pests, researchers and practitioners can develop more comprehensive pest management strategies that address both traditional and emerging threats to sesame cultivation (Shalaby *et al.,* 2020). In the realm of sesame cultivation, a diverse array of insect pests poses significant challenges to crop health and yield. Among the key insect pests affecting sesame production, the sesame webworm (*Antigastra catalaunalis*) stands out as a major threat, causing substantial economic losses. The severe incidence of *A. catalaunalis* on sesame crops, with late-sown varieties particularly vulnerable to infestations (Gupta *et al.,* 2002). The impact of *A. catalaunalis* is most pronounced during the vegetative phase of sesame growth, leading to yield reductions ranging from 10% to 20% during this critical stage (Chaudhry *et al.,* 1989). Additionally, the presence of sucking insect pests like *Orosius albicinctus, Nesidiocoris tenuis,* and *Bemisia tabaci* further exacerbates the damage by feeding on plant sap, resulting in leaf curling, stunted growth, and reduced yields (Mishra *et al.,* 2015). Moreover, the mirid bug, specifically *Crytopeltis tenuis* (*Nesidiocoris tenuis*), has emerged as a significant pest of sesame, causing notable damage to the crop. The regular occurrence of mirid bugs in sesame fields, highlighting their detrimental impact on crop productivity (Ahirwar *et al.,* 2009). The mirid bug's feeding habits, which include sucking cell sap from leaves, flowers, and pods, contribute to growth stunting and yield reduction in sesame plants. The seasonal incidence of major insect pests, including mirid bugs, whiteflies, aphids, and stink bugs, underscores the importance of implementing effective pest management strategies to mitigate losses and ensure sustainable sesame cultivation practices (Mishra *et al.,* 2015). Understanding the dynamics of these key insect pests, including the mirid bug, is crucial for developing targeted control measures that can safeguard sesame crops and optimize yields in the face of evolving pest pressures.

Biology, Damage symptom and Management of Insect pests of sesame

Leaf webber/roller and capsule borer/Sesame webworm, *Antigastra catalaunalis* (Crambidae: Lepidoptera): The sesame webworm, *Antigastra catalaunalis,* is a key pest of sesame, causing significant damage and yield losses. Studies have shown that *A. catalaunalis* can lead to yield reductions ranging from 10% to 20% during the vegetative phase of sesame growth (Suliman *et al.,* 2013). The total life cycle of *A. catalaunalis* occupies around 26.5 ± 7.78 days under laboratory conditions. The eggs of A. catalaunalis are small, measuring 0.32 ± 0.02 mm in length and 0.12 ± 0.02 mm in breadth. The incubation period of eggs ranges from 2 to 3 days, with a mean of 2.38 ± 0.54 days (Chaitra *et al.,* 2020). Upon hatching, the larvae feed on tender foliage by webbing the top leaves and later bore into the pods and shoots. The larval period lasts for 10.2 ± 1.05 days, with the larvae completing five instars. Pupation occurs both inside the webbed leaves and in the soil.

A. catalaunalis larvae causes severe damage to sesame plants, feed concealed within leaves and capsules, leading to reduced yields. The infestation can occur from the seedling stage to maturity, with the attack being more severe during dry seasons and after the initiation of flowering. To manage *A. catalaunalis* effectively, a combination of eco-friendly approaches can be employed. Studies have shown that aqueous extracts of neem (*Azadirachta indica*) and castor (*Ricinus communis*) are effective in controlling webworm development and reducing sesame damage (Araya *et al.,* 2023). These extracts possess antifeeding properties and toxicants that act against the target insect pest. Applying these extracts to coincide with the growth of new leaves, flowers, and capsules can help minimize damage to the crop. *Bracon* sp. (Hymenoptera: Braconidae), a gregarious, ecto-larval parasitoid that can be used as a biological control agent to manage the sesame webworm (Kumar *et al.,* 2019). Integrating the use of these locally available, inexpensive and environmentally friendly extracts with other management strategies can help control sesame webworms effectively and ensure sustainable sesame production.

Leaf hopper, *Orosius albicinctus* (Cicadellidae: Hemiptera): Leaf hopper, Orosius albicinctus, is a significant pest of sesame crops, causing substantial damage and yield losses. The biology and life cycle of *O. albicinctus* involves a complex process of reproduction, with both winged and wingless forms of adults and a great variety in colour (Zemedkun *et al.,* 2022). The larvae feed on the plant sap, causing the development of tubular galls on the leaves and stems of sesame plants. The total life cycle is completed in 23-27 days (Gebregergis *et al.,* 2018). Damage symptoms caused by *O. albicinctus* include reduced yields, seed quality, and germination rates. The pest can also transmit plant viruses, causing significant economic losses. Yield losses due to *O. albicinctus* infestation can range from 10% to 20% during the vegetative phase of sesame growth (Lekamoi *et al.,* 2022).

Management strategies for *O. albicinctus* include cultural control methods such as crop rotation, intercropping, and proper plant density management. Biological control methods involve the use of natural enemies like predators and parasitoids to suppress pest populations, *Cycloneda sanguinea* (Coleoptera: Coccinellidae) is a predator that can be used to manage leafhoppers. Chemical control methods include the use of insecticides to manage pest populations (Singh *et al.,* 2018). However, the overuse of synthetic pesticides can lead to environmental pollution, health hazards, and the development of insecticide resistance in pests (Zemedkun *et al.,* 2022).

Mirid bug, *Crytopeltis tenuis* (Miridae: Hemiptera): The mirid bug, *Crytopeltis tenuis* Reuter, is a significant pest of sesame crops, causing substantial damage and yield losses. The biology and life cycle of *C. tenuis* involves a complex process of reproduction, with both winged and wingless forms of adults and a great variety in colour (Sanchez, 2008). The larvae feed on tender foliage by sucking the cell sap from leaves, flowers, and fruits, and the average pupal period was 4.9±0.21 days. The total life cycle (L.C) was 21.26±0.64 days, with the egg period lasting for 2.45 days during summer and 7 days during winter. Damage symptoms caused by *C. tenuis* include leaf curling, stunted growth, and reduced yields. The pest can also transmit plant viruses, causing significant economic losses. Yield losses due to *C. tenuis* infestation can range from 10% to 20% during the vegetative phase of sesame growth (Kakati *et al.*, 2005).

Management strategies for *C. tenuis* in sesame include cultural control methods such as intercropping sesame with green gram, black gram, sorghum, pearl millet, cluster bean, and pigeon pea, which significantly reduced the damage caused by C. tenuis. Biological control methods involve releasing parasitoids and predators, such as *Trichoderma* spp., *Bracon brevicornis*, and *Campoplex* spp. *Coccinella septempunctata* (Coleoptera: Coccinellidae). A predator that can which can help manage mirid bug populations (Kumar *et al.,* 2017). Use of microbial pesticides, such as *Bacillus thuringiensis* var. kurstaki, which can provide effective control while being more environmentally friendly (Kakati *et al.,* 2005).

Whitefly *Bemisia tabaci* (Aleyrodidae: Hemiptera): The whitefly, *Bemisia tabaci,* is a significant pest of sesame crops, causing substantial damage and yield losses. The biology and life cycle of *B. tabaci,* the larvae feed on tender foliage by sucking the cell-sap from leaves, flowers, and fruits, and the average pupal period was 4.9±0.21 days. The total life cycle (L.C) was 21.26±0.64 days, with the egg period lasting for 2.45 days during summer and 7 days during winter. (Sanchez *et al.,* 2008). Damage symptoms caused by *B. tabaci* include leaf curling, stunted growth, and reduced yields. The pest can also transmit plant viruses, causing significant economic losses. Yield losses due to B. tabaci infestation can range from 10% to 20% during the vegetative phase of sesame growth. (Sylla *et al.,* 2016).

Management strategies for *B. tabaci* include the use of cultural control methods such as crop rotation, intercropping sesame with green gram, black gram, sorghum, pearl millet, cluster bean, and pigeon pea, which significantly reduced the damage caused by *B. tabaci.* Biological control methods involve releasing parasitoids and predators, such as *Trichoderma* spp., *Bracon brevicornis,* and *Campoplex* spp., which can help manage *B. tabaci* populations. *Encarsia formosa* is a parasitoid that can be used to manage whiteflies (Singh *et al.,* 2016). Chemical control methods include the use of microbial pesticides, such as *Bacillus thuringiensis* var. kurstaki, which can provide effective control while being more environmentally friendly.

The hawk moth, *Acherontia styx* (Sphingidae: Lepidoptera): The hawk moth, *Acherontia* styx, is a significant pest of sesame crops, causing substantial damage and yield losses. The biology and life cycle of *A. styx* involve a complex process of reproduction, with the total life cycle being completed in 50.95 ± 4.48 days. The longevity of the female and male moths was 13.5 ± 0.94 and 9.85 ± 0.93 days, respectively (Mishra *et al.,* 2015). Damage symptoms caused by *A. styx* include leaf webbing, which can lead to reduced yields and oil content. The larvae feed on tender foliage by webbing the top leaves, bores into the pods and shoots, and the average pupal period was 4.9±0.21 days. Yield losses due to *A. styx* infestation can range from 10% to 20% during the vegetative phase of sesame growth (Karuppaiah, 2014).

Management strategies for *A. styx* in sesame include cultural control methods such as intercropping sesame with green gram, black gram, sorghum, pearl millet, cluster bean, and pigeon pea, which significantly reduced the damage caused by *A. styx.* Biological control methods involve releasing parasitoids and predators, such as *Trichoderma* spp., *Bracon brevicornis,* and *Campoplex* spp., which can help manage *A. styx* populations (Kumar *et al.,* 2015). Chemical control methods include the use of microbial pesticides, such as *Bacillus thuringiensis* var. kurstaki, which can provide effective control while being more environmentally friendly. (Karuppaiah, 2014).

Table 1 Season for sesame growing in India

Season	Situation	Area (in %)	Name of states
Rainy (*kharif*)	Rainfed	70	Rajasthan , Uttar Pradesh, Madhya Pradesh, Gujarat, Andhra Pradesh, Maharashtra, Odissa, Tamil Nadu and Karnataka
Late *kharif*	Rainfed	10	Andra Pradesh, Gujarat, Madhya Pradesh, Maharashtra
Winter (*Rabi*)	Irrigated	Rare	Tamil Nadu, Andhra Pradesh and Odissa
Summer	Irrigated	20	West Bengal, Odissa, Gujarat, Andhra Pradesh,Tamil Nadu and Kerala
Pre *kharif*	Rainfed	10	Karnataka and Andhra Pradesh

Table 2 List of natural enemies in sesame ecosystem

Natural enemies	Taxonomic position	Host
Cremastus flavoorbitalis	Ichneumonidae: hymenoptera	Leaf webber
Bracon hebetor	Braconidae: Hymenoptera	Leaf webber larva, gall fly maggot
Brumus suturalis	Coccinellidae: Coleoptera	Leaf hopper
Eurytoma sp.	Eurytomidae: Hymenoptera	Sesame gall fly maggot
Trichogramma sp.	Trichogramatidae: Hymenoptera	Eggs of stynx caterpillar
Protapanteles obliquae	Brachonidae: Hymenoptera	Larva of bihar hairy caterpillar
Aphelinus asychis	Aphilinidae: Hymenoptera	Nymph and adult of sesame aphids

Bihar hairy caterpillar, *Spilosoma obliqua* (Arctiidae: Lepidoptera): The Bihar hairy caterpillar, *Spilosoma obliqua,* is a significant pest of sesame crops, causing substantial damage and yield losses. The biology and life cycle of *D. oblique* involve a complex process of reproduction, with both winged and wingless forms of adults and a great variety in colour. The total life cycle (L.C) was 21.26±0.64 days, with the egg period lasting for 2.45 days during summer and 7 days during winter (Ahirwar *et al.,* 2009). Damage symptoms caused by *D. obliqua* include leaf curling, stunted growth, and reduced yields. The pest can also transmit plant viruses, causing significant economic losses. Yield losses due to *D. obliqua* infestation can range from 10% to 20% during the vegetative phase of sesame growth (Ahirwar *et al.,* 2009).

Management strategies for *D. obliqua* in sesame include cultural control methods such as intercropping sesame with green gram, black gram, sorghum, pearl millet, cluster bean, and pigeon pea, which significantly reduced the damage caused by *D. obliqua.* Biological control methods involve releasing parasitoids and predators, such as *Trichoderma* spp., *Bracon brevicornis,* and *Campoplex* spp., which can help manage *D. obliqua* populations (Singh *et al.,* 2014). Use of microbial pesticides, such as *Bacillus thuringiensis* var. kurstaki, which can provide effective control while being more environmentally friendly (Sylla *et al.,* 2016).

Sesame gall fly, *Asphondylia sesami* (Cecidomyiidae: Diptera): The sesame gall fly, *Asphondylia sesami* Felt, is a significant pest of sesame crops, causing substantial damage and yield losses. The biology and life cycle of *A. sesame* involves a complex process of reproduction, with the total life cycle being completed in 23-27 days. The adult is a small mosquito-like fly that lays eggs in the flowers or buds. The egg period is 2-4 days. The maggot is white and found inside the flowers. The larval period is about 2-3 weeks. It pupates inside the malformed capsules, and the fly emerges from galls in 7-12 days (Ahirwar *et al.,* 2009). Damage symptoms caused by *A. sesame* include the malformation of pods without the proper setting of seeds. Flowers and young capsules develop gall-like swellings, which is the typical symptom of attack. The maggots feed on the ovary, resulting in the malformation of pods. Yield losses due to *A. sesame* infestation can become severe, as the pest could become a major issue due to sesame gall formation (Zemedkun *et al.,* 2021).

Management strategies for *A. sesame* in sesame include cultural control methods such as intercropping sesame with green gram, black gram, sorghum, pearl millet, cluster bean, and pigeon pea, which significantly reduced the damage caused by other pests. For biocontrol *Pseudacteon parasitoid* can be used to manage sesame gall flies (Kumar *et al.,* 2013). The list of biological agents (Table) are given in the following table 2. Use of microbial pesticides, such as *Bacillus thuringiensis* var. kurstaki, which can provide effective control while being more environmentally friendly (Eisa *et al*., 2017).

Effective pest management strategies are crucial for sustainable sesame cultivation. These strategies encompass cultural practices such as crop rotation and intercropping, biological controls like the use of natural predators and parasitoids, and the application of eco-friendly chemical controls, including microbial pesticides. The integration of these approaches can mitigate the impact of pests and enhance sesame yields. Understanding the biology, damage symptoms, and life cycles of these pests is essential for developing targeted control measures. Continued research and advancements in pest management techniques are vital to address the evolving challenges posed by climate change and intensified cultivation practices. By adopting comprehensive and sustainable pest management strategies, it is possible to ensure the long-term productivity and health of sesame crops, thereby supporting the livelihoods of farmers and meeting the global demand for this valuable oilseed.

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New high yielding sesame (*Sesamum indicum* L.) variety Phule Purna for Maharashtra

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ABSTRACT

Sesame is one of the important oilseeds crop requiring low inputs. The productivity of summer sesame is very low in Maharashtra state. The present improved varieties of sesame have lower yield potential and disease susceptibility. That is why need to develop high yielding varieties combined with early to mid-synchronous maturity, better quality and resistance to major pests and diseases. The new culture JLT-408-2 for summer season is advance generation selection from the cross JLT-26 x KMR 90 at Oilseeds Research Station, Jalgaon. It was tested over several locations and environments for its stability performance. The results indicated a significant improvement in yield level under field conditions. On an average performance of 55 station, multilocation, coordinated and adaptive trials conducted during 2014 to 2020.The new culture Phule Purna recorded 752 kg/ha yield as against the check JLT-408 (581 kg/ha), TKG-22 (622 kg/ha), AKT-101 (635 kg/ha), PT-1 (636 kg/ha) and GT-10 (673 kg/ha) which was higher by 22%, 14%, 12%,11.94 and 3.71 per cent increase over, respectively. This new culture is white bold seeded and also found superior in quality *viz.,* oil content (Av. 49.02%) as compare to PT-1 (47.58%), JLT-408 (45.16%), (GT-10 (44.82%) and AKT-101 (44.58%). FFA%: 0.81% as compare to PT-1 (2.80%), JLT-408 (1.60%) and AKT-101 (1.10%). Iodine Value: 106.8 as compare to PT-1 (108%), JLT-408 (107%) and AKT-101 (106.8%).

Keywords: Multilocation trials, Phule Purna, Sesame, Yield

Sesame (*Sesamum indicum* L.) is an important oilseed crop in the tropics and subtropics belongs to the family Pedaliaceae. It is the oldest indigenous oil plant with longest history of its cultivation in India. India is the world leader in the area and production of sesame. Presently, sesame ranks 5th in area (18 lakh ha) and 6th in production (6.5 lakh tons) among the nine oilseeds grown countries of the World (Agricultural Statistics at a Glance. 2019). India is world leader not only in area and production but also in export of sesame. In recent years sesame export showed an increasing trend in global market. India's share in the world trade of sesame export has gone up to 40 per cent. The lustrous white coloured, uniform and bold size seed of sweet taste with low in free fatty acid (<2%) and lignin content (>830mg/100gm. seed) are preferred as these earn a premium in international market. Sesame seeds having approximately 50% oil and 25% protein and contains about 47% oleic and 39% linoleic acid. Sesame has remarkable antioxidant function due to the presence of lignins and tocopherol. The oil with 85% unsaturated fatty acids is highly stable and has reducing effect on cholesterol and prevents coronary heart diseases. Sesame is called as the 'Queen of oils' (Prathyusha *et al.,* 2023). The oil content of sesame is higher than soybean and mustard. To make the country self-sufficient in edible oil, it is imperative to increase the production of oilseeds by increasing productivity.

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In Maharashtra sesame is cultivated over an area of 0.199 lakh ha with production of 0.398 lakh tones and productivity of 201 kg/ha (2018-19). In Jalgaon, it is mainly grown in on an area of 1170 hectares with production 320 tones and average productivity 275 kg/ha (2018-19). In Maharashtra State; Jalgaon, Beed, Dhule, Nandurbar, Aurangabad, Latur, Osmanabad, Nanded, Buldhana and Akola are the major *kharif* sesame growing Districts.

In northern parts of Maharashtra (Khandesh and adjoining areas) of assured rainfall Zone, generally early to medium maturing varieties (75-85 days) are cultivated, whereas, in southern parts of same Zone (Nanded, Osmanabad and Latur), the varieties maturing in 85-90 days are cultivated. In western parts of plain zones (Nashik and Pune), the varieties maturing in 90-100 days are cultivated. In central and western Vidarbha Zone, the varieties maturing in 90- 95 days are cultivated.

The low productivity in the Maharashtra can be attributed to the fact that sesame is grown under rainfed conditions which is characterized by erratic rainfall, growing of early local varieties having low yield potential and susceptibility to major pest and diseases (Boopathi *et al.,* 2023; Sangeetha *et al.,* 2024). Therefore, there is a need to develop high yielding variety combined with early to mid-late synchronous maturity, better quality and resistance to major pest and diseases. With this object in view, hybridization programme was undertaken at the Oilseeds Research Station, Jalgaon under Mahatma Phule Krishi Vidyapeeth, Rahuri. A cross between diverse parents viz;

JLT-26 and KMR 90 resulted in isolation of promising culture Phule JLT-408-2 (Phule Purna). The culture Phule JLT-408-2 was entered in the sesame regional varietal trial during 2013 and State Multilocation varietal trial during 2014 to 2020.

MATERIALS AND METHODS

The sesame promising var. Phule Purna (JLT-408-2) was developed by pedigree selection method from a cross between JLT-26 X KMR 90 at Oilseeds Research Station, Mahatma Phule Krishi Vidyapeeth, Jalgaon. This selected genotype has been screened for higher yield with pest and disease resistance in F_1 to F_5 generations. The genotype was studied for its yield and ancillary characteristics in station trials, multi-location, AICRP trials and Adaptive trials during 2013 to 2020 in summer seasons (Table 1 to 7). It was tested for several locations and environments for its stability performance. The variety was evaluated in a randomized block design with 3 replications in university, state trials and in AICRP trials with checks. The variety Phule Purna and existing released varieties were evaluated for their yield performance under field conditions. At maturity, yield and yield attributing characteristics were recorded. The statistical analysis was carried out according to Panse and Sukhatme (1985). The candidate variety was evaluated for its reaction to major diseases under endemic conditions during 2017 to 2019 summer seasons.

CROP MANAGEMENT

Right after sowing, the experimental plots were taken care regularly at every growth stage interval until pods matured. Weeding was done manually. Plant protection measures were applied as and when required. The various morphological observations were recorded at proper stage till harvest.

Table 1 Location wise yield performance of proposed varietyJLT-408-2 Co coordinated Trials in Zone-I (*Rabi*/summer 2013 to 2017)

IVTS-(2013-14) Zone I						
Location	JLS-408-2	TKG-22	GT-10	SE±	CD	CV
Bangalore	451	525	523	6.36	18.14	12.29
Jagtial	743	640	1003	72.10	25.50	16.60
Mandya	640	611	299	25.77	75.58	6.72
Nagpur	1130	829	829	78.70	224.30	16.54
Parbhani	580	508	496	14.45	41.3	4.81
Mean	709	623	630			
AVTS-(2014-15) Zone I						
Jagtial	827	360	1137	8.29	23.61	12.50
Jalgaon	1268	831	805	46.2	128.10	9.4
Mandya	811	984	943	164	474	16.57
Parbhani	611	-	459	10.24	29.38	4.46
Mean	879	725	836			
AVTS-(2015-16) Zone I						
Jagtial	694	531	686	37.3	107.7	11.7
Jalgaon	522	405	347	42.70	124.1	16.4
Mandya	526	442	876	59.7	182.3	14.8
Parbhani	428	460	472	12.50	36.0	5.2
Mean	542	460	595			
AVTS-(2016-17) Zone I						
Jagtial	875	795	803	49.1	141.3	11.8
Jalgaon	360	529	422	29.4	86.1	10.5
Mean	618	662	612			
Overall mean	698	612	673			
% increase over		14.05	3.71			

Table 2 Summary of yield performance of proposed varietyJLT-408-2 Coordinated Trials in Zone-I (*Rabi*/summer 2014 to 2017) - (Seed yield (kg/ha)

Trial	Year	No. of trials	JLT-408-2	TKG-22(NC)	GT-10(NC)
IVTS	2014	5	709	623	630
AVTS	2015	4	879	725	836
AVTS	2016	4	542	460	595
AVTS	2017	2	617	662	612
Overall mean		15	698	612	673
% increase over				14.05	3.71

Table 3 Yield performance of JLT-408-2 in University Multilocation Trials (Summer 2016-20)

Year	Locations	No. of locations	Seed yield (kg/ha)				SE±	CD at (5%)	CV (%)
			JLT-408-2	AKT-101(C)	JLT-408(C)	PT-1(C)			
2016	Jalgaon	2	924	1000	866	895	61.2	173.9	11.42
	Pandharpur		756	777	878	737	40.54	127.8	9.08
2017	Jalgaon	3	424	434	375	334	28.38	86.28	12.13
	Rahuri		374	226	264	367	9.90	29.81	4.69
	Pune		775	696	310	499	27.14	80.66	11.74
2018	Jalgaon	3	709	611	527	592	32.05	94.29	9.57
	Rahuri		945	903	467	880	36.39	105.7	9.06
	Pandharpur		759	779	785	813	41.0	121.0	18.0
2019	Jalgaon	3	783	634	681	667	33.73	98.04	9.18
	Rahuri		1078	763	851	950	53.00	153.0	10.54
	Dhule		686	323	675	502	42.60	167.0	14.60
2020	Jalgaon	3	685	479	722	558			
	Dhule		833	689	521	740			
	Pandharpur		634	269	470	391			
Overall Mean		14 trials	750	677	619	672			
% Increase over				10.78	21.16	10.40			

Table 4 Summary of yield performance of proposed variety JLT-408-2 in State trials (UMLTS 2016 to 2020) : Seed yield (kg/ha)

Trial	Year	Trials	JLT-408-2	AKT-101(C)	JLT-408(C)	PT-1(C)
UMLTS	2016	2	840	888	872	816
UMLTS	2017	3	524	452	316	400
UMLTS	2018	3	804	764	593	762
UMLTS	2019	3	870	679	736	765
UMLTS	2020	3	713	606	579	621
Overall mean		14	750	677	619	672
% increase over				10.78	21.16	10.40

Table 5 Adaptive trials data of Phule Purna sesame variety on farmers field (Summer 2020)

Name of the farmer	Address	Yield (Qt/ha)		
		Phule Purna	Local	Local variety
Shri.Suhas Shamrao Patil	Chahardi, Chopada, Jalgaon	7.50	5.0	Western-11
Shri.Abhay Narayan Patil	Chahardi, Chopada, Jalgaon	8.75	5.5	Western-11
Shri.Ashok Nimba Chaudhari	Borkheda, Dharangaon, Jalgaon	11.25	5.65	Labdhi
Shri.Prakash Nimba Chaudhari	Borkheda, Dharangaon, Jalgaon	13.75	6.00	Labdhi
Shri.Rajendra Ichharam Chaudhari	Vanjari, Dharangaon, Jalgaon	8.75	5.75	Western-11
Shri.Tukaram Madhav Mahajan	Shiragad, Yawal, Jalgaon	7.50	6.00	Western-11
Smt.Bibabai Tukaram Mahajan	Shiragad, Yawal, Jalgaon	6.50	4.50	Western-11
Shri.Harashal Tukaram Mahajan	Pimpalgaon, Pachora, Jalgaon	9.50	5.50	Western-11
Shri.Sanjay Dinkar Patil	Kondhaval, Amalner,Jalgaon	8.00	4.50	Western-11
Shri. Dinkar Pundlik Patil	Kondhaval, Amalner,Jalgaon	10.00	7.00	Western-11
Smt.Surekha Sanjay Patil	Kondhaval, Amalner,Jalgaon	7.00	5.50	Western-11
Shri.Kavita Shivaji Patil	Bilwadi, Jalgaon	6.50	4.00	Daftari
Smt.Jijabai Waman Patil	Bilwadi, Jalgaon	7.60	4.00	Daftari
Shri.Shivaji Waman Patil	Bilwadi, Jalgaon	8.50	4.5	Daftari
Shri.Mahendrasingh Dhansingh Patil	Kalyanehol,Dharangaon, Jalgaon	8.00	4.25	Labdhi
Shri.Rajendra Pandurang Chaudhari	Borkheda, Dharangaon, Jalgaon	12.50	7.00	Labdhi
Shri.Kiran Pandurang Chaudhari	Borkheda, Dharangaon, Jalgaon	10.00	6.50	Labdhi
Shri.Balu Ramchandra Misal	Walsa, Bhokaradan, Jalna	8.75	6.00	Labdhi
Smt Kasturabai Balu Misal	Walsa, Bhokaradan, Jalna	7.5	5.00	Labdhi
Shri.Nilesh Ashok Patil	Paladhi, Jamner, Jalgaon	12.50	7.00	Labdhi
Shri.Vasant Waman Mahajan	Pardhade, Pachora, Jalgaon	13.75	7.50	Western-11
Shri.Yadavrao Keshav Dhavale	Shirpur, Malegaon, Washim	6.50	4.50	AKT-101
Shri. Kisan Sakharam Bali	Shirpur, Malegaon, Washim	7.50	6.5	AKT-101
Shri.P. D. Deshmukh	Pahur, Jamner, Jalgaon	8.75	6.00	Western-11
Shri.Abasaheb Chudaman Patil	Wanegaon, Pachora, Jalgaon	8.12	6.00	Western-11
Shri.Rajendra Narayan Patil	Naygaon, Yawal, Jalgaon	6.50	6.00	Gopi
Average yield(Q/ha)		8.09	5.60	
% increase over local		44.46%		

Table 6 Summary of Adaptive trials data of Phule Purna sesame variety on farmers field (Summer 2020)

Number of the farmers under : Adaptive trials data of Phule– Purna sesame variety	Yield (kg/ha)		% increase over
	Phule Purna	Local	
26 farmers	809	560	44.46%

Table 7 Overall yield performance of proposed variety JLT-408-2 in Coordinated State trials & adaptive trials (Summer- 2013 to 2020)

Trials	No of trials	Yield(Kg/ha)
Coordinated Trials	15	698
State trials	14	750
Adaptive trials	26	809
Overall average (55 trials)		752

Table 8 Effect on sesame seed yield (kg/ha); gross and net monetary returns (₹/ha) and B:C ratio as influenced by various genotypes and spacing's

Treatment	Seed yield (kg/ha)	GMR (₹/ha)	Cost of cultivation (₹/ha)	NMR (₹/ha)	B:C ratio
A) Main plot(Genotypes)					
JLT-408-2	820	98400	26000	72400	3.78
JLS-708	785	94200	26000	68200	3.62
JLT-408(C)	760	91200	26000	65200	3.50
AKT-101(C)	771	92520	26000	66520	3.56
SE+	29.00				
CD at 5%	N.S.				
B) Sub plot (Spacing)					
S1: 30 x 15 cm	746	89520	26000	63520	3.44
S2: 45 x 10 cm	792	95040	26000	69040	3.66
SE+	34				
CD at 5%	101				
C) Interaction (G x S)					
SE+	41.0				
CD at 5%	N.S.				

Rate: Seed @120/kg; Cost of cultivation: ₹26000/ha

Table 9 Reaction of JLS-408-2 to major diseases recorded at various AICRP centers under summer condition

Disease	Trial	Year	Location	JLS-408-2(Phule purna)	TKG-20(NC)	GT-10(NC)
Cercospora leaf spot (0-5 scale)	AVTS	2016-17	Jagtial	2(R)	2(R)	1(R)
	AVTS	2017-18	Kolkatta	2(R)	1(R)	2(R)
Alternaria leaf spot (0-5 scale)	AVTS	2016-17	Jagtial	2.0 R	1.0R	0.0I
	AVTS	2017-18	Kolkatta	1.0 R	1.0R	2.0R
Phyllody(%)	AVTS	2016-17	Jagtial	3.0R	2.0R	0.0 I
	AVTS	2016-17	Dharwad	13.63 MR	10.20 MR	0.0 I
	AVTS	2017-18	Jagtial	0 I	0 I	4 R
	AVTS		Kolkatta	0 I	0I	0 I
Maccrphomina Stem/root rot (%)	AVTS	2016-17	Jagtial	7.7 R	10.7 MR	9.5 R
	AVTS		Dharwad	31.81 MS	20.0 MR	50.0 S
	AVTS	2017-18	Jagtial	0I	0I	4R
	AVTS		Kolkatta	0R	10.8MR	15.8MR
Powdery mildew (0-5 Scale)	AVTS	2016-17	Jagtial	0.0 I	16.0 MR	5.3 R
	AVTS	2017-18	Jagtial	2 R	4R	3R
	AVTS	2018-19	Jabalpur	0 I	4R	0 I

Table 10 Reaction of JLS-408-2 to major diseases recorded in UMLTS under summer condition

Disease	Trial	Year	Location	JLS-408-2 (Phule purna)	AKT-101(C)	JLT-408(C)	PT-1(C)
Cercospora leaf spot (0-5 scale)	UMLTS	2019	Jalgaon	4(R)	8.5 R	2(R)	1(R)
			Rahuri	5.6(R)	10.7 MR	1(R)	2(R)
			Pandharpur	4.0R	29.75 MS	3.0R	18.00 MR
	UMLTS	2020	Jalgaon	3.0R	8.5 R	2.0R	10.20 MR
			Dhule	8.28 R	31.81 MS	10.20 MR	5.0R
			Pandharpur	7.5R	27.75 MS	5.0R	4 R
Alternaria leaf spot (0-5 scale)	UMLTS	2019	Jalgaon	2.0 R	8.5 R	1.0R	10.20 MR
			Rahuri	1.0 R	10.7 MR	1.0R	2.0R
			Pandharpur	6.5R	26.50 MS	4.0R	4 R
	UMLTS	2020	Jalgaon	4.0 R	10.7 MR	3.0 R	3.0 R
			Dhule	7.73 R	31.81 MS	10.20 MR	10.7 MR
			Pandharpur	4.0R	29.75 MS	3.0R	18.00 MR
Phyllody(%)	UMLTS	2019	Jalgaon	3.0R	8.5 R	2.0R	10.20 MR
			Rahuri	9.50 R	31.81 MS	10.20 MR	5.0R
			Pandharpur	7.5R	27.75 MS	5.0R	4 R
	UMLTS	2020	Jalgaon	4.0 R	10.7 MR	3.0 R	3.0 R
			Dhule	8.63 R	31.81 MS	10.20 MR	10.7 MR
			Pandharpur	3.0R	27.75 MS	2.0R	18.00 MR
Macrphomina Stem/root rot(%)	UMLTS	2019	Jalgaon	7.7 R	8.5 R	10.7 MR	9.5 R
			Rahuri	7.0 R	31.81 MS	18.00 MR	22.00 MR
			Pandharpur	4R	27.75 MS	10.20 MR	5.0R
	UMLTS	2020	Jalgaon	1.00R	10.7 MR	11.7 MR	10.5 R
			Dhule	3.63 R	31.81 MS	10.8MR	15.8MR
			Pandharpur	3.5R	19.00 MR	20.00 MR	4 R
Powdery mildew (0-5 Scale)	UMLTS	2019	Jalgaon	2 R	8.5 R	16.0 MR	5.3 R
			Rahuri	7.5R	27.75 MS	4R	3R
			Pandharpur	0 I	10.7 MR	4R	4 R
	UMLTS	2020	Jalgaon	6.28 R	31.81 MS	3.0R	10.20 MR
			Dhule	7.5R	29.75 MS	2.0R	2.0R
			Pandharpur	4.0 R	8.5 R	10.20 MR	4 R

Disease: Score

Score	Description	Reaction	Abbreviation
0	No infestation	Immune	I
1	1-10	Resistant	R
2	11-25	Moderately Resistant	MR
3	26-50	Moderately Susceptible	MS
4	51-70	Susceptible	S
5	71-100	Highly Susceptible	HS

Source: Annual report: Sesame and Niger,2018-19, PC Unit, Jabalpur

RESULTS AND DISCUSSION

The evaluation of Phule Purna (JLT-408-2) was done in summer season through station, multi-location trials, coordinated and adaptive trials for eight years during 2012 to 2020 in 55 trials and performance of the genotype Phule Purna was recorded on various traits. It was revealed that seed yield was 752 kg/ha yield as against the check JLT-408 (581 kg/ha), TKG-22 (622 kg/ha), AKT-101 (635 kg/ha), PT-1 (636 kg/ha) and GT-10 (673 kg/ha) which was higher by 22%, 14%, 12%, 11.94% and 3.71 percent increase over respectively. This new culture is white bold seeded also found superior in quality *viz.,* oil content (Av. 49.02%) as compare to PT-1 (47.58%), JLT-408 (45.16%), GT-10 (44.82%) and AKT-101 (44.58%). FFA%: 0.81% as compare to PT-1 (2.8%), JLT-408 (1.60%) and AKT-101

(1.10%), Iodine Value: 106.8 as compare to PT -1 (108%), JLT- 408 (107%) and AKT-101 (106.8%).

The genotype Phule Purna (JLT-408-2) was tested in co-ordinated trials under AICRP project in summer for one year. Performance of Phule Purna (JLT-408-2) in these trials was also superior over the corresponding checks.

Taking into account best performance of Phule Purna (JLT-408-2) in summer multilocation trials as well as co-ordinated trials, it was released for Maharashtra state for cultivation for farmers in summer season.

Performance of Phule Purna (JLT-408-2) in State Multilocation trials: State multilocation trials were conducted at 14 locations during summer 2016 to 2020. On the basis of mean performance for five years data Phule Purna (JLT-408-2) recorded 750 kg/ha seed yield as against check varieties *viz.,* AKT-101 (677 kg/ha), JLT-408 (619 kg/ha) and PT-1 (672 kg/ha) with a percentage increase of 10.78, 21.16 and 10.40% respectively (Table 3 and 4).

Performance of Phule Purna (JLT-408-2) in Adaptive trials on farmers field: The genotype Phule Purna (JLT-408-2) was tested under Adaptive trials on farmers field during summer, 2020. Phule Purna (JLT-408-2) recorded 809 kg/ha seed yield as against Local variety (560 kg/ha.) with a percentage increase of 44.46% (Table 5 and 6).

Performance of Phule Purna (JLT-408-2) in AICRP trials: The genotype Phule Purna (JLT - 408 - 2) was tested in AICRP IVT (2013 to 17) all over India. The overall mean performance for one year in 15 trials showed that Phule Purna (JLT-408-2) recorded 698 kg/ha grain yield which was 14.05 and 3.71 percent increase over the check variety TKG-22 (612 kg/ha) and GT-10 (673kg/ha) respectively (Table 1 and 2).

Overall Performance of Phule Purna (JLT-408-2) State, Co-ordinated and Adaptive trials: The genotype Phule Purna (JLT-408-2) was tested in total 55 trials comprising of 14 state, 26 adaptive trials and 15 multilocation trials in summer season during 2016 to 2020. The overall mean performance for eight years in 55 trials reported that Phule Purna (JLT-408-2) recorded higher grain yield of 752 kg/ha as against check varieties *viz.,* AKT-101 (677 kg/ha), JLT-405 (619 kg/ha), PT- (672 kg/ha), TKG-22 (612 kg/ha), GT-10 (673 kg/ha), and Local (566 kg/ha) with a percentage increase of 10.78, 21.16, 10.40. 14.05, 3.31 and 44.46 percent respectively (Table 7).

Effect of Variety Phule Purna (JLT-408-2): The results revealed that the variety Phule Purna (JLT-408-2) recorded significantly higher plant height (98 cm), number of branches/plant (5.0), number of capsules/plant (76) and seed yield (820 kg/ha) over the check variety AKT-101 (771 kg/ha) and JLT - 408 (760 kg/ha) respectively (Table 8). The same variety Phule Purna (JLT-408-2) also recorded the maximum net returns ₹ 72,400 / ha and B:C ratio of 3.78. However, both the varieties did not show any significant effect on growth parameters like plant height, number of branches, number of capsules per plant.

Effect of spacing: The seed yield per plant (792 kg/ha) were recorded significantly higher under border spacing 45x10 cm over normal spacing of 30x15 cm (746 kg/ha) (Table 8). However, all the yield attributes and economics shown non-significant effect at varying levels of spacing.

Reaction to major diseases: The candidate variety was tested at various locations under AICRP *viz.,* Jagtial, Kolkatta, Dharwad and Jabalpur against major diseases of sesame. In 0-5 scale, the powdery mildew disease score in the variety Phule Purna (JLT-408-2) ranged from 0 to 2 as compared to check varieties 3 to 16. In 0-5 scale, the cercospora leaf spot disease score in this variety was in the range from 1 to 2 as compared to checks, Table 9.

The candidate Variety was tested under UMLTS under summer season under Jalgaon, Rahuri, Pandharpur and Dhule against major diseases of sesame. In 0-5 scale, the cercospora leaf spot disease score in the Phule Purna ranged from 4 to 5-6 as compared to check varieties 8.5 to 29.75 scale. Alternaria leaf spot disease score in this variety was in range from 10 to 7.73 as compared to checks (10.7 to 26-50), Table 10.

Ancillary characters of Phule Purna (JLT-408-2): The ancillary data is reported in Table 11. The candidate variety Phule Purna (JLT-408- 2) requires on an average 47 days for 50% flowering and 90 days for maturity. The number of branches/plant (5.0) is more than checks *viz.,* AKT-101, JLT-408 and PT-1. The mean plant height (98 cm) is more than check varieties AKT-101, JLT-408 and PT-1. The number of capsules/plant (76) is more than checks *viz.,* AKT-101, JLT-408 and PT-1. The 1000 seeds weight is more 4.80 g than the check varieties AKT-101, JLT-408 and PT-1.

Quality parameters: The genotype Phule Purna (JLT-408-2) was tested for different quality parameters *viz.,* oil (%) FFA (%) and Iodine value. Overall this genotype contains 49.30% oil and 0.81 FFA %. It is superior in cooking percentage than the check varieties (Table 12).

The new variety Phule Purna (JLT-408-2) developed at Oilseeds Research Station, MPKV, Jalgaon reported an average yield of 752 kg/ha which is 22, 14, 12, 11.94 and 3.75 percent higher than the check JLT-408 (581 kg/ha), TKG-22 (605 kg/ha), PT-1 (636 kg/ha) and GT-10 (613 kg/ha) per cent respectively. The leaves are dark green, stem is green coloured with pubescence. It is bold seeded variety having early maturity, resistant to major diseases like Cercospora, Phyllody under field conditions. Considering the consistent performance, the sesame genotype JLT-408-2 has been released for cultivation in the summer season for Maharashtra under the name of Phule Purna by Varietal Release Committee in Joint Agresco during 29-30 October, 2020 held at Dr. PDKV, Akola and State Seed Hub Committee meeting held by video conference on 2nd September, 2021 (Anonymous, 2021).

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Table 11 Ancillary observations of JLT-408-2 in comparison with checks

Year	Locations No.	Location	JLT-408-2	AKT-101©	JLT-408©	PT-1©
			Days to 50% flowering			
2014	1	Jalgaon	44	47	45	48
2015	1	Jalgaon	46	46	43	48
2016	2	Jalgaon, Pandharpur	54	54	57	55
2017	3	Jalgaon, Rahuri, Pandharpur	50	51	51	49
2018	3	-“-	44	45	45	42
2019	3	Jalgaon, Rahuri, Dhule	45	44	44	48
		Mean	47	48	48	49
			Days to maturity			
2014	1	Jalgaon	94	98	93	97
2015	1	Jalgaon	84	93	85	93
2016	2	Jalgaon, Pandharpur	93	90	88	90
2017	3	Jalgaon, Rahuri, Pandharpur	97	99	95	99
2018	3	-“-	89	90	88	90
2019	3	Jalgaon, Rahuri, Dhule	94	96	96	92
		Mean	90	94	91	94
			Plant height (cm)			
2014	1	Jalgaon	98	88	97	110
2015	1	Jalgaon	99	98	88	107
2016	2	Jalgaon, Pandharpur	86	82	68	77
2017	3	Jalgaon, Rahuri, Pandharpur	100	96	95	102
2018	3	-“-	95	91	89	93
2019	3	Jalgaon, Rahuri, Dhule	105	98	102	113
		Mean	98	92	90	100
			No.of branches			
2014	1	Jalgaon	3.9	3.8	3.7	3.7
2015	1	Jalgaon	4.7	4.8	3.8	4.5
2016	2	Jalgaon, Pandharpur	3.0	3.8	3.3	3.2
2017	3	Jalgaon, Rahuri, Pandharpur	5.8	5.2	4.8	4.8
2018	3	-“-	5.0	4.0	5.0	5.0
2019	3	Jalgaon, Rahuri, Dhule	5.5	4.5	3.9	4.0
		Mean	5.0	4.0	4.0	4.0
			No. of capsule per plant			
2014	1	Jalgaon	70	62	44	52
2015	1	Jalgaon	68	65	51	54
2016	2	Jalgaon, Pandharpur	62	61	57	57
2017	3	Jalgaon, Rahuri, Pandharpur	77	78	68	68
2018	3	-“-	76	79	68	46
2019	3	Jalgaon, Rahuri, Dhule	102	81	88	82
		Mean	76	71	63	60
			1000 seed weight (g)			
2014	1	Jalgaon	3.36	3.30	3.01	3.03
2015	1	Jalgaon	3.46	3.21	3.00	3.24

Table 12 Quality parameters of JLT-408-2 (Phule Purna)

Quality parameter	JLT-408-2	AKT-101(C)	JLT-408(C)	PT-1(C)
Oil (%)	49.30	44.58	45.46	47.58
FFA (%)	0.81	1.10	1.60	2.80
Iodine Value	106.80	106.80	107.0	108.0

Source: Shree Analytical testing laboratory & research laboratory, Jalgaon Dt.11.12.2020

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Genetic variability, correlation and path analysis for selection in elite breeding material of sesame (*Sesamum indicum* L.)

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ABSTRACT

Sesame is an oilseed crop with chromosome number 2n=26 belonging to the family Pedaliaceae. Although it is a potent crop, yet its yield is not at par with other oilseeds. Its indeterminate growth habit and seed shattering due to non-synchronous maturity are the major causes of its low yield. Focusing on this problem research was designed to study the various morphological traits related to the crop and their inter-relationship with yield. Twenty-nine sesame genotypes including three checks, two national checks (GT-10, TKG-22) and one zonal check (JTS-08) from different sources were planted in Randomized Block Design with three replications and data were collected on 14 quantitative characters. All the genotypes have significant variance for all the character under study. Two characters flowering period and growth during flowering was used to classify the genotypes determinate, semi-determinate and indeterminate. RT-103, BRT-10-01 comes under determinate, 11 under semi-determinate and 3 under indeterminate were found. High heritability coupled with high genetic advance was observed for flowering period, number of primary branches, seed per capsule, capsule length, indicating that heritability is mainly due to additive gene action and selection for these traits would be more effective. Further correlation studies revealed positive significant correlation with number of primary branches, number of capsules per plant, seed per capsule thereby direct selection of these traits may lead to increase in genetic potential of seed yield. High positive direct effect of seed per capsule on yield per plant and some other traits shown high positive indirect effect on seed yield. Hence, these characters should be given preference during selection.

Keywords: Correlation, GCV, Heritability, PCV, Sesame, Variability

Sesame (*Sesamum indicum* L.) is an ancient oilseed crop, it belongs to the family Pedaliaceae, with chromosome number 2n = 26. In India, it is popularly known as "Til" or "Gingelly". Genus Sesamum includes more than 30 species out of which Sesamum indicum is widely cultivated as a crop and widely recognized as cultivated species with a wide distribution covering tropical Africa, Madagascar, Arabia, Sri Lanka, India, tropical Australia, and a few of the eastern Islands of the Malayan Archipelago. It is referred as "Queen of Oilseeds" because of its high oil content (45-60%), premium quality oil and resistant to oxidation even when kept at normal ambient temperature. The high levels (83-90%) of unsaturated fatty acids (UFA) and polyunsaturated fatty acids (PUFAs) of sesame oil, mainly linoleic acid (37-47%), oleic acid (35-43%) (Prathyusha *et al.*, 2023).

Despite its long history and nutritional value, the crop has low yielding capacity compared to other oilseed crops, mainly due to its low harvest index, susceptibility to diseases, seed shattering and indeterminate growth habit (Yol and Uzun, 2012; Abate *et al.,* 2015; Mandviwala *et al.,* 2023). Plant architecture of sesame is not well adapted to modern farming due to its indeterminate growth habit and seed shattering at maturity. The indeterminate growth habit of sesame causes continual flowering and heterogeneous capsule maturation, thus making it difficult to decide when to harvest the seeds. Flowering can continue over a period of 2 months if the environmental conditions are favorable for sesame growth (Day, 2000; Çagirgan, 2006). Yield is a complex trait and it is very much affected by the environmental factors. For improvement in a particular trait of sesame crop, genetic variability present in the crop needs to be exploited (Kumhar and Rajani, 2021). Variability may be naturally present, or breeder may create it through several means. Analysis of variance, PCV, GCV, heritability, genetic advance, correlation coefficient and path analysis are helpful parameters to understand the relationship of yield with other characters. Breeders are interested in correlation studies between yield and yield contributing traits of the crop when they plan for future hybridization program and evaluating individual plant in segregating generation. With the help of path analysis direct and indirect effect of each component trait on yield can be worked out. It also helps in identification of cause and effect as well as the assessment of their relative importance.

MATERIALS AND METHODS

Total 29 sesame genotypes (Table1) including two national checks and one zonal check namely, GT-10,

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TKG-22, JTS-08 (ZC) were planted in summer 2023 in Randomized Block Design with three replications at Bihar Agricultural University at BAU farms, Sabur, Bihar. Size of each plot is 2.7 sq. m consists of three rows, each 3 m long, of plant in which 10 cm is plant to plant distance and 30 cm is row to row distance. The crop is planted on heavy alluvial soil. All the respective package and practices were followed during crop growth.

Table 1 List of genotypes under study

Entry
RT-46
RT-54
RT-103
RT-125
RT-127
RT-346
RT-351
Pragati
Smarak
Sekhar
AT-336
AT-255
GT-4
GJT-5
Subhra
Sabour Til-1
BRT-08
BRT-09
BRT-10-1
PCS-20-1
RT-390
VS-19-036
PCUS-2021-1
AT-410
Kalika
OSM-170
GT-10 (NC)
TKG-22 (NC)
JTS-08 (ZC)

Observations were recorded on five plant basis on days to beginning of flowering, days to terminal flowering, flowering period, plant height at the beginning of flowering, plant height at terminal flowering, growth during flowering, days to physiological maturity, stem length to the first capsule, number of primary branches, number of capsule/plant, seed per capsule, capsule length (cm), days to physiological maturity 1000-Grain weight, and yield (g/plant). Genotypic and phenotypic correlation between yield and its attributing traits were worked.

RESULTS AND DISCUSSION

The mean sum of square due to genotypes was significant for all the characters studied (Table 2). This revealed that considerable amount of variability was present in the genotypes for all the characters under study. Hence, there is a scope for inclusion of promising genotypes in breeding program for yield and its component characters. Parameshwarappa *et al.* (2009), Sumathi and Muralidharan (2010) while working on sesame crop also find presence of significant amount of variation for all the characters under study, this helps breeder for selection as per objective.

The estimate of phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV) for all the characters are represented in Table 3. The measures of phenotypic coefficient of variation (PCV) were slightly higher than genotypic coefficient of variation (GCV) for all the characters under study which tells about the interaction of genotype with environment. PCV ranged from 41.04 (Number of primary and secondary branches) to 6.04 (Days to physiological maturity), while GCV ranged from 40.78 (Number of primary and secondary branches) to 5.66 (Days to physiological maturity). Higher value of PCV was observed for number of primary and secondary branches followed by yield and capsule length. Lower value of PCV was observed for days to physiological maturity followed by plat height at terminal flowering and days to beginning of flowering. Similar result was obtained by Abate *et al.* (2015), Hika *et al.* (2015), Kumar *et al.* (2022) and Kadvani *et al.* (2020) this indicates the importance of these characters for further sesame improvement.

Heritability is the most important property of a metric character that signals about its transferability to the next generation. It expresses the reliability of the phenotypic value of a character and also a guide to breeding value. The breeding value determines the influence in the next generation. Therefore, breeders rely on the phenotypic values of a character for successful changing the character of a population, and this can be predicted by heritability. High heritability in board sense is reliable only if accompanied with high genetic advance. Genetic advance as percent of mean shows great level of differences among fourteen quantitative traits. Heritability in board sense for all the fourteen quantitative characters ranges from 18% (stem length to the first capsule) to 98.7% (number of primary and secondary branches). High heritability was recorded for number of primary and secondary branches

(98.7%), test weight (95%), number of seed/capsule (95%), days to physiological maturity (87%), days to terminal flowering (87%), yield/plant (80%), plant height at terminal flowering (78%), days to beginning of flowering (74%), flowering period (72%), growth during flowering (70%), capsule length (62%), while moderate heritability was recorded for number of capsule/plant (59%) and plant height at beginning of flowering (59%) and low heritability was observed for stem length to the first capsule (18%). Hika *et al.* (2015), Saxena and Bisen (2017) observed high heritability for seeds per capsule followed by oil content, yield per plant, harvest index, days to 50% flowering, number of primary and secondary branches per plant, days to maturity, capsule length, 1000-seed weight and number of capsules per plant. Kalaiyarasi *et al.* (2019) that number of branches per plant, number of capsules per plant, seed yield per plant, plant height, 1000 seed weight and number of seeds per capsules showed high heritability. Sasipriya *et al.* (2022) observed high heritability for plant height (cm), number of branches per plant, number of capsules per plant, capsule length (cm), number of seeds per capsule, 1000-seed weight (g) and seed yield per plant (g) and days to 50% flowering, indicating those characters with high heritability are largely influenced by genetic factors rather than environment and characters with low heritability are highly influenced by environment. Hence, breeding programme can gain faster genetic gain for high heritability traits.

High heritability coupled with high genetic advance observed for number of primary and secondary branches, number of seeds per capsule, capsule length (cm), test weight (g), yield (g/plant). Prithviraj and Parameshwarappa (2017), Saxena and Bisen (2017), Divya *et al.* (2018) and Pratyusha *et al.* (2022) observed similar result indicating that, these traits can be considered as favorable attributes for improvement through selection and this may be due to presence of additive gene effect.

Character association between fourteen quantitative traits were analyzed and shown in table 4. It measures the reciprocal association between the character and gives idea about which trait should be selected for fast yield improvement. Yield per plant exhibit positive & highly significant correlation with number of seeds per capsule (0.69), test weight (0.67), capsule length (0.66), number of primary branches (0.63), and number of capsule/plant (0.56) and negative but highly significant correlation with plant height at terminal flowering (-0.23), flowering period (-0.41) and days to terminal flowering (-0.41), but negative significant correlation with growth during flowering (-0.21). Gnanasekaran *et al.* (2008), Fazal *et al.* (2015) and Rohit *et al.* (2022) observed similar positive and negative correlation which suggest that these traits should be included in selection criteria while improving sesame.

Table 2 ANOVA for the fourteen quantitative traits

Name of trait		Mean sum of square		
		Replication (df= 2)	Genotype (df=28)	error (df=56)
Days to beginning of flowering	BF	0.594625	22.53612**	2.339047
Days to terminal flowering	TF	0.261805	130.9521**	6.124721
Flowering period	FP	1.634073	81.1974**	8.994309
Plant height at beginning of flowering	PHBF	6.805835	17.10288**	3.164144
Plant height at terminal flowering	PHTF	9.18174	85.33168**	6.995159
Growth during flowering	GF	4.734038	77.07207**	9.258635
Stem length to the first capsule	SFLC	1.947241	8.876215**	5.300574
Number of primary branches	NPB	0.024498	2.294**	0.009776
Number of capsule/plant	C/P	1783.802	101.8329**	18.56613
Number of seeds per capsule	S/C	5.686898	162.8917**	2.569278
Capsule length	CL	0.013091	0.499313**	0.084734
Days to physiological maturity	PM	1.322777	79.37104**	3.512991
Test weight	TW	0.002184	0.745169**	0.011343
Yield (g/plant)	Y	12.5144	12.34641**	0.927943

** significant at 1% level

Table 3 Genetic Parameters for fourteen Quantitative traits

Characters	BF	TF	FP	PHBF	PHTF	GF	SFLC	NPB	C/P	S/C	CL	PM	TW	Y
ECV	3.84	3.05	7.26	8.48	3.18	4.89	11.98	4.62	6.01	3.03	10.46	2.11	3.24	11.69
GCV	6.52	7.95	11.87	10.28	6.14	7.64	5.68	40.78	7.35	13.82	13.36	5.66	15.04	23.67
PCV	7.57	8.52	13.91	13.33	6.92	9.07	13.26	41.04	9.5	14.15	16.97	6.04	15.38	26.4
h2 (broad sense)	0.74	0.87	0.72	0.59	0.78	0.7	0.18	0.98	0.59	0.95	0.62	0.87	0.95	0.8
GA	4.6	12.4	8.62	3.42	9.34	8.24	0.96	1.78	8.4	14.71	0.6	9.7	0.99	3.6
GAM	11.58	15.3	20.87	16.33	11.24	13.26	5.01	83.48	11.72	27.81	21.68	10.93	30.29	43.73

Note: GCV=Genotypic Coefficient of Variation, PCV=Phenotypic Coefficient of Variation, ECV= Environmental Coefficient of Variation, h2=Heritability in broad sense, GA=Genetic Advance, GAM=Genetic Advance as percent of mean, BF=Days to beginning of flowering, TF=days to terminal flowering, FP= Flowering period, PHBF= Plant height a beginning of flowering, PHTF= Plant height at terminal flowering, GF= Growth during flowering, SFLC= Stem length to the first capsule, NPB= Number of primary and secondary branches, C/P= Number of capsule/plant, S/C= Number of Seeds/Capsule, CL=Capsule Length, PM=Days to physiological maturity, TW=Test weight, Y= Yield (g/ha).

Table 4 Phenotypic correlation of 14 quantitative traits in sesame genotypes

	BF	TF	FP	PHBF	PHTF	GF	SLFC	NPSB	C/P	S/C	CL	PM	TW	Y
BF	1	0.57**	0.16	0.06	0.38**	0.37**	0.10	-0.12	-0.12	-0.27**	-0.08	0.61**	-0.13	-0.18
TF		1	0.90**	0.35**	0.65**	0.49**	0.13	-0.25*	-0.25	-0.28**	-0.36**	0.78**	-0.43**	-0.43**
FP			1	0.39**	0.58**	0.39**	0.10	-0.24*	-0.24	-0.19	-0.39**	0.62**	-0.44**	-0.42**
PHBF				1	0.28**	-0.21	0.55**	0.16	0.08	-0.15	-0.15	0.19	-0.23*	-0.15
PHTF					1	0.88**	0.26*	-0.11	-0.14	-0.09	-0.34**	0.72**	-0.27*	-0.28**
GF						1	-0.01	-0.19	-0.18	-0.02	-0.27**	0.63**	-0.16	-0.22*
SLFC							1	0.08	0.09	-0.07	0.027	0.09	-0.04	-0.002
NPSB								1	0.53**	0.59**	0.51**	-0.06	0.59**	0.64**
C/P									1	0.38**	0.43**	-0.14	0.41**	0.56**
S/C										1	0.52**	-0.06	0.72**	0.69**
CL											1	-0.12	0.54**	0.66**
PM												1	-0.09	-0.14
TW													1	0.67**
Y														1

*** Significance at 5% and 1% level of probability, respectively. Abbreviation: BF=Days to beginning of flowering, TF=days to terminal flowering, FP= Flowering period, PHBF= Plant height a beginning of flowering, PHTF= Plant height at terminal flowering, GF= Growth during flowering, SFLC= Stem length to the first capsule, NPSB= Number of primary and secondary branches, C/P= Number of capsule/plant, S/C= Number of Seeds/Capsule, CL=Capsule Length, PM=Days to physiological maturity, TW=Test weight, Y= Yield (g/ha).

Table 5 Direct (diagonal) and indirect effects of component traits attributing to grain yield (g/plant) in sesame at phenotypic level

	BF	TF	FP	PHBF	PHTF	GF	SLFC	NPSB	C/P	S/C	CL	PM	TW
BF	0.043	0.024	0.006	0.002	0.016	0.015	0.0045	-0.005	-0.0049	-0.011	-0.003	0.026	-0.005
TF	-0.193	-0.338	-0.305	-0.119	-0.221	-0.166	-0.0448	0.084	0.0834	0.096	0.124	-0.265	0.144
FP	0.006	0.036	0.039	0.015	0.023	0.015	0.0042	-0.009	-0.0094	-0.007	-0.015	0.025	-0.017
PHBF	-0.004	-0.027	-0.030	-0.078	-0.02	0.016	-0.0428	-0.012	-0.0066	0.011	0.011	-0.015	0.018
PHTF	-0.057	-0.096	-0.085	-0.041	-0.147	-0.130	-0.038	0.016	0.0206	0.014	0.050	-0.106	0.039
GF	-0.008	-0.011	-0.009	0.004	-0.020	-0.023	0.0002	0.004	0.0043	0.00	0.006	-0.014	0.003
SLFC	0.008	0.010	0.008	0.043	0.020	-0.00	0.0786	0.006	0.0072	-0.006	0.002	0.007	-0.002
NPSB	-0.018	-0.040	-0.038	0.025	-0.018	-0.031	0.0135	0.162	0.0865	0.096	0.083	-0.01	0.096
C/P	-0.024	-0.053	-0.051	0.018	-0.030	-0.039	0.0199	0.115	0.2168	0.082	0.094	-0.030	0.089
S/C	-0.098	-0.102	-0.071	-0.054	-0.035	-0.008	-0.0282	0.212	0.1362	0.358	0.187	-0.023	0.259
CL	-0.013	-0.061	-0.066	-0.024	-0.057	-0.046	0.0045	0.085	0.0723	0.087	0.166	-0.020	0.090
PM	0.174	0.224	0.179	0.055	0.205	0.182	0.026	-0.017	-0.0406	-0.018	-0.036	0.286	-0.026
TW	0.001	0.005	0.005	0.002	0.003	0.001	0.0004	-0.007	-0.0049	-0.008	-0.006	0.001	-0.012
Y	-0.187	-0.430	-0.419	-0.150	-0.284	-0.215	-0.0022	0.636	0.561	0.694	0.664	-0.140	0.675
Partial R2	-0.008	0.145	-0.016	0.011	0.042	0.005	-0.0002	0.103	0.121	0.248	0.111	-0.040	-0.008

Note: R SQUARE = 0.7158 RESIDUAL EFFECT = 0.5331, BF=Days to beginning of flowering, TF=days to terminal flowering, FP= Flowering period, PHBF= Plant height a beginning of flowering, PHTF= Plant height at terminal flowering, GF= Growth during flowering, SFLC= Stem length to the first capsule, NPSB= Number of primary and secondary branches, C/P= Number of capsule/plant, S/C= Number of Seeds/Capsule, CL=Capsule Length, PM=Days to physiological maturity, TW=Test weight, Y= Yield (g/ha).

The direct and indirect effects on the grain yield are presented in Table 5 (phenotypic). Path coefficient analysis is worked out to assess the magnitude and direction of particular trait. The trait which shows high direct effect on yield, then that trait is selected directly for the yield improvement program. Seed per capsule had high positive direct effect on seed yield per plant and had high positive indirect effect (0.694) on seed yield per plant *viz.,* days to terminal flowering, plant height at beginning of flowering, plant height at terminal flowering, growth during flowering, number of primary branches, number of capsule/plant, capsule length. Goudappagoudra *et al.* (2011), Ibrahim and Khidir (2012), Kalaiyarasi *et al.* (2019) and Fazal *et al.* (2015) observed similar findings indicating that these characters may be considered for selection criteria in the breeding program.

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Effect of row spacing and varieties on growth and yield of linseed (*Linum usitatissimum* L.)

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ABSTRACT

A field experiment was conducted during *rabi* season of 2021-22 to study the effect of row spacing and varieties on growth and yield of linseed. There were nine treatment combinations comprising of three row spacings (22.5 cm, 30 cm and 45 cm) and three varieties (Neelam, T 397 and Pusa 3) were tested in a split plot design. Significantly the highest plant population at 30 DAS and at harvest as well as plant height at 30, 60 DAS and at harvest were recorded under the row spacing of 22.5 cm. Significantly the highest numbers of branches per plant, number of capsules per plant and test weight were observed under the row spacing of 45 cm. Linseed sown at narrow row spacing of 22.5 cm produced significantly the highest seed and stover yield. The maximum net realization and benefit cost ratio were recorded under the row spacing of 22.5 cm. Pusa 3 variety recorded significantly the highest plant height at 30, 60 DAS and at harvest. Significantly higher number of branches per plant, number of pods per plant, test weight and seed yield were recorded with Pusa 3 variety but it was remained at par with T 397 variety. The variety Pusa 3 recorded significantly the highest stover yield. The maximum net realization and benefit cost ratio were accured with the Pusa 3 variety.

Keywords: Growth, Linseed, Spacing, Variety, Yield

Linseed (*Linum usitatissimum* L.) commonly known as alsi or flax belonging to the family Linaceae. It is grown mainly for seed and used for extracting oil. The oil content of the seed varies from 33-47 per cent. Linseed oil is an excellent drying oil used in manufacturing paints and varnishes, oil cloth, waterproof fabrics and linoleum. Linseed-cake is a very good manure and animal feed. Linseed is also used in making paper and plastics. Flax is considered as a "founder crops" that has been providing raw materials for medicine, food and textiles for more than 8000 years and is of great importance to the human welfare due to the presence of higher concentration of health promoting omega-3 fatty acids (alpha-linolenic acid) which lowers cholesterol level and impart cardiovascular benefits, many linseed-based recipes have been standardized. The crushed seeds/flour is used for value addition and for making various nutritious food preparations. But the linseed oil is not edible due to the laxative properties of the mucilage in the seed coat and presence of higher level of linolenic acid which causes rancidity and emits pungent flavors on oxidation. So on a very small scale, it is used for edible purpose as flax seed breads, bagels and fried food stuff by a small segment of people (Dash *et al.,* 2017). In world, linseed crop cultivated area of 3.26 million ha and seed production is 3.18 million tonnes. Madhya Pradesh, Karnataka, Jharkhand, Bihar, Uttar Pradesh and Chhattisgarh are the leading states in linseed production in India (Anonymous, 2019). India is largest linseed growing country in the world and production wise it is on third rank in the world after Canada and China. Among *rabi* oilseed crops in India, linseed occupy the second position i.e. next to rapeseed-mustard in importance from the view point of area as well as production. Linseed is good source of calcium and phosphorus with their contents as 170 and 370 mg/100 g respectively (Kasana *et al.,* 2018; Lohitha *et al.,* 2023).

The area under cultivation of linseed crop in North Gujarat is increasing recently but least research work in agronomic aspect of linseed has been done. Yield variation in the crop is mostly bought by different agro-climatic location specific various agronomic practices. Among these variety and spacing are important factors contributing for higher production. Now a days various varieties of linseed are released by ICAR and State Agriculture Universities for getting higher productivity. It is necessary to find out the agronomic requirements of newly released varieties, to exploit their yield potential. Selection of appropriate variety is most important factor for secure higher yield in particular climate. In North Gujarat, there is not any recommended variety for this particular climate. Therefore, need to identify an appropriate variety for particular climate. Row spacing plays an important role in increasing production per unit area. There is a direct effect of row spacing on number of capsule per plant, number of seeds per capsule, weight of seeds and seed yield per plant in linseed for particular variety and climate. Therefore, it is necessary to find out the optimum plant population for getting higher yield. Row spacing is dependent upon the expected growth of a particular crop and variety in a given Agro-climatic condition. Therefore, optimum row spacing is one of the most important factors in increasing the yield per hectare (Ganvit *et al*., 2019).

MATERIALS AND METHODS

A field experiment on effect of row spacing and varieties on growth and yield of linseed was conducted during the *rabi* season of the year 2021-22 on Agronomy Instructional Farm, C P College of Agriculture, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar, Banaskantha, Gujarat. The soil of the experimental plot was loamy sand in texture, low in available nitrogen (138.56 kg/ha), medium in available phosphorus (44.42 kg/ha) and high in available potassium (281 kg/ha) with slightly alkaline soil with pH of 7.50. There were nine treatment combinations comprising of three row spacings (22.5 cm, 30 cm and 45 cm) and three varieties (Neelam, T 397 and Pusa 3) were tested in a split plot design with four replication. The entire quantity of phosphorous (40 kg P_2O_5/ha) in the form of DAP and 50 percent dose of nitrogen (30 kg N/ha) in the form of DAP and urea were manually applied uniformly in previously opened furrows before sowing of linseed crop. Remaining 50 per cent nitrogen (30 kg N/ha) in the form of urea was applied at 40 days after sowing as top dressing when irrigation was applied. The biometric observations were recorded from plant present in one m^2 and five randomly selected tagged plants within each net plot. The data were statistically analyzed for various characters as described by Panse and Sukhatme (1967).

RESULTS AND DISCUSSION

Effect of row spacing: Significantly the highest plants population (44.33 and 43.70) were recorded at 30 DAS and at harvest with the row spacing of 22.5 cm (S1), respectively. Significantly the highest plant height (22.69, 39.65 and 56.64 cm) were recorded with the row spacing of 22.5 cm (S1) at 30 DAS, 60 DAS and at harvest, respectively. Plant height was remarkably accelerated at row spacing 22.5 cm might be due to unavailability of sufficient space and sunlight which forced the plants to grow vertically rather than horizontally. The present results are in close conformity with those of Darja *et al.* (2008), Kumar *et al.* (2015), Gohil *et al.* (2016) and Ganvit *et al.* (2019). Significantly the highest numbers of branches per plant (7.68), number of capsules per plant (53.44) and test weight (7.07 g) were observed under the row spacing of 45 cm (S3). The maximum number of branches per plant and number of capsules per plant recorded under the wider row spacing might be due to sufficient availability of sunlight and nutrient reflected in increased plant growth and development. The present result is in close conformation with Kushwaha *et al.* (2006), Saoji *et al.* (2007), Kumar *et al.* (2015) and Ali *et al.* (2016). Linseed sown at narrow row spacing of 22.5 cm (S1) produced significantly the highest seed (1307 kg/ha) and stover yield (2214 kg/ha). Higher seed yield under the narrow spacing treatment 22.5 cm (S1) due to more number of plants occupied per unit area under narrow spacing as compared to wider spacing crop which could led to produce higher seed yield per unit area. Similar results were reported by Khan *et al.* (2005), Kushwaha *et al.* (2006), Saoji *et al.* (2007), Gohil *et al.* (2016) and Ganvit *et al.* (2019). The remarkable increase in stover yield under narrow spacing (22.5 cm) was mainly due to more plants per unit area as well as taller plant which ultimately led to produce higher dry matter per unit area. Similar results were reported by Gohil *et al.* (2016) and Ganvit *et al.* (2019). The maximum net realization (₹ 43713/ha) and benefit cost ratio (2.01) were recoded under the row spacing of 22.5 cm. This increase in profitability was mainly due to higher seed yield. These results are in conformity with the results reported Gohil *et al.* (2016) and Ganvit *et al.* (2019).

Effect of varieties: Pusa 3 variety recorded significantly the highest plant height of 22.65, 39.66 and 55.52 cm at 30, 60 DAS and at harvest, respectively. The variation in plant height by different varieties due to different varietal character as observed by Andruszczak *et al.* (2015), Adagale *et al.* (2016) and Gaikwad *et al.* (2019). Significantly higher number of branches per plant (7.55), number of capsules per plant (52.12) and test weight (7.08 g) were recorded with Pusa 3 variety but it was remained at par with T 397 variety. This might be due to different genetic potential of the varieties and Pusa 3 variety might be considered the best variety among the three varieties. This variation was found due to the variation of the varietal characteristics in this study. Singh *et al.* (2013), Ganga *et al.* (2015) and Gaikwad *et al.* (2019) found similar results in linseed variety. Significantly higher seed yield (1291 kg/ha) was recorded under Pusa 3 variety however it was found at par with variety T 397 (1188 kg/ha). The highest seed yield of Pusa 3 variety might be due to higher value of number of branches per plant, number of capsules per plant and test weight as compared to other varieties. The results are agreed with Adagale *et al.* (2016) and Maurya *et al.* (2017). The variety Pusa 3 recorded significantly the highest stover yield (2335 kg/ha). The highest stover yield of Pusa 3 variety might be due to higher value of plant height, number of branches per plant, number of capsules per plant and test weight per plant as compared to other two varieties.

The results agreed with Adagale *et al.* (2016), Maurya *et al.* (2017) and Gaikwad *et al.* (2019). The maximum net realization (₹ 44604/ha) and benefit cost ratio (2.08) were accured with the Pusa 3variety. This increase in profitability was mainly due to higher seed yield. These results are in conformity with the results reported by Ganga *et al.* (2015), Adagale *et al.* (2016) and Maurya *et al.* (2017).

Table 1 Plant population and plant height of linseed as influenced by different row spacing and varieties

Treatments	Plant population per metre square		Plant height (cm)		
	At 30 DAS	At harvest	At 30 DAS	At 60 DAS	At harvest
		Row spacing (S)			
S1 : 22.5 cm	44.33	43.70	22.69	39.65	56.64
S2 : 30 cm	32.50	31.95	20.75	36.81	51.56
S3 : 45 cm	21.38	20.70	20.41	36.05	49.25
S.Em.±	0.71	0.76	0.50	0.81	1.25
C.D. (P=0.05)	2.47	2.64	1.72	2.81	4.33
C.V.%	7.55	8.24	8.08	7.51	8.26
		Variety (V)			
V1 : Neelam	32.38	31.70	19.97	36.02	49.93
V2 : T 397	32.75	32.28	21.23	36.84	52.01
V3 : Pusa 3	33.08	32.36	22.65	39.66	55.52
S.Em.±	0.65	0.67	0.44	0.72	1.13
C.D. (P=0.05)	NS	NS	1.29	2.15	3.34
		Interaction (S × V)			
S.Em.±	1.13	1.16	0.75	1.25	1.95
C.D. (P=0.05)	NS	NS	NS	NS	NS
C.V.%	6.93	7.23	7.09	6.67	7.43

Table 2 Number of branches per plant, number of capsules per plant, test weight, seed and stover yield of linseed as influenced by different row spacing and varieties

Treatments	Number of branches per plant	Number of capsules per plant	Test weight (g)	Seed yield (kg/ha)	Stover yield (kg/ha)
		Row spacing (S)			
S1 : 22.5 cm	6.50	45.88	6.24	1307	2214
S2 : 30 cm	7.11	49.43	6.58	1138	1925
S3 : 45 cm	7.68	53.44	7.07	1031	1893
S.Em.±	0.15	1.11	0.14	41.57	54.88
C.D. (P=0.05)	0.54	3.83	0.47	143.87	189.91
C.V.%	7.56	7.73	7.07	12.43	9.46
		Variety (V)			
V1 : Neelam	6.63	46.39	6.08	995	1745
V2 : T 397	7.12	50.24	6.74	1188	1951
V3 : Pusa 3	7.55	52.12	7.08	1291	2335
S.Em.±	0.15	1.03	0.13	38.51	51.88
C.D. (P=0.05)	0.45	3.06	0.39	114.43	154.15
		Interaction (S × V)			
S.Em.±	0.26	1.78	0.23	66.71	89.86
C.D. (P=0.05)	NS	NS	NS	NS	NS
C.V.%	7.33	7.20	6.94	11.52	8.94

Table 3 Economics of linseed as influenced by different row spacing and varieties

Treatments	Seed yield (kg/ha)	Stover yield (kg/ha)	Gross realization (₹/ha)	Cost of cultivation (₹/ha)	Net realization (₹/ha)	BCR
Row spacing (S)						
S1 : 22.5 cm	1307	2214	87169	43456	43713	2.01
S2 : 30 cm	1138	1925	75895	41503	34392	1.83
S3 : 45 cm	1031	1893	68908	39978	28930	1.72
Variety (V)						
V1 : Neelam	995	1745	66420	41646	24774	1.60
V2 : T 397	1188	1951	79171	41646	37525	1.91
V3 : Pusa 3	1291	2335	86250	41646	44604	2.08

Selling price of seed = ₹ 65/kg; Selling price of stover = ₹ 1/kg

Interaction effect: Interaction effect of row spacing and varieties on growth attribute, yield attribute, yield and quality parameters of linseed were found to be non -significant.

Based on the results of one year experimentation, it is concluded that linseed crop should be sown at row spacing of 22.5 cm for securing higher seed yield and net realization on loamy sand. Linseed varieties Pusa 3 and T 397 performed better over Neelam.

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Evaluation of castor parental lines for drought stress tolerance

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ABSTRACT

Twelve (12) castor parental lines along with 2 checks (48-1, DCH-519) were sown in the field during November, 2020-21 and 2021-22, water stress was imposed from 30-90 DAS along with irrigated control in split plot design with three replications. Crop growth before relieving stress (BRS) *viz.,* plant height, stem girth, branch production and primary spike growth were affected with drought stress. Reduction in spike length, effective spike length (ESL), capsule number, spike weight, seed weight of primary and secondary spikes with drought stress was observed. Very few genotypes produced tertiary spikes during both the years. Genotypes ICS-164 and 1932-1 recorded high seed yield both in control and drought stress. Along with these two, ICS-200, ICS-299, IPC-42, DPC-9 and 48-1 also recorded less % reduction in seed yield due to drought stress with low drought susceptibility index (DSI) values.

Keywords: Castor, Drought stress tolerance, Parental lines

Castor, a non-edible oilseed crop, is grown in an area of 0.8 m. ha with a productivity of 2200 kg/ha (2021-22). It is generally grown in low fertile Alfisols in southern India with poor management. Crop survives harsh environments, so considered as drought tolerant crop. Though, it can survive drought, yields are very low. To get good yields, like any other crop, it needs good management. If the yield in irrigated and rainfed conditions is compared, there is huge gap with irrigated crop recording more than 2000 kg/ha and rainfed crop gives only 450 kg/ha (Diyol *et al.,* 2023).

Among the different abiotic stresses, drought is the severe one as water is a scarce commodity. Castor crop is grown without any irrigation in *kharif* and amount and distribution of rainfall vary in different years exposing the crop to intermittent drought stress during rainy season and terminal drought stress in the post rainy season. Drought stress may coincide with critical stages i.e. flowering/maturity of either one or more than one of the three spike orders *viz.,* primaries, secondaries or tertiaries, more so with the later order spikes due to cessation of monsoon season by October/November. Contribution from different spike orders differ with duration of the crop and occurrence of stress.

There is a dire need to develop genotypes with drought tolerance, to yield better even during severe drought years and maximum yield during normal rainfall years. The basic advantage in taking yield as selection criteria is that it integrates all additive traits of many underlying mechanisms of drought tolerance (Kambiranda *et al.,* 2011). Promising breeding lines were screened under imposed drought stress conditions during critical crop growth to select best tolerant parents for drought to be used for developing drought tolerant hybrids that can yield better during severe drought years and maximum during normal rainfall years.

MATERIALS AND METHODS

Twelve castor parental lines along with two checks (48-1, DCH-519) were grown during late *rabi,* 2020-21 and 2021-22 in split plot design with irrigations as main plots (control, drought stress) and parental lines (12) as sub plots with three replications. Five rows per each replication were sown with a spacing of 90 x 60 cm. Seed rate was 5 kg/ha. Soil of the experimental site was red sandy loams with low water holding capacity. Fertilizers were applied based on STCR equation with target yield of 20 q/ha. Crop was sown during 19th November in 2020 and 15th November in 2021. Irrigations were withheld from 30-90 DAS for stress plots. These plots received four irrigations less than control plots.

Data on crop growth *viz.,* plant height, node number, stem girth, branch production, dry matter partitioning was recorded at 90 DAS i.e. before relieving stress (BRS). During 2021, data on SPAD chlorophyll meter reading (SCMR), specific leaf area (SLA), specific leaf weight (SLW) and relative water content (RWC) were recorded before relieving stress.

SCMR was measured using SPAD chlorophyll meter and the unit corresponds to the green content in the leaf and its value is equivalent to the amount of light transmitted by the leaf in two wavelength regions of red and infrared, the amount of red light absorbed indicates the amount of

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chlorophyll, whereas the amount of light absorbed near the infrared serves as an internal reference to offset the thickness of the leaf (Jan Naus *et al.,* 2010).

SLA, SLW was computed by measuring leaf area and dry weight by using the formula

SLA = leaf area (dm^2) / leaf dry weight (g)
SLW = leaf dry weight (g)/ leaf area (dm^2)

Relative water content (RWC) was estimated as per the procedure of Dhopte and Manuel, 2002 by using the formula

RWC (%) = [(FW-DW) / (TW-DW)] x 100, Where, FW - sample fresh weight, TW - sample turgid weight, DW - sample dry weight).

At harvest, spike characters *viz.,* spike length, effective spike length (ESL), capsule number, seed weight, test weight of different spike orders, total dry matter (TDM) at harvest were recorded. Oil content of primary, secondary and tertiary seeds was estimated.

Drought susceptibility index (DSI) values were calculated based on the formula given by Fischer and Maurer (1978).

Drought intensity index (DII) =1-(mean yield averaged across genotypes in stress/mean yield averaged across genotypes in non-stress).

DSI = (1-(mean yield of genotype under stress/mean yield of genotype under non stress))/Drought intensity index (DII).

Split plot analysis was done for individual years for all characters. Pooled analysis over two years for seed yield of different spike orders (primary, secondary, tertiary), total seed yield and HI was carried out using SAS 9.3. (SAS Institute, Cary NC).

RESULTS AND DISCUSSION

Gravimetric estimation of soil moisture was done at regular intervals and soil moisture % at 0-15 cm, 15-30 cm depth before relieving stress was recorded. Moisture content was found to be less in stressed plots and with increase in soil depth (13; 8% at 0-15 cm; 7.8; 6.5% at 15-30 cm depth in control and drought stress respectively). Drought intensity index (DII) of the crop was moderate (0.409, 0.308) during the two years of study.

Crop growth before relieving stress (BRS) *viz.,* plant height, stem girth and branch production was affected with drought stress during both years (Table 1). There was significant reduction in stem, leaf, spike weight and total dry matter (TDM) with moisture stress at 90 DAS as reported in earlier studies in castor (Lakshmamma and Lakshmi, 2006, Lakshmamma *et al*., 2015). Tongoona and Hussein (1989) also recorded reduced leaf area, branches and racemes production in stress.

Table 1 Crop growth and development before relieving stress (BRS)

Character	2020-21			2021-22		
	Treatments		CD ($p \leq 0.05$)	Treatments		CD ($p \leq 0.05$)
	Control	Stress	Main plot	Control	Stress	Main plot
Plant height (cm)	73.7	46.1	0.8	68.6	50.1	1.7
Node no.	10	10	NS	12	12	NS
Stem girth (mm)	24.8	18.2	0.6	24.5	18.7	0.31
Secondary branches (no.)	2	1	0.4	3	1	1.0
Tertiary branches (no.)	1	0	0.3	4	4	
Stem dry weight (g/plant)	70.4	17.3	1.17	47.8	17.3	4.3
Leaf dry weight (g/plant)	34.0	14.1	3.19	33.6	18.2	1.73
Spike dry weight (g/plant)	75.3	42.2	6.58	53.3	27.0	2.91
TDM (g/plant)	179.6	76.6	2.51	134.6	62.0	2.45
SCMR	53.1	58.9	2.46	63.5	59.0	NS
SLA (dm^2/g)	1.791	1.953	NS			
SLW (g/dm^2)	0.567	0.521	NS			
RWC (%)	89.0	85.0	0.76			

Genotypes with significantly higher TDM during two years before relieving drought stress at 90 DAS in control (175-189 g/plant) include IPC-41, IPC-46, ICS-321 and checks 48-1, DCH-519; genotypes with high TDM in stress (70-109 g/plant) are 1932-1, ICS-164, IPC-41, IPC-46, and DPC-25; genotypes with less reduction in TDM (38-41%) were IPC-41, IPC-42 and 1932-1 (Table 3). IPC-41 showed good crop growth in terms of TDM both in control and drought stress and recorded good root growth and TDM at 90 DAS in poly bags under irrigation (Lakshmamma *et al*., 2023).

Data recorded during 2020 on physiological traits showed increase in SPAD chlorophyll meter reading (SCMR) that corresponds to the green content in the leaf, non-significant effect on SLA, SLW and reduction in RWC in drought stress (Table 1). Efficient stomatal control, greater conservation capacity of CO_2 fixation under drought stress (Sausen and Rosa, 2010) and water use efficiency (Barros Junior *et al*., 2008) are some of the physiological mechanisms for drought tolerance in castor bean plants that were recorded when grown in controlled environments. The mechanism of the stomatal closure, in order to restrict water loss by transpiration, can be considered an adaptive strategy used by castor plants to limit water loss under drought stress, which helps in crop establishment in semi-arid regions. Most of the genotypes showed increased bloom content (visual) in response to stress thus acquire tolerance by minimizing cuticular transpiration and increased bloom content in stress was reported in our previous studies (Lakshmamma *et al*., 2009) also. Higher levels of leaf epicuticular wax have been shown to be correlated with relative drought tolerance in oat cultivars (Bengston *et al*., 1978).

During both the years, primary, secondary spike growth was affected with drought stress. There was reduction in spike length, effective spike length (ESL), capsule number and spike weight, seed weight of primary and secondary spikes with drought stress imposed from 30-90 DAS (Table 2). Tertiary branches were not produced in 1932-1, ICS-321, DPC-22 in control and in 1932-1, IPC-41, IPC-44, DPC-21, DCH-519 in drought stress.

Mean Primary seed yield in control was 61.3 g/plant and in drought stress was 39.0 g/plant with reduction of 34.9% due to drought stress from 30-90 DAS. ICS-164, 1932-1, DPC-22, DPC-25 and DCH-519 recorded 68-89 g/plant primary seed weight in control; 1932-1, ICS-164, IPC-46, DPC-9, DPC-22, DPC-25 and DCH-519 recorded 42-50 g/plant in stress. Genotypes with <30% reduction in primary seed yield include IPC-42, IPC-46, ICS-164, and DPC-9. There was 37.8% reduction in secondary seed yield (46.1, 27.9 g/plant in control and stress respectively). Genotypes, 1932-1, ICS-321, IPC-41, DPC-9, 48-1 and DCH-519 recorded 52-59 g/plant in control and ICS-164, ICS-200, 1932-1, 48-1 and DCH-519 produced 30-47g/plant secondary seed yield in stress. Genotypes with <30% reduction in secondary seed yield include ICS-164, ICS-200, ICS-299 and 1932-1. Very few genotypes produced tertiaries with very low seed yield and contribution of tertiaries to total seed yield was very less in both control and drought stress.

Total seed yield of 116.5 g/plant in control, 74.9 g/plant in stress was recorded with average reduction of 34.8% with drought stress. Genotypes with high seed yield in control (131-158 g/plant) include IPC-41, 1932-1, 48-1 and DCH-519. Parental lines, ICS-164, 1932-1, DPC-9 and 48-1 recorded high seed yield (82-95 g/plant) in drought stress. Genotypes with <30% reduction in seed yield include 1932-1, ICS-164, ICS-200, ICS-299, IPC-42 and DPC-9. Genotypes with <1.0 DSI were 1932-1, ICS-164, ICS-200, ICS-299, ICS-321, IPC-42, DPC-9 and 48-1 (Table 4).

No significant difference was observed in oil content of primaries and secondaries with drought stress during both years. Among the genotypes, ICS-299, ICS-321 and IPC-41 recorded >45% oil in control, ICS-164, ICS-299,IPC-41, IPC-44 and IPC-46 recorded >45% oil in drought stress (Table 4).

Genotypes, 1932-1, ICS-164 recorded high seed yield both in control and drought stress. Along with these two, ICS-200, ICS-299, IPC-42, DPC-9 and 48-1 also recorded less % reduction in drought stress with low DSI values. DSI is the predominant selection criteria used for identifying drought tolerant genotypes. The genotypes with less DSI (<1) can be considered as drought tolerant. But low DSI values of a genotype could be due to less yield production under well-watered conditions rather than an indication of its ability to tolerate water stress. Therefore the stress tolerant genotypes defined as per DSI, need not necessarily have high yield potential (Karaba *et al.,* 2011). But, the genotypes selected in this study also recorded good seed yield in control, drought stress, with less % reduction in seed yield apart from low DSI values (Lakshmamma *et al.,* 2006, 2015, 2017). The genotypes with low/moderate DSI (<0.7) were considered least drought susceptible in wheat also (Chowdhury *et al.,* 1988).

Castor crop has very strong stem and stem is the major contributor to total dry matter (TDM). There was significant reduction in stem, leaf (data not presented), spike dry weight and TDM at harvest with stress (Table 4). Though there was significant reduction in TDM before relieving stress (57.3%), crop tried to compensate after relieving stress by producing more branches hence showed less reduction in TDM (35.6%) at harvest. Genotypes with 341-396 g/pl. TDM in control include: 1932-1, IPC-41, IPC-46, DPC-9 and DCH-519. Genotypes 1932-1. ICS-164, ICS-200, DPC-9 and DCH-519 recorded more TDM (232-290 g/plant) in drought stress (Table 4).

Genotypes with stem reserve mobilization are needed to produce under abiotic stress conditions. Due to heavy foliage and limited translocation to reproductive parts when current photosynthesis is inhibited, it results in very low HI values (<30%) in castor. In this study, control plants recorded 38% harvest index (HI), whereas stressed plants recorded 35% HI. Genotypes with high HI (39.5-41.1%) in control include: IPC-41, IPC-44, ICS-321, DPC-22, 48-1 and DCH-519. HI of 34.6-42.2% was recorded in ICS-164, ICS-299, ICS-321, IPC-42, DPC-9, DPC-22 and 48-1 in stress. Increase in HI in ICS-164, ICS-299, DPC-9 and 48-1 with drought stress shows the efficiency of these genotypes to translocate more dry matter to reproductive structures. Efficient use of stored water, increased biomass productivity per unit water use and highest conversion of vegetative biomass to economic yield are the ultimate goals of any drought management research.

Best parental lines selected in this study include: ICS-164, 1932-1 with high seed yield both in control and drought stress along with ICS-200, ICS-299, IPC-42, DPC-9 and 48-1 with less % reduction in drought stress and with low drought susceptibility index (DSI) values.

Table 2 Growth of different spike orders in control and drought stress

Character	2020-21			2021-22		
	Treatments		CD ($p \leq 0.05$)	Treatments		CD ($p \leq 0.05$)
	Control	Main plot	Irrigations	Control	Stress	Main plot
Primary spike data (per plant)						
Days to harvesting	116	117	NS			
ESL (cm)	46.6	30.9	3.2	43.9	33.7	3.21
Capsule Number	57	44	1.61	73	54	1.24
Spike weight (g)	100.9	61.3	4.77	115.1	85.8	5.18
Seed weight (g)	60.6	35.8	0.92	62.1	42.3	0.89
100 seed weight (g)	29.6	28.1	1.17	32.63	32.81	NS
Secondary spike data (per plant)						
Days to harvesting	130	148	4.0			
Spike Number	3	3	NS	3	3	NS
ESL (cm)/spike	28.7	18.8	0.24	20.6	21.3	0.27
Capsule Number/spike	26	16	2.61	22	20	NS
Spike weight (g)	85.9	44.6	1.81	107.0	81.5	6.15
Seed weight (g)	48.3	24.1	3.75	44.0	31.6	5.33
100 seed weight (g)	30.3	29.6	NS	31.4	28.1	1.43
Tertiary spike data (per plant)						
Days to harvesting	156	155				
Spike Number	2	2		3	2	
ESL (cm)/spike	4.1	5.5	0.30	13	12	
Capsule Number/spike	3	5	0.31	29.0	18.5	
Spike weight (g)	7.5	12.8	0.58	14.3	9.3	
Seed weight (g)	3.8	6.6	0.18	17.7	11.4	9.68
100 seed weight (g)	28.2	27.0				
Total seed yield (g/plant)	112.6	66.5		120.3	83.3	4.32
TDM at harvest (g/plant)	274.5	176.6		351.8	263.6	10.3
HI (%)	41.0	38.0		34.7	32.3	NS
Oil content (%)						
Primary spike	45.2	46.5	1.25	43.3	45.7	NS
Secondary spikes	45.2	43.8	1.08	45.0	43.6	NS
Tertiary spikes	-	-	-	30.7	21.3	NS
Average oil content	45.3	45.2	NS	43.8	44.5	NS

Table 3 Mean performance of different spike orders

Parental lines	TDM before relieving stress(g/plant)		Primary spike characters (per plant)							
			Effective spike length (cm)		Capsule number		Spike weight (g)		Seed weight (g)	
	Control	Stress	Control	Stress	Control	Stress	Control	Stress	Control	Stress
1932-1	150.9	88.7	50.6	36.2	74	54	130.9	91.8	74.6	47.3
ICS-164	165.5	70.9	49.3	41.4	80	66	112.8	86.6	68.5	49.5
ICS-200	124.8	57.8	34.1	21.8	57	45	82.8	56.7	47.5	27.2
ICS-299	126.3	52.0	56.5	40.2	64	54	106.0	72.6	57.1	38.2
ICS-321	176.3	62.3	37.2	25.0	57	42	88.8	65.0	59.4	29.6
IPC-41	182.8	108.7	60.0	41.7	60	42	100.0	60.6	61.7	35.0
IPC-42	103.0	63.6	41.3	31.2	35	41	52.1	49.7	31.8	30.5
IPC-44	149.3	68.8	28.3	22.6	36	28	67.0	48.2	40.0	25.2
IPC-46	193.2	71.7	51.3	38.3	69	54	129.4	95.4	63.9	45.6
DPC-9	128.5	51.6	38.9	26.9	77	54	117.0	91.8	57.4	48.3
DPC-22	167.2	69.5	48.1	31.9	82	52	153.3	85.7	79.0	43.7
DPC-25	168.1	71.1	46.7	29.9	65	47	127.3	77.3	67.9	42.3
48-1	174.9	67.7	40.4	29.5	60	44	98.4	62.5	60.8	36.9
DCH-519	188.8	65.7	50.3	35.7	87	58	146.3	85.9	88.9	47.0
Mean	157.1	69.3	45.2	32.3	65	49	108.0	73.6	61.3	39.0
CD (0.05)										
Main plot	0.912		1.104		0.494		1.749		0.308	
Sub plot	12.25		3.20		6.22		8.70		5.91	
interaction	17.33		4.53		8.79		12.3		8.36	
CV (%) a	2.66		5.48		2.04		5.69		1.35	
b	12.65		9.65		12.87		11.21		13.79	

Table 3 Mean performance of different spike orders (contd...)

Parental lines	Secondary spike characters (per plant)										Tertiary seed weight (g/plant)	
	Spike number		Effective spike length (cm)		Capsule number		Spike weight (g)		Seed weight (g)			
	Control	Stress	Control	Stress	Control	Stress	Control	Stress	Control	Stress	Control	Stress
1932-1	3	4	24.8	23.5	24	18	105.4	101.7	55.9	46.7	0.0	0.0
ICS-164	3	3	22.9	20.1	19	18	86.7	89.2	32.8	34.1	9.5	11.6
ICS-200	3	3	19.0	13.1	26	19	91.1	79.1	44.7	34.5	7.8	11.1
ICS-299	3	3	25.9	16.5	19	16	67.9	52.1	32.2	23.9	8.0	7.9
ICS-321	3	2	22.2	15.3	26	19	105.8	55.4	58.3	25.6	0.0	21.9
IPC-41	3	3	33.6	28.8	26	16	107.8	54.4	58.6	21.8	12.6	0.0
IPC-42	3	2	32.4	19.6	25	17	80.6	49.7	36.5	22.8	16.0	11.9
IPC-44	3	3	26.1	14.9	29	15	95.1	54.7	48.2	27.0	25.2	14.2
IPC-46	3	3	24.8	22.5	19	17	91.0	59.1	39.7	21.8	7.7	0.0
DPC-9	3	3	23.9	20.1	27	20	119.8	61.4	52.2	26.3	5.5	7.4
DPC-22	3	2	20.8	23.5	22	18	94.0	53.2	37.7	26.0	0.0	0.0
DPC-25	2	2	27.9	22.3	23	17	90.7	39.6	37.4	17.7	6.2	3.8
48-1	3	2	20.7	14.7	24	19	105.5	65.6	54.4	32.3	16.5	22.0
DCH-519	3	3	20.2	26.0	23	22	108.7	67.7	57.1	29.7	11.7	0.0
Mean	3	3	24.7	20.1	24	18	96.5	63.1	46.1	27.9	9.0	8.0
CD (0.05)												
Main plot			0.40		0.88		1.45		1.58			
Sub plot			3.09		3.11		13.12		4.65			
interaction			4.37		4.39		18.56		6.58			
CV (%) a			2.6		6.0		5.0		8.1			
b			16.18		17.6		19.3		14.7			

Table 4 Mean seed yield, DSI, TDM, HI and oil content at harvest

Parental lines	Total seed yield (g/plant)		% reduction in seed yield	Drought susceptibility index (DSI)	Total spike weight (g/plant)		TDM at harvest (g/plant)		Harvest Index (HI)		Total oil content (%)	
	Control	Stress			Control	Stress	Control	Stress	Control	Stress	Control	Stress
1932-1	130.5	93.9	28.0	0.78	236.3	193.5	355.1	289.8	36.5	33.8	44.3	44.1
ICS-164	110.7	95.1	14.1	0.40	214.7	199.0	296.5	233.8	37.0	40.1	44.8	47.0
ICS-200	100.0	72.8	27.2	0.76	188.0	158.3	293.2	256.0	35.1	32.3	44.6	43.5
ICS-299	97.2	70.0	28.0	0.78	193.1	140.1	250.9	169.6	37.8	41.1	45.6	46.5
ICS-321	117.7	77.1	34.5	0.97	194.7	164.3	284.4	219.2	41.1	34.6	45.2	44.9
IPC-41	132.8	56.9	57.2	1.60	202.5	127.6	341.2	218.2	41.0	25.6	45.3	45.1
IPC-42	84.3	65.1	22.8	0.64	213.9	118.6	221.5	167.2	37.8	36.5	44.4	44.3
IPC-44	113.4	66.4	41.5	1.16	193.3	128.1	298.4	187.5	40.9	33.8	44.9	45.7
IPC-46	111.3	67.5	39.4	1.10	238.9	141.9	343.0	216.7	35.4	32.3	43.8	45.8
DPC-9	115.1	82.1	28.7	0.80	253.9	165.7	355.5	246.0	34.9	37.5	44.4	43.3
DPC-22	116.7	69.7	40.2	1.13	279.4	149.0	313.7	216.8	40.5	35.7	43.8	44.1
DPC-25	111.5	63.8	42.8	1.20	232.6	139.1	319.4	216.6	35.4	32.3	44.6	44.2
48-1	131.7	91.2	30.7	0.86	230.3	159.3	314.3	212.8	40.6	42.2	43.9	44.9
DCH-519	157.7	76.7	51.4	1.44	246.1	147.3	396.3	231.9	39.5	32.6	44.0	44.4
Mean	116.5	74.9	34.8	0.97	222.7	152.3	313.1	220.1	38.1	35.0	44.5	44.8
CD (0.05)												
Main plot	1.533			3.321	2.880	1.077	0.702					
Sub plot	6.62			16.07	17.91	2.84	1.23					
interaction	9.37			22.72	25.33	4.02	1.74					
CV (%) a	4.85			7.51	5.46	5.68	3.26					
b	8.1			10.03	7.86	5.52	0.587					

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Influence of weather parameters on progress of rust disease severity caused by *Melampsora lini* (Ehrenb.) Lev. in linseed

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ABSTRACT

Linseed rust caused by *Melampsora lini* (Ehrenb.) Lev. has been reported as major disease every year in Kanke region of Ranchi district limiting the potential yield of linseed and incurred severe losses to linseed crop. Field trial was conducted during the *rabi* season 2019-2020 and 2020-2021 to study the progress of rust on linseed using variety T-397 in relation to weather parameters. Present study revealed that rust disease generally appeared 90 -100 days after sowing and was subsequently increased with a period of time till harvest (0.67 to 73.33 per cent). Disease was observed at a maximum temperature of 26.4 to 34.26°C, 7.58 to 16.8°C minimum temperature, 83 to 89 per cent morning relative humidity (RH), 67to 69 per cent afternoons RH, 0 to 43.6 mm rainfall, sunshine hours 2.2 to 9.7 hrs and soil moisture at 0-15 cm was 10.12 to 24.73 % and 15-30 cm depth was 10.88 to 26.38%. The correlation between different meteorological parameters and rust severity revealed that per cent disease severity showed highly significant positive correlation with minimum temperature (r = 0.764), RH % Morning (r= 0.779) and soil moisture at different depths 0-15 cm (r = 0.786) and 15-30 cm (r = 0.768) whereas disease severity show negative correlation with sunshine hours (r = -0.353).It was observed that the rust severity is highly influenced by the different weather parameters such as temperature, relative humidity and soil moisture at different depths.

Keywords: Linseed, Rust, Relative humidity, Rainfall, Soil moisture, Temperature

Linseed rust caused by *Melampsora lini* (Ehrenb.) Lev. inflicts severe epidemics year after year with estimated range between 40 to 100% depending upon the amount of initial inoculum, time to first appearance of the disease and subsequent build up and dissemination of the pathogen. The disease can cause 13.1% reduction in oil content of heavily rusted plants (Saharan, 1978). The severely affected plants are killed prematurely. Seeds are shriveled and fibers are weakened and stained black in diseased plants. Linseed rust is macrocyclic and euautoecious, surviving only on Linum species. In India the uredospores and teleutospores do not survive in plains due to unfavorable weather conditions (Vasudeva, 1962). However, they may survive in hills throughout the year (Mathur *et al.,* 1961). Misra and Sethi (1962) and Prasada (1967) have shown actual role of teleutospores in initiating the disease in hilly areas of Northern India. The disease is initiated from pieces of linseed straws, bearing viable teleutospores in stored seeds, which is common in the hills, hence, clean seeds preferably after seed dressing was recommended. Singh *et al.* (2016) reported that the germination and survival of the uredospores dependent upon temperature, leaf wetness and light. The disease appears in seven days at temperatures between 13° to 21°C, while in 18 days at 0°-10°C. They are killed on exposure for 24h at 38-43°C and in 9h at 43-50°C. Teleutospores develop and germinate best at 18-24°C. The leaf wetness and light intensity also play a vital role in infections. Saharan (1978) reported that 4h leaf wetness and 15 to 25°C temperature were optimum for infection. At 0°C the maximum duration of leaf wetness required is 8 hour. Light affects the incubation period and it is twice in reduced light as compared to continuous light. Race and cultivar speciality with regards to effect of light intensity, incubation and latent period have been demonstrated by Saharan and Singh (1979). Analyses of simple correlation coefficient indicated that TEMP, MRH and RH have a highly significant positive correlation with latent period whereas MTEMP had a highly significant negative correlation. Studies showed that mean temperature below 5ºC considerably influences rust development. For the progress of rust, the partial regression coefficients for TEMP are significant in TEMP, MRH. The multiple regression equation build up from different combination of variables for the progress of disease with R^2 values explained variation ranging from 39.9 to 61.5 percent (Saharan and Singh,1985).

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MATERIALS AND METHODS

The field trial was conducted during *rabi* 2019-20 and 2020-21 crop season in randomized block design in three replications using 'T397' a susceptible cultivar, to rust disease. The plot size was 2.0×4 m^2 and inter-row spacing 25 cm. To study the progress of rust disease, Observation on the first appearance of disease on 10 randomly plants were selected in each plot and thereafter severity of disease at biweekly interval till the maturity of the crop were recorded. The weather parameters were correlated with per cent disease severity by calculating the, Karl Pearson's correlation coefficient (r) as given below.

$$r = \frac{1}{n-1}\sum\frac{(x_i-\bar{X})(y_i-\bar{Y})}{S_x S_y}$$

Where, r = coefficient of correlation,

$X = x_i - \bar{X}$, $Y = y_i - \bar{Y}$, S_x = standard deviation of x series, Sy= standard deviation of y series, n= number of series.

Also, Partial regression equations were calculated for the meteorological factors as independent variable with the prediction equation.

Prediction equation $Y = b_0 + b_1X_1 + b_2X_2 \dots\dots\dots b_7X_7$. Where, Y = Percent disease severity, b_0= constant; b_1, b_2.....b_7 = regression coefficients and X_1, X_2....X_7= Independent weather variable.

RESULTS AND DISCUSSION

Year 2019-2020: The effect of weather parameters on rust severity for the progress of rust was shown in Table 1. It is evident from the Table 1 that lowest linseed rust disease severity of 1.33% was recorded on 17th February whereas highest rust severity of 73.33% was recorded on 24th March 2020. Kumar (2016) also observed that rust of linseed appeared in kangra during 7th to 9th standard meteorological week during 2009-2012. It was also found that the disease severity increases with increasing order from 17th February to 8th March, therefore rust severity showed only 2.0 per cent increment and after that the disease severity increases with decreasing trend i.e. from 8th March to 24th March. Temperature ranges from 10.1 to 31.1ºC, Relative humidity ranges from 67 to 89%, Rainfall ranges from 1 to 43.6 mm, soil moisture ranges from 10.12 to 24.73% for upto 15 cm depth, Soil moisture 15-30 cm depth ranges from 10.8 to 24.87% helps in development of the disease. Highest disease severity of 73.33% was recorded when maximum temperature (31.1ºC), minimum temperature (16.6ºC), Relative humidity morning (87%) and afternoon (69%), Sunshine hours (8.3), Rainfall (4.2 mm), Soil moisture 0-15 cm (14.55%) and Soil moisture 15-30 cm (15.65%). Whereas lowest disease severity 0f 1.3% was recorded when maximum temperature (26.4ºC), minimum temperature (10.1ºC), Relative humidity morning (83%) and afternoon (68%), Sunshine hours (9.7), Rainfall (0 mm), Soil moisture 0-15 cm (10.38%) and Soil moisture 15-30 cm (11.07%). Kumar (2016) also reported that maximum temperature during the period of outbreak of disease ranged from 16.3ºC to 25.9ºC whereas minimum temperature fluctuated between 6.5ºC to 11.1ºC, relative humidity at morning varied from 48 to 96% whereas 30 to 95% relative humidity at afternoon and an average rainfall of 22mm was recorded for outbreak of rust. The references on linseed rust in relation to weather variables are not available in relation to sunshine hrs and soil moisture. This is in accordance with the present findings.

Simple correlation worked out between the weather parameters and disease severity % of linseed rust (Table 2). The data revealed that there was significant positive correlation with minimum temperature (r = 0.637*) and morning relative humidity (r=0.782**) while non-significant positive correlation with maximum temperature, afternoon relative humidity and rainfall. The association of disease severity with bright sunshine hour was negative and non-significant. The result indicated that linseed is more susceptible to rust under high minimum temperature and morning relative humidity. Soil moisture percent at 0-15 cm (r= 0.64*) and 15-30 cm (0.66*) depth exhibited significant positive relationship with per cent disease severity of linseed rust. This indicates that increase in soil moisture will increase incidence of linseed rust. But in field pea rust high positive correlation was observed with maximum temperature, minimum temperature and rainfall (Upadhyay *et al.,* 2017). Singh *et al.* (2012) also recorded significant positive correlation with temperature in relation to pea rust. Lal *et al.* (2008) while working on lentil rust predicted the rust severity. They also reported that minimum temperature, maximum relative humidity and maximum cloud cover had significant and positive effect on disease progress.

Multiple regression analysis for prediction of disease severity (Y) of rust of linseed

Multiple coefficient of determination between rust severity and group of independent variables i.e. weather parameters were found to be 0.937 which indicate that 93.7% change in disease severity was attributed to all the meteorological factors *viz.,* maximum temperature, minimum Temperature, relative humidity morning and afternoon, rainfall, sunshine hrs and soil moisture at upto 15 cm and soil moisture between 15-30 cm. Whereas rest of the variation is due to unexplained factors (Table 2). Saharan and Singh (1985) also worked out regression analysis of rust with weather variables and reported that multiple regression equation build up from different combination of variables for progress of rust with R^2 values explained variation ranging from 39.9 to 61.5 per cent. The unit change of maximum temperature would influence the rust upto an extent of 9.745 units, followed by Soil moisture between 15-30 cm depth (0.865), Soil moisture upto 0-15 cm depth (0.775) and minimum temperature (4.899).

Year 2020-2021: During 2020-2021, first appearance of disease was observed on 14th February and was subsequently increased with a period of time (0.67 to 69.33 per cent). Rust disease was observed at a maximum temperature of 26.5 to 34.26°C, 7.58 to 16.8°C minimum temperature, 82 to 88 morning RH, 67 to 69 afternoon RH, 0.00 to 12.4 rainfall, 5.08 to 9.7 hrs sunshine hrs and soil moisture at 0-15 cm depth ranges from 10.15 to 24.67 percent and 10.89 to 26.38 percent at 15-30 cm depth (Table 3).

Correlation among different weather parameters and the disease severity in the year 2020-2021 indicated that the per cent disease severity was having a positive correlation with maximum temperature (0.680) and morning relative humidity (0.758) and rust disease severity was highly significant positive correlation with minimum temperature (0.846) and soil moisture at different depths 0-15 cm (0.825) and 15-30 cm (0.779) while non-significant correlation with relative humidity at afternoon, sunshine hrs and rainfall as shown in Table 4. The multiple linear regression equation indicating that an unit increase in maximum temperature and morning relative humidity enhance the disease severity by 8.947 and 12.490 units. whereas every unit increase in minimum temperature, relative humidity (afternoon) and rainfall will decrease the severity of disease by 3.553, 1.413 and 2.236 units.

Pooled data of 2019-20 and 2020-21: The pooled data (Table 5) of the year 2019-20 and 2020-2021 revealed that disease initiation was first observed 90-100 days after sowing and was subsequently increased with a period of time (0.67 to 73.33 per cent). Disease was observed at a maximum temperature of 25.9 to 34.26°C, 7.58 to 16.8°C minimum temperature, 82 to 89 morning RH, 67 to 69 afternoons RH, 0.0 to 43.6 mm rainfall and sunshine hours 2.2 to 9.7 hrs and soil moisture at 0-15 cm was 10.12 to 24.73% and 15-30 cm depth was 10.88 to 26.38%. Correlation among different weather parameters and the disease severity at bi-weekly interval for both the year 2019-2020 and 2020-202021 indicate that the percent disease severity was having a highly significant positive correlation with minimum temperature (0.764), morning relative humidity (0.779) and soil moisture at different depths at 0-15 cm(0.786) and 15-30 cm (0.768) (Table 6.). The multiple linear regression equation after step down elimination for disease severity was, $Y=-280.674 + 2.233X_1 +1.385X_2+2.548X_3-0.020X_4-1.334X_5+ 0.170X_6 +1.5859X_7 -0.095X_8$ indicating an unit increase in minimum temperature, relative humidity morning and soil moisture at different depths enhance the disease severity by 2.233, 1.385 and 1.585, 0.095 units (Table 6.).

Table 1 Effect of weather parameters on severity of linseed rust during 2019-2020

SMW	Date of Observations	*Disease Severity (%)	Temperature (ºC)		Relative Humidity (%)		Sunshine hours	Rainfall (mm)	Soil moisture (%)	
			Max	Min	Morning	Afternoon			0-15 cm	15-30 cm
7th	17-Feb-20	1.33 (6.53)	26.4	10.1	83	68	9.7	0.0	10.38	11.07
8th	21-Feb-20	4.67 (12.02)	26.9	13.0	84	69	8.6	0.0	10.12	10.88
8th	25-Feb-20	11.33 (19.54)	27.9	14.8	85	68	5.9	1.0	15.56	16.28
9th	29-Feb-20	19.33 (25.99)	25.9	13.1	84	67	5.3	6.2	18.43	18.96
9th	04-Mar-20	27.33 (31.48)	27.6	16.2	87	68	7.3	8.2	20.49	20.88
10th	08-Mar-20	46.67 (43.06)	26.8	13.6	86	68	5.0	43.6	24.73	24.87
11th	12-Mar-20	57.33 (49.20)	26.5	14.1	87	69	4.9	8.4	21.85	22.92
11th	16-Mar-20	66.67 (54.73)	26.1	13.4	85	69	2.2	20.4	22.97	23.73
12th	20-Mar-20	71.33 (57.62)	29.4	16.1	89	67	5.6	0.0	18.77	19.26
12th	24-Mar-20	73.33 (58.90)	31.1	16.6	87	69	8.3	4.2	14.55	15.65
	SEm (±)	1.378	Year of Observations - 2020							
	CD (P=0.05)	4.126								
	CV %	7.630								

*Average of three replications; Figures in parentheses are transformed arc sine values; SMW- Standard Meteorological Week

Table 2 Correlation and multiple regression analysis of rust severity with weather parameters in linseed during 2019-2020

	Temperature (ºC)		Relative Humidity (%)		Sunshine (hrs)	Rainfall (mm)	Soil moisture (%)	
	Max	Min	Morning	Afternoon			0-15cm	15-30 cm
Percent rust severity	0.469	0.637*	0.782**	0.141	-0.561	0.332	0.642*	0.665*

Dependent parameter	Multiple regression equation	R2
Percent rust Severity (Y) =	$-0.775 + 9.745X_1 + 4.899X_2 + 4.179X_3 + 3.583X_4 - 3.355X_5 + 0.028X_6 + 0.775X_7 + 0.865X_8$	0.937

**Correlation is significant at 0.01 level   *Correlation is significant at 0.05 level,
X_1= Maximum temperature, X_2 = Minimum temperature, X_3 = Relative humidity at morning, X_4 = Relative humidity at afternoon, X_5 = Sunshine hrs, X_6 = Rainfall, X_7 = Soil moisture (0-15 cm), X_8 = Soil moisture (15-30 cm)

Table 3 Effect of weather parameters on severity of linseed rust during 2020-2021

SMW	Date of Observations	*Disease Severity (%)	Temperature (ºC)		Relative Humidity (%)		Sunshine hours	Rainfall (mm)	Soil moisture (%)	
			Max	Min	Morning	Afternoon			0-15 cm	15-30 cm
7th	14-Feb-21	0.67 (3.82)	29.87	7.58	82	67	9.7	0	10.15	10.89
8th	18-Feb-21	1.67 (7.33)	27.98	11.45	83	69	7.46	0	10.25	11.87
9th	22-Feb-21	5.33 (12.9)	26.5	12.7	85	68	5.08	0	11.51	12.86
9th	26-Feb-21	10.67 (18.79)	26.72	11.65	84	67	9.5	0	11.24	12.58
10th	02-Mar-21	23.33 (28.85)	31.5	16.3	88	69	9.12	0	10.97	12.08
10th	06-Mar-21	40.67 (39.59)	30.7	13.68	85	68	9.32	0	10.35	11.49
11th	10-Mar-21	53.33 (46.89)	30.8	15.38	87	69	8.82	12.4	22.48	25.92
11th	14-Mar-21	59.33 (50.39)	28.56	14.6	86	69	6.44	6	24.67	26.38
12th	18-Mar-21	64.67 (53.52)	32.76	16.4	88	68	8.4	0	21.56	20.49
13th	22-Mar-21	69.33 (56.38)	34.26	16.8	86	69	8.42	0	19.84	20.25
	SEm (±)	1.477	Year of Observations – 2021							
	CD (P=0.05)	4.424	SMW- Standard Meteorological Week							
	CV %	7.778								

*Average of three replications; Figures in parentheses are transformed arc sine values

Table 4 Correlation & Multiple Regression Analysis of rust severity with weather parameters in linseed during 2020-2021

	Temperature (ºC)		Relative Humidity (%)		Sunshine (hrs)	Rainfall (mm)	Soil moisture (%)	
	Max	Min	Morning	Afternoon			0-15 cm	15-30 cm
Percent rust severity	0.680*	0.846**	0.758*	0.482	0.039	0.396	0.825**	0.779**

Dependent parameter	Multiple regression equation	R2
Percent rust Severity (Y) =	$+772.208 + 1.149X_1 + 7.875X_2 - 5.278X_3 - 6.738X_4 + 0.892X_5 + 0.868X_6 + 2.689X_7 - 1.304X_8$	0.949

**Correlation is significant at 0.01 level   *Correlation is significant at 0.05 level,
X_1= Maximum temperature, X_2 = Minimum temperature, X_3 = Relative humidity at morning, X_4 = Relative humidity at afternoon, X_5 = Sunshine hrs, X_6 = Rainfall, X_7 = Soil moisture (0-15 cm), X_8 = Soil moisture (15-30 cm)

Table 5 Effect of weather parameters on severity of linseed rust during 2019-2020 and 2020- 2021 (Pooled)

SMW	Date of Observations	*Disease Severity (%)	Temperature (ºC)		Relative Humidity (%)		Sunshine hours	Rainfall (mm)	Soil moisture (%)	
			Max	Min	Morning	Afternoon			0-15 cm	15-30 cm
7th	17-Feb-20	1.33 (6.53)	26.4	10.1	83	68	9.7	0.0	10.38	11.07
8th	21-Feb-20	4.67 (12.02)	26.9	13.0	84	69	8.6	0.0	10.12	10.88
8th	25-Feb-20	11.33 (19.54)	27.9	14.8	85	68	5.9	1.0	15.56	16.28
9th	29-Feb-20	19.33 (25.99)	25.9	13.1	84	67	5.3	6.2	18.43	18.96
9th	04-Mar-20	27.33 (31.48)	27.6	16.2	87	68	7.3	8.2	20.49	20.88
10th	08-Mar-20	46.67 (43.06)	26.8	13.6	86	68	5.0	43.6	24.73	24.87
11th	12-Mar-20	57.33 (49.20)	26.5	14.1	87	69	4.9	8.4	21.85	22.92
11th	16-Mar-20	66.67 (54.73)	26.1	13.4	85	69	2.2	20.4	22.97	23.73
12th	20-Mar-20	71.33 (57.62)	29.4	16.1	89	67	5.6	0.0	18.77	19.26
12th	24-Mar-20	73.33 (58.90)	31.1	16.6	87	69	8.3	4.2	14.55	15.65
7th	14-Feb-21	0.67 (3.82)	29.87	7.58	82	67	9.7	0	10.15	10.89
8th	18-Feb-21	1.67 (7.33)	27.98	11.45	83	69	7.46	0	10.25	11.87
9th	22-Feb-21	5.33 (12.9)	26.5	12.7	85	68	5.08	0	11.51	12.86
9th	26-Feb-21	10.67 (18.79)	26.72	11.65	84	67	9.5	0	11.24	12.58
10th	02-Mar-21	23.33 (28.85)	31.5	16.3	88	69	9.12	0	10.97	12.08
10th	06-Mar-21	40.67 (39.59)	30.7	13.68	85	68	9.32	0	10.35	11.49
11th	10-Mar-21	53.33 (46.89)	30.8	15.38	87	69	8.82	12.4	22.48	25.92
11th	14-Mar-21	59.33 (50.39)	28.56	14.6	86	69	6.44	6	24.67	26.38
12th	18-Mar-21	64.67 (53.52)	32.76	16.4	88	68	8.4	0	21.56	20.49
13th	22-Mar-21	69.33 (56.38)	34.26	16.8	86	69	8.42	0	19.84	20.25
	SEm (±)	2.216								
	CD (P=0.05)	6.369								
	CV %	10.268								

Year of Observations 2019-2020 & 2020-2021 (Pooled)
SMW- Standard Meteorological Week

*Average of three replications Figures in parentheses are transformed arc sine values

Table 6 Correlation & Multiple Regression Analysis of rust severity with weather parameters in linseed during 2019-2020 and 2020-2021 (Pooled)

	Temperature (ºC)		Relative Humidity (%)		Sunshine (hrs)	Rainfall (mm)	Soil moisture (%)	
	Max	Min	Morning	Afternoon			0-15 cm	15-30 cm
Percent rust severity	0.387	0.764**	0.779**	0.283	-0.353	0.384	.786**	.768**

Dependent parameter	Multiple regression equation	R2
Percent rust Severity (Y) =	$-280.674 + 2.233X_1 + 1.385X_2 + 2.548X_3 - 0.020X_4 - 1.334X_5 + 0.170X_6 + 1.5859X_7 - 0.095X_8$	0.842

**Correlation is significant at 0.01 level *Correlation is significant at 0.05 level,
X_1= Maximum temperature, X_2 = Minimum temperature, X_3 = Relative humidity at morning, X_4 = Relative humidity at afternoon, X_5 = Sunshine hrs, X_6 = Rainfall, X_7 = Soil moisture (0-15 cm), X_8 = Soil moisture (15-30 cm)

The rust severity is highly influenced by the different weather parameters such as temperature, relative humidity, sunshine hrs, rainfall and soil moisture at different depths. The results of the present investigation revealed that the rust severity has positive relationship with temperature, relative humidity rainfall and soil moisture at different depths whereas it shows negative correlation with sunshine hours. Similar results were found by Upadhyay *et al.* (2017) who mentioned highly significant positive correlation between the pea rust disease severity with morning relative humidity. Kumar (2016) also observed significant and positive correlation between rust severity and temperature, relative humidity and rainfall. However, disease severity has a negative correlation with sunshine hours. Many more researchers have observed the similar relationship between different weather parameters and rust severity. Stavely (1991) stated that moist weather with a temperature of 15-24°C increased the severity of pea rust. Kushwaha *et al.* (2006) reported the germination of aeciospores of pea rust favoured by a temperature in the range of 10-25°C. Joshi and Tripathi (2012) observed that a temperature of 20°C is optimum for the germination of aeciospores, uredospores and teliospores of rust disease of lentil. This justifies the importance of weather factors in rust disease development. Long term research on role of weather factors need to be carried out for the development of appropriate forecasting model.

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Unravelling the evolutionary trajectory: Exploring the dynamics of oilseeds cultivation in Haryana 1989-90 to 2020-21

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ABSTRACT

The performance of all oilseeds in Haryana is examined in the current research utilizing time series data gathered from 1989-1990 to 2020-2021 from various sources. After reviewing the performance of oilseeds, it was determined that the yield aspect of all oilseeds at the national level had demonstrated notable performance. Over the course of the study period, there was a slow but significant increase in the area, output, and yield of all oilseeds. Oilseed supply and demand in the country are out of balance, forcing us to import edible oils. To close the gap between oilseed production and consumption, the government must implement technological advances and increase oilseed output. The various climatic conditions of Haryana provide ideal habitats for the development of oilseeds throughout each of its districts. The state has a predominately dry climate with warm summers and rather chilly winters. Oilseed crops including mustard, sunflower, and soybean are particularly well-suited to these circumstances. The state's winter environment is well-aligned with the *rabi* season, which runs from November to April. This creates an optimal window for the growth of oilseeds. The comparatively low levels of humidity during this time aid in the prevention of fungi diseases and encourage strong plant growth. The loamy and sandy-loam soils of Haryana also aid in the success of oilseeds by promoting root growth and good drainage.

Keywords: Climatic conditions, Consumption, Linseed, Oilseeds, Performance, Production

Oilseeds are an essential component of the Indian cuisine and are regarded as one of the earliest cultivated plants in human history. History has it that the discovery of wild mustard in the Near East, southern Iran, and India provides evidence of its origin. In China, it is also grown as a leafy vegetable. However, due to their geographic location, adaptability, and resource abundance, the United States, China, and India have become the top mustard producing nations (Kalia *et al.,* 2021). India ranks among the top producers of oilseeds globally and plays a significant role in the country's agricultural economy. Nine significant oilseed crops are farmed in India, seven of which are edible oils (soybean, groundnut, rapeseed, mustard, sunflower, sesame, safflower, and Niger) and two of which are not (castor and linseed). Oilseed output, acreage, and economic importance are only surpassed by food grains. India is the world's top producer of groundnuts, rapeseed-mustard, and soybeans. India has the fourth-largest vegetable oil economy in the world. Next to the United States, China, and Brazil, the nation produces 6-7% of the world's vegetable oils and consumes 9-10% of all edible oils. India currently produces 6.8% of the world's oil meal, exports 5.9% of it, exports 6.1% of its vegetable oil, imports 9.0% of its vegetable oil, and uses 9.3% of the world's edible oil. Castor, Niger, safflower, and sesame are among the minor oilseeds that India produces the most of. India is the world's top producer of groundnut, third in rapeseed-mustard, and fifth in soybean when it comes to main oilseeds (Rai *et al.,* 2016). Due to globalization, the world's agricultural situation is changing. India is the world's second-largest producer of mustard, but it still has a long way to go before dominating the global market. Improvements to research facilities and contemporary technology are required for mustard farming, along with the identification of those places that can function more effectively and produce higher production. Rajasthan is the state with the most production, although the Bundelkhand region of Uttar Pradesh has produced greater results (Kalia *et al.,* 2021). To compete internationally in a wide range of agricultural commodities, Indian agriculture must overcome new obstacles. Second-generation issues in Indian agriculture include a rise or fall in the water table, an imbalance in nutrients, deteriorating soil, salinity, a resurgence of pests and illnesses, environmental pollution, and a loss in farm profit (Sujeela Gulzar and Mubarak, 2024; Verma *et al.,* 2024). Crop diversification holds great promise for addressing these issues by ensuring that basic needs are met, controlling farm income, enduring weather anomalies, managing price fluctuations, providing a balanced food supply, preserving natural resources, lowering the use of chemical fertilizers and pesticides, protecting the environment, and generating employment opportunities. Depending on the chances for diversification that are

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available, the need for diversification, and how receptive the farmers are to these requirements and opportunities, a country may be able to change its cropping pattern to achieve the goals. Technological advancements, shifts in consumer demand, irrigation expansion, availability of marketing infrastructure, and new trade agreements all create chances for crop diversification. Crop diversification is necessary to (i) reduce yield, market, and price risks, (ii) stop the depletion of natural resources, (iii) achieve national objectives like creating jobs, achieving self-sufficiency in essential crop products, and (iv) generating foreign exchange (Reddy and Suresh, 2009). The following oilseeds are farmed in Haryana: groundnut, sesame, rapeseed, mustard, and linseed. In the state, *rabi* oilseeds predominate over *kharif* oilseeds. The cropping pattern makes it clear that *kharif* oilseeds are almost non-existent due to a notable rise in the rice planting area. The cultivation of oilseeds has been impacted by the introduction of irrigation and modern inputs across most of the northern states, including Haryana. The current study reveals the district-level's spatiotemporal pattern of Haryana State's oilseeds farming. The study was conducted to study the trends and pattern of growth of different edible and non-edible oilseeds over time and to analyse the spatial distribution of oilseeds farming in the study area after the green revolution.

MATERIALS AND METHODS

Study area: Northern India's Haryana is a landlocked state. Its latitude ranges from 27°39 to 30°35' N and its longitude ranges from 74°28 to 77°36' E. Area is 4.42 million hectares (ha) overall, or 1.4% of the country's land area, make up the state. There are 154 cities and towns, 6,222 village panchayats, 93 revenue tehsils, 72 sub-divisions, 22 districts, 6 administrative divisions, 7,356 villages, and 93 revenue tehsils in Haryana. It shares borders with Punjab and Himachal Pradesh to the north, by Rajasthan to the west and south, while river Yamuna forms its eastern border with Uttar Pradesh. Haryana surrounds Delhi, the nation's capital, on three sides (the north, the west, and the south), hence for planning and development purposes, a sizable portion of the state is incorporated within India's economically significant National Capital Region.

The present investigation was mainly based on the secondary data of area, production under oilseeds retrieved from different published sources covering a period of 30 years from 1990- 91 to 2019-20. The data sources used were Statistical Abstract of Haryana, the Economic Survey of Haryana and India. The period was subdivided into three sub-periods i.e. 1990-91 to 1999-2000, 2000-01 to 2009-10 and 2010-11 to 2019-20 to understand decadal performance.

RESULTS AND DISCUSSION

Oilseeds play a significant role in Haryana in agriculture landscape. It contributes to the economy by significantly contributing to the state's income and employment opportunities (Miah *et al.,* 2015). The cultivation of oilseeds provides cash through both domestic and foreign sales, contributing to the overall economic prosperity of the region. Oilseeds add diversity to the cropping pattern and it is promoted as a strategy to diversify Haryana's agricultural industry (Reddy and Suresh, 2009). Farmers are encouraged to cultivate oilseeds alongside staple crops like wheat and rice, reducing dependency on monoculture (Choudhary, 2018). This diversification enhances agricultural resilience and contributes to a more sustainable and varied farming system.

Oilseeds are a valuable source of healthy fats, proteins, and essential nutrients (Jithender and Rathod, 2019). The production of edible oils from oilseeds, are widely used in cooking and meal preparation, and they play a crucial role in the human diet (Sarwar, 2013).The by-products of oilseeds, such as oilseed cakes and meals, serve as essential components in animal feed (Shenoi, 2003). This supports the growth (Sharma, 2014) and production of Haryana's dairy and poultry industries by providing high protein, essential amino acids, and other nutrients to animals.

Cultivating oilseeds also generates employment and bring about socio-economic growth. The entire value chain of oilseeds, including growing, harvesting, processing, and selling, generates employment opportunities at various stages (Mruthyunjaya *et al.,* 2005). This not only benefits farmers but also contributes to job creation in marketing, shipping, storage, and oilseed processing mills (Gaddi *et al.,* 1999). Cultivating oilseeds ensures crop rotation and improves soil fertility. Oilseeds, like mustard, are incorporated into crop rotation systems to enhance soil fertility (Olabiyi *et al.,* 2010). They break cycles of pests and diseases, reduce weed infestations, leguminous oilseeds like soybean and groundnut fix nitrogen, and add organic matter to the soil, promoting sustainable and healthier agricultural practices (Ball *et al.,* 2005). Including oilseeds in the agricultural portfolio helps diversify crops, lowering the risk of crop failure, pest infestation, disease, and adverse weather conditions (Shahi and Umesh, 2012). Considering the immense benefits of growing oilseeds, The Haryana government provides incentives, subsidies, and support schemes to boost oilseed production (Mathur *et al.,* 2023). These initiatives aim to increase farmer earnings, enhance oilseed production, and reduce reliance on foreign edible oils, demonstrating a commitment to supporting the agricultural sector (Tinde *et al.,* 2016) including oilseeds in the cropping pattern

1. Government incentives and support schemes

2. Provide farmers with a second source of revenue, reducing their reliance on a single crop (Sen *et al.,* 2017; Basantaray and Nancharaiah, 2017). This diversification helps mitigate financial risks associated with market fluctuations, stock prices, and potential crop calamities, providing a more stable and sustainable income for farmers. There has been a growing demand for oilseeds and their by-products, such as edible oils, is substantial in both domestic and international markets (Jat *et al.,* 2019). Growing oilseeds allows farmers to capitalize on this demand, offering opportunities to create value-added products like processed oils or cakes and meals for increased profitability. Farmers can benefit from governmental insurance programs and risk management strategies that typically cover a variety of crops, enhancing their overall risk management capabilities (Pandey and Kumar, 2005).

As indicated in the tables 1 and 2, over the span of 30 years, from 1989-1990 to 2020-2021, there has been a discernible shift in the cultivation landscape of oilseeds in Haryana, as reflected in the provided data. In 1989-1990, the total area dedicated to oilseed cultivation stood at 446.8 hectares, and over the subsequent decades, this figure has witnessed a noteworthy increase, reaching 643.2 hectares in 2020-2021. Concurrently, the overall cropped area in Haryana has experienced growth, rising from 5651 hectares in 1989-1990 to 6528 hectares in 2020-2021. This expansion is indicative of a broader trend in agricultural practices and land use in the region. Notably, the percentage of oilseeds in the total cropped area has seen a significant uptick, climbing from 7.9% to 9.85% over the same period. This shift signifies a spatial reconfiguration, suggesting that oilseed cultivation has gained prominence within the agricultural landscape of Haryana. These fluctuations could be attributed to a myriad of factors, including advancements in agricultural technology, changes in government policies, and evolving market dynamics. The observed trends not only underscore the adaptability of Haryana's agricultural sector but also have broader implications for the state's economy, food security, and overall agricultural sustainability in the years to come.

The data presented in Table 3 illustrates the percentage of land devoted to oilseed cultivation across various districts during the 1990-91 agricultural years. Notably, the district of Rewari stands out with a substantial 26.88% of its total cropped area dedicated to oilseed cultivation, marking the highest percentage among the districts listed. This suggests a significant emphasis on oilseed production in Rewari during the specified period. Following closely, Gurgaon and Mahendragarh also demonstrated considerable commitment to oilseed cultivation, allocating 20.6% and 20.9% of their respective total cropped areas to this endeavour. Conversely, districts like Karnal, Rohtak, and Faridabad allocated relatively smaller proportions of their total cropped areas to oilseed cultivation, with percentages ranging from 0.3% to 14.1%. These variations may be indicative of diverse agricultural practices, resource availability, and regional priorities. Examining the overall distribution, it is evident that there is a considerable diversity in the allocation of land for oilseed cultivation across the districts, reflecting the distinct agricultural landscapes and priorities in each region. This diversity may be influenced by factors such as soil suitability, climatic conditions, and historical agricultural practices. In conclusion, the data from Table 3 underscores the regional disparities in oilseed cultivation percentages, providing valuable insights into the agricultural landscape of these districts during the 1990-91 periods. These variations warrant further investigation into the underlying factors influencing the choice of crops and the agricultural strategies adopted by farmers in different regions.

The data in Table 4 provide a comprehensive overview of the distribution of oilseed cultivation percentages across various districts in the year 2020-21. Notably, Rewari emerged as a prominent district with the highest percentage of its total cropped area, an impressive 37.54%, dedicated to oilseed cultivation. This significant increase from the 1990-91 period suggests a substantial shift in agricultural practices, emphasizing the importance of oilseed production in Rewari. Mahendragarh follows closely, with 34.74% of its total cropped area allocated to oilseeds, showcasing a noteworthy commitment to this crop. Other districts such as Bhiwani and Charkhi Dadri also exhibited substantial increases in oilseed cultivation percentages, recording 27.35% and 27.6%, respectively. Conversely, districts like Faridabad, Karnal, and Kaithal showed relatively lower percentages, reflecting variations in regional agricultural priorities. It is intriguing to note the substantial increase in oilseed cultivation in Gurugram, with a percentage of 17.36%, indicating the changing agricultural dynamics in this district over the years. The overall trend indicated a diversification and intensification of oilseed cultivation in Haryana, with several districts showing a considerable rise in the percentage of land dedicated to oilseeds. This shift could be influenced by the factors such as market demand, technological advancements, and government initiatives promoting oilseed cultivation. Exploring the reasons behind these changes can provide valuable insights into the evolving agricultural landscape in Haryana and guide future agricultural policies and practices.

Table 1 Percentage of area under Oilseeds in Haryana State

Years	Oilseeds (total area) (in hectare)	Total cropped area (in hectare)	Percentage
1989-1990	446.8	5651	7.9
1990-1991	488.5	5919	8.25
1991-1992	701.3	5570	12.59
1992-1993	589.4	5853	10.07
1993-1994	595.3	5815	10.23
1994-1995	618.7	5989	10.33
1995-1996	611	5974	10.22
1996-1997	673	6075	11.07
1997-1998	616	6143	10.02
1998-1999	526	6320	8.32
1999-2000	463	6029	7.67
2000-2001	414	6115	6.77
2001-2002	545	6318	8.62
2002-2003	621	6035	10.28
2003-2004	642	6300	10.19
2004-2005	714.6	6425	11.12
2005-2006	735.8	6509	11.3
2006-2007	616.2	6407	9.61
2007-2008	511.3	6458	7.91
2008-2009	527.6	6500	8.11
2009-2010	523	6351	8.23
2010-2011	521	6505	8
2011-2012	545.8	6489	8.41
2012-2013	567.6	6376	8.9
2013-2014	548.5	6471	8.47
2014-2015	495.4	6536	7.57
2015-2016	526.8	6578	8
2016-2017	523	6452	8.1
2017-2018	559.6	6549	8.54
2018-2019	626.6	6605	9.48
2019-2020	661.7	6617	10
2020-2021	643.2	6528	9.85

(Source - Statistical Abstract of Haryana from 1989 - 90 to 2020 - 21)

Table 2 Differentiation in percentage of area under oilseeds in 1989-1990 and 2020-21

Years	Oilseeds(total area) (in hectare)	Total cropped area (in hectare)	Percentage
1989-1990	446.8	5651	7.9
2020-2021	643.2	6528	9.85

Table 3 Percentage of area under oilseeds (District wise in 1990-91)

Districts	Oilseeds (total area) (in 000 hectare)	Total cropped area (in 000 hectare)	Percentage
Ambala	6.1	240	2.54
Yamunanagar	3.9	195	2
Kurukshetra	1.7	255	0.6
Kaithal	4.6	379	1.12
Karnal	0.9	294	0.3
Panipat	1.8	246	0.73
Sonipat	4.3	160	2.68
Rohtak	73.9	523	14.1
Faridabad	18.7	254	7.36
Gurgaon	61	295	20.6
Rewari	53.5	199	26.88
Mahendragarh	55.2	263	20.9
Bhiwani	59.1	658	8.98
Jind	15.2	417	3.64
Hisar	80.3	950	8.45
Sirsa	48.3	591	8.17

(Source: Statistical Abstract of Haryana from 1990-91)

Table 4: Percentage of area under Oilseeds (District wise in 2020-21)

Districts	Oilseeds (total area) (in 000 hectare)	Total cropped area (in 000 hectare)	Percentage
Ambala	5.8	209	2.77
Bhiwani	143.6	525	27.35
Charkhi Dadri	61.7	223	27.6
Faridabad	0.6	63	0.95
Fatehabad	20.8	435	4.78
Gurugram	19.1	110	17.36
Hisar	77.6	653	11.88
Jhajjar	30.6	253	12.09
Jind	6.1	467	1.3
Kaithal	1	386	0.25
Karnal	1.8	395	0.45
Kurukshetra	8.4	279	3.01
Mahendragarh	100.4	289	34.74
Nuh	21.7	183	11.85
Palwal	2.7	205	1.31
Panchkula	2	46	4.34
Panipat	1.1	192	0.57
Rewari	78.1	208	37.54
Rohtak	11	227	4.84
Sirsa	63.7	750	8.49
Sonipat	1.8	303	0.59
Yamunanagar	2.1	217	0.96

(Source: Statistical Abstract of Haryana from 2020-21)

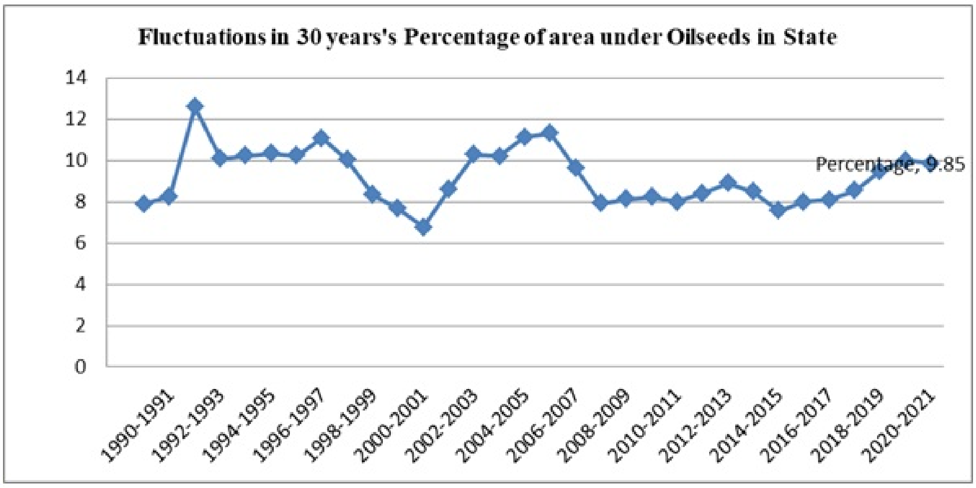

Fig. 1. Fluctuations in 30 years' percentage of area under oilseeds in state

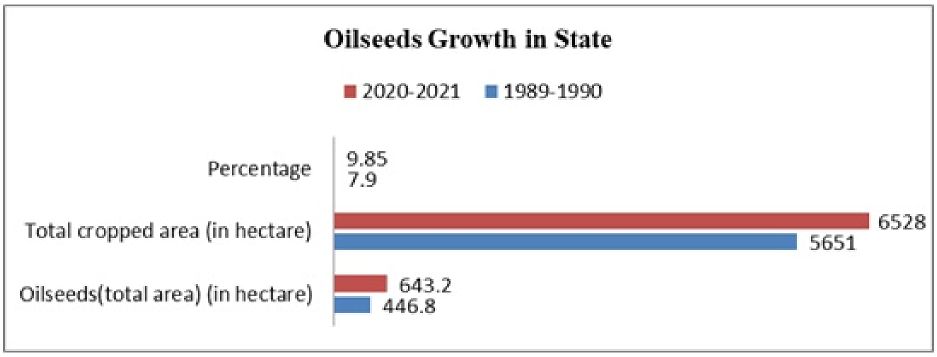

Fig. 2. Oilseeds growth in state

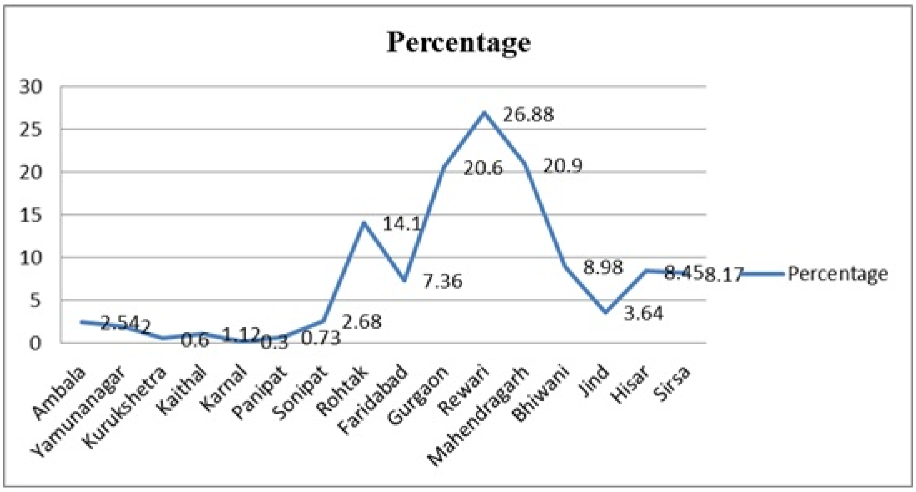

Figure 3: Percentage of area under oilseeds (District wise in 1990-91)

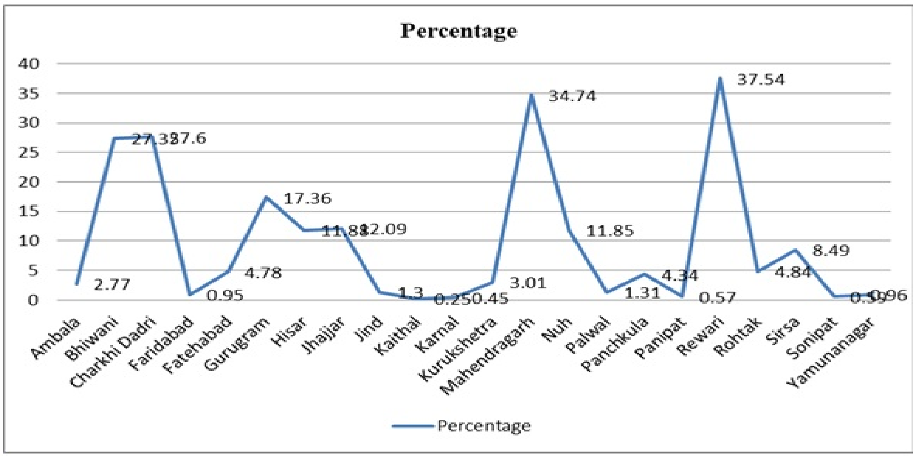

Fig. 4. Percentage of area under oilseeds (District wise in 2020-21)

Schemes by state and central governments to promote oilseeds production:

The Haryana state government and the Indian federal government have taken up many initiatives to encourage the production of oilseeds between 1990 and 2020. The success of these programmes varied, and they affected the output of oilseeds depending on several variables, such as their implementation and the degree to which farmers adopted them. The major such government initiatives include National Oilseeds and Vegetable Oils Development (NOVOD) Board (1986), Technology Mission on Oilseeds (1986-87), Integrated Scheme of Oilseeds, Pulses, Oil Palm, and Maize (ISOPOM) (2004), National Mission on Oilseeds and Oil palm (NMOOP) and National Mission on Edible Oil-Oil Palm (NMEO-OP). Each of these programmes was started with specific strategies to increase domestic oilseed and vegetable oil production and they succeeded to a great extent in achieving the set goals. NMEO-OP programme is still operating and it is expected to deliver the outputs as envisaged.

Even though there has been a positive increase in area, productivity, and yield since the start of the specific Missions on Oilseeds, the growth has been modest. This has been ascribed to many factors such asa change in cropping patterns due to increased incentives for farmers to plant wheat, paddy, and sugarcane. The area under cultivation for different oilseed crops significantly decreased due to a change in cropping patterns. Overall, since the nation depends on imports to meet it's expanding need for edible oil, the oilseeds industry has been a source of concern for policymakers and research managers. The profitability of oilseeds is a crucial consideration for decreasing import dependence by raising domestic production of oilseeds. Due to rainfed farming, small operational landholdings, a lack of varietal replacement (groundnut and sesame), losses from biotic and abiotic challenges, low adoption of agronomic and other improved practices and technologies, the productivity of oilseed crops in India is low. By employing optimum production practices and the proper combination of inputs at the appropriate time, it is possible to boost the productivity of oilseeds (Kumar *et al.,* 2020), (Sharma, 2018). The Indian government has made numerous efforts to improve the output of oilseeds and oil palm from 1991-1992. From 275 lakh tonnes in 2014-15 to 365.65 lakh tonnes in 2020-21, the production of oilseeds has increased. The Indian Institute of Oil Palm Research (IIOPR) has estimated that 28 lakh ha of oil palm can be grown to fully utilise the potential of palm oil output.

In conclusion, this research provided a comprehensive examination of the evolutionary trajectory of oilseed cultivation in Haryana from 1989-1990 to 2020-2021. The findings revealed a significant shift in the cultivation landscape, with notable increases in the area, output, and yield of oilseeds. The study emphasizes the critical role of oilseeds in Haryana's agricultural economy, contributing to income, employment, and nutritional value analysing district-level variations underscores regional disparities in oilseed cultivation, influenced by factors such as soil suitability and historical agricultural practices. The research identified key objectives, including studying growth patterns and spatial distributions post green revolution. The importance of oilseeds in Haryana is highlighted through their contributions to economic prosperity, agricultural diversification, nutritional value, livestock support, and employment generation. The detailed analysis of the area under oilseeds from 1989-1990 to 2020-2021 illustrates a substantial increase, reflecting changing agricultural dynamics. The study concluded that by adopting government schemes like NOVOD, Technology Mission on Oilseeds, ISOPOM, NMOOP, and NMEO-OP, aimed at promoting oilseed production had positive effects on oilseed production. While acknowledging the positive impact of these initiatives, the research suggests that there is a need for continued efforts to address challenges and enhance the productivity through adoption of modern technology and increased farmer awareness. Overall, the research contributes valuable insights into the evolving agricultural landscape in Haryana, emphasizing the importance of oilseeds for sustainable and resilient agricultural practices in the region.

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Mapping productivity zones for Indian mustard in Haryana: A comprehensive analysis of climatic and physical influences

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ABSTRACT

This study aims to conceptualize the productivity zoning of Indian mustard in Haryana by analysing winter season temperature, rainfall, soil characteristics, and crop area and production. Data for this study was sourced from Chaudhary Charan Singh Haryana Agricultural University (CCS HAU), Hisar. The analysis identified that the western, southern, and central regions of Haryana exhibit favourable physio-climatic conditions for mustard cultivation, while the north-eastern districts are less suitable. A winter isotherm of 18°C and isohyets of 50 mm significantly influenced the mustard-growing areas. Despite increasing rainfall, the lower temperatures in the north-eastern districts likely limit mustard productivity in those areas. Hisar and Rewari emerged as the most suitable districts due to their optimal soil and climatic conditions. The study highlights that the decreasing temperatures towards the north-eastern districts, despite higher rainfall, adversely affect mustard productivity. This research provides valuable insights for agricultural planning and policy formulation, aiming to enhance mustard crop yield in Haryana by identifying regions with optimal conditions and addressing the limitations in less suitable areas. These findings are crucial for improving mustard cultivation strategies and ensuring better resource allocation to maximize productivity in the state.

Keywords: Isotherm, Isohyets, Productivity zones, Soil texture, Winter rainfall

The present study aims to delineate productivity zones for Indian mustard in Haryana, utilizing long-term data on winter temperature, rainfall, soil texture, and mustard yield. The Trans-Gangetic Plains of India, which include the states of Punjab, Haryana, Delhi, the Union Territory of Chandigarh, and the Sriganganagar district of Rajasthan, experience regular winter phenomena characterized by three to four western disturbances (WD). These disturbances bring significant rainfall, crucial for meeting the irrigation requirements of standing Indian mustard in the region (Singh *et al.,* 2020). The concept of productivity zoning is invaluable for understanding and managing agricultural planning in this area (Kumar and Sharma, 2018). Productivity zoning and agro-climatic characterization for mustard growing zones in different states have been previously achieved based on area, production, and crop productivity (Sharma *et al.,* 2019). By employing Geographic Information System (GIS) technology, this study maps and analyses various agro-climatic and soil parameters to create distinct productivity zones within Haryana. Temperature plays a critical role in crop production, affecting cropping patterns, rainfall amount, intensity, and distribution (Gupta and Mehta, 2017). Rainfall, particularly during the winter season, is essential for maintaining soil moisture levels and meeting the irrigation needs of mustard crops. Soil characteristics, including texture, fertility, and structure, significantly influence the types of crops that can be grown and the soil management practices required (Patel *et al.,* 2016; Barik, 2023; Gulzar and Mubarak, 2024). The inherent properties of soil determine its water-holding capacity, aeration, and root penetration, which are vital for healthy crop development. The data for this study were sourced from Chaudhary Charan Singh Haryana Agricultural University (CCS HAU), Hisar. This comprehensive dataset enables a detailed analysis of the factors influencing mustard productivity in Haryana. By plotting these parameters 0using GIS, six distinct productivity zones were identified, highlighting areas with varying potential for mustard cultivation. The western, southern, and central parts of Haryana demonstrated favourable physio-climatic properties, whereas the north-eastern districts were less suitable for mustard cultivation. The analysis revealed that a winter isotherm of 18°C and isohyets of 50 mm significantly influence mustard-growing areas in the state (Raj and Kumar, 2021). Despite increasing rainfall, the lower temperatures towards the north-eastern districts likely limit mustard productivity. Hisar and Rewari emerged as the most suitable districts for mustard cultivation due to their optimal soil and climatic conditions. This research provides crucial insights for agricultural planning and policy formulation, aimed at enhancing mustard crop yields

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and ensuring sustainable agricultural practices in Haryana. Integrating various agro-climatic factors with advanced GIS techniques, this study offers a detailed and informative analysis of productivity zoning for Indian mustard. Such an approach not only aids in understanding the current agricultural landscape but also in making informed decisions for future agricultural development in Haryana and similar regions (Yadav and Singh, 2022).

MATERIALS AND METHODS

Data collection and zoning of agro-climatic zones

To delineate the agro-climatic zones for Indian mustard in Haryana, we utilized comprehensive data on area and productivity of rapeseed and mustard from various districts. This data was sourced from the Statistical Abstract of Haryana. The data calculated district-wise percentage of area and production for these crops. Using the cumulative percentage of total method, the data was sorted in ascending order and categorized into three distinct zones. This method is particularly useful as it involves cumulative percentages instead of frequencies, resulting in a cumulative percentage distribution, which provides a clearer picture of the distribution patterns (Singh *et al.,* 2018).

Soil textural classification

Information on soil textural classification was obtained from the Resource Atlas of Haryana and the Department of Soil Science at Chaudhary Charan Singh Haryana Agricultural University (CCS HAU), Hisar. The state was found to have eight distinct soil textural types, each influencing the suitability for mustard cultivation differently. The soil texture types include sandy, loamy sand, sandy loam, loam, silt loam, clay loam, silty clay, and clay (Patel *et al.,* 2017).

RESULTS AND DISCUSSION

Classification of growing environment: To classify the growing environment of rapeseed and mustard in the state, we analyzed the total area under crop, production, and productivity across different districts for the most recent five-year period (2014-15 to 2020-21). This analysis incorporated the winter season's average temperature and rainfall, using GIS, along with the textural classification of soil in Haryana.

Area, production, and productivity of rapeseed and mustard: The district-wise average area, production, and productivity of mustard during the rabi seasons from 2014-15 to 2020-21 were computed based on data from the Statistical Abstract of Haryana. By applying the cumulative frequency distribution method, which uses the cumulative total frequency of area and productivity of mustard in the state's districts as inputs, the criteria and categorization of the districts were determined (Table 1). Districts were divided into three categories based on the cumulative percentage of the total.

Table 1 Agro-climatic Conditions of Different Rapeseed and Mustard Production Zones

Zone	*Rabi* rain (mm)	Soil texture	Category of zone	Districts
I	<50 and 50 to 75	Loamy to clay loam, sandy	HH	Hisar, Rewari
II	<50	Sandy loam, sandy	HM	Bhiwani, Mahendergarh
III	50 to 100	Sandy loam, clay loam, sandy	MH	Sirsa
IV	<50 and 50 to 75	Loam to clay loam, sandy loam	LH	Fatehabad, Gurgaon, Palwal
V	75 to 200	Loam to clay loam, clay loam, silt	LM	Panchkula, Ambala, Kurukshetra, Karnal, Yamunanagar, Kaithal, Jind, Panipat, Jhajjar, Mewat
VI	50 to 75	Loam to clay loam, clay to clay loam	LL	Sonipat, Rohtak, Faridabad

Source: Haryana Space Applications Centre, Hisar

The following three categories were formulated for both area and productivity:

i. Area:

High Spread (H): Area > 60,000 hectares
Medium Spread (M): Area from 40,000 to 60,000 hectares
Low or Poor Spread (L): Area < 40,000 hectares

ii. Productivity:

High Productivity Zone (H): Yield > 1,700 kg/hectare
Medium Productivity Zone (M): Yield ranging from 1,600 to 1,700 kg/ha
Low or Poor Productivity Zone (L): Yield < 1,600 kg/ ha

Winter season rainfall: Rainfall is a critical weather parameter that significantly impacts the growth and yield of rapeseed and mustard crops. The amount, intensity, and distribution of winter or seasonal rainfall play a crucial role in determining crop growth during the rabi season in north-western India. For this study, long-term winter season rainfall data spanning the past 30 years for Haryana state were collected and analysed.

The rainfall data were used to describe the pattern of isohyets, which are lines on a map connecting points having equal rainfall. The analysis identified five distinct isohyets to represent the winter season rainfall distribution across the state:

1. Isohyet < 50 mm: Areas receiving less than 50 mm of rainfall.
2. Isohyet 50 to 75 mm: Areas receiving between 50 mm and 75 mm of rainfall.
3. Isohyet 75 to 100 mm: Areas receiving between 75 mm and 100 mm of rainfall.
4. Isohyet 125 to 150 mm: Areas receiving between 125 mm and 150 mm of rainfall.
5. Isohyet 150 to 200 mm: Areas receiving between 150 mm and 200 mm of rainfall.

These isohyets were mapped to demarcate different rainfall zones within the state, providing a detailed understanding of the spatial distribution of winter season rainfall and its potential impact on rapeseed and mustard crop growth and productivity (Table 1).

Detailed analysis of specific districts within Haryana revealed the following patterns:

- Bhiwani, Mahendergarh, Rewari, and parts of Hisar districts: These regions receive less than 50 mm of rainfall during the winter season, placing them in the lowest isohyet category.
- Parts of Sirsa, Bhiwani, Gurgaon, Rohtak, and Faridabad districts: These areas are situated within the isohyet range of 50 to 75 mm of rainfall, indicating slightly higher winter rainfall.
- Western parts of Kurukshetra and Karnal, and the eastern part of Sonepat districts: These districts experience winter season rainfall between 75 and 100 mm.
- Kurukshetra, Karnal, and the western part of Ambala districts: These areas receive rainfall ranging from 100 to 125 mm during the winter season.
- Extreme northern parts of Ambala district: This region records the highest winter season rainfall, around 150 mm.

Winter temperature: In Haryana, the winter temperatures vary across different districts, influencing crop growth during the Rabi season. The district of Sirsa, along with the western part of Fatehabad, Hisar, Palwal, and Sonipat, experiences a normal mean winter temperature of 18°C. In contrast, the districts of Mahendergarh, Rewari, and Mewat have slightly higher winter temperatures, averaging 19°C. This is notably warmer compared to other regions in the state. The north-eastern districts of Ambala, Yamunanagar, and Panchkula record the lowest winter temperatures in the state, averaging 16°C. Overall, the average winter temperature across Haryana ranges from 16°C to 19°C, creating diverse thermal conditions for the growth of rapeseed and mustard crops.

Soil of Haryana: Soil quality is a crucial factor that significantly impacts the production and productivity of mustard crops in Haryana. Productivity is heavily influenced by soil type, fertility gradients, mechanical composition, as well as soil moisture and temperature. The texture and structure of soils in Haryana vary widely from one location to another. The primary soil texture classes found in the state include clay loam, clay to clay loam, sandy, loamy sand, sandy loam to clay loam, and silt. There are also hilly areas, which are less extensive, found in the western parts of Faridabad, eastern and central parts of Gurgaon, western part of Mewat, and parts of Mahendergarh district. Most districts in Haryana have predominantly loamy soils, which are favourable for mustard cultivation. This is followed by areas with sandy soils. Specifically, parts of Sirsa, Hisar, the northern part of Bhiwani, the southern part of Ambala, Jind, Sonipat, and some parts of Rohtak have loam to clay loam soils. These soils are known for their moderate water retention and fertility, which support good crop growth. On the other hand, sandy soils, which are more porous and have lower water retention capacity, dominate along the Rajasthan-Haryana border. This includes regions within Sirsa, Hisar, Bhiwani, Mahendergarh, and Rewari districts. Understanding these soil types and their distribution is essential for optimizing agricultural practices and improving mustard crop yields across Haryana.

Differentiation of Rapeseed and Mustard Production Zones in Haryana: Based on the comprehensive analysis of area, productivity, winter season temperature, rainfall, and soil texture, Haryana was divided into six distinct rapeseed and mustard production zones. Each zone is designated with a two-letter code, where the first letter represents the level of crop spread (area) and the second letter indicates productivity, as defined earlier.

Zone-I (HH): High Spread and High Productivity This zone encompasses the districts of Rewari and Hisar. Both districts exhibit extensive cultivation areas coupled with high productivity, making them key regions for rapeseed and mustard production in the state.

Zone-II (HM): High Spread and Medium Productivity This zone includes the districts of Bhiwani and Mahendergarh. While these districts have a large area under cultivation, their productivity is moderate compared to Zone-I.

Zone-III (MH): Medium Spread and High Productivity The sole district in this zone is Sirsa. It has a moderate cultivation area but boasts high productivity levels, indicating efficient agricultural practices and favourable growing conditions.

Zone-IV (LH): Low Spread and High Productivity This zone covers the districts of Fatehabad, Gurgaon, and Palwal. Although these areas have a smaller spread of rapeseed and mustard cultivation, they achieve high productivity, suggesting optimal use of resources and favourable environmental conditions.

Zone-V (LM): Low Spread and Medium Productivity This zone comprises the districts of Jhajjar, Mewat, and the north-eastern districts of Haryana, including Jind and Panipat. These areas have limited cultivation spread and medium productivity. The lower productivity in this zone can be attributed to lower winter temperatures and more frequent abnormal weather conditions, which adversely affect crop yields.

Zone-VI (LL): Low Spread and Low Productivity The districts of Rohtak, Sonipat, and Faridabad fall into this zone. These areas exhibit both limited cultivation spread and low productivity, indicating challenges in achieving higher yields due to less favourable growing conditions and possibly suboptimal soil types.

By classifying the state into these six zones, tailored agricultural practices and interventions can be implemented to enhance rapeseed and mustard production efficiency and productivity across Haryana.

The state of Haryana exhibits significant diversity in topography and climatic conditions, resulting in varied soil textures and structures across different locations. Based on an analysis of secondary data on climate and soil properties, Haryana has been divided into six distinct agro-climatic zones for mustard crop cultivation. These zones are categorized by the spread (area under cultivation) and productivity of the mustard crop: high spread and high productivity (HH), high spread and medium productivity (HM), medium spread and high productivity (MH), low spread and high productivity (LH), low spread and medium productivity (LM), and low spread and low productivity (LL). Our study identifies Hisar and Rewari as the most promising districts for mustard cultivation, given their high area under crop and productivity. The greatest variability in productivity and cultivation spread was found in regions characterized by a winter average temperature of 18°C (isotherm) and a *rabi* season rainfall of 50 mm (isohyet). This zone spans a larger area and includes numerous districts located in the western, southern, and central parts of Haryana. These areas benefit from optimal growing conditions that support extensive and productive mustard cultivation. In contrast, regions with comparatively higher rainfall and lower winter temperatures were found to have lower to medium productivity and cultivation spread. Despite better rainfall supporting crop growth, the cooler temperatures may constrain the overall productivity potential in these areas. This suggests that while moisture availability is crucial, temperature also plays a significant role in determining mustard crop yields. The classification into these six zones provides a nuanced understanding of the agro-climatic conditions affecting mustard cultivation in Haryana. This zoning can inform targeted agricultural practices and policy interventions aimed at optimizing mustard production. By tailoring strategies to the specific conditions of each zone, it is possible to enhance the efficiency and productivity of mustard farming, thereby supporting the agricultural economy of the state.

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Double Null (Kunitz Trypsin Inhibitor and Lipoxygenase-2 Gene Free) soybean genotype: MACSNRC 1898

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ABSTRACT

An investigation was undertaken during 2016-2022 to eliminate the off-flavour generating lipoxygenase-2 gene from Kunitz trypsin inhibitor-free (null KTi) soybean genotypes developed in the background of the popular variety JS 93-05 using molecular markers. Agronomically, MACSNRC 1898 has a semi-determinate plant type and semi-erect type growth habit with pointed ovate leaves. The plant grows to an average height of 65-69 cm, bears purple-coloured flowers in 35 days, and matures in 95 days after sowing. It gives an average yield of 2460 kg/ha. It bears three seeded pods with medium-sized yellow-coloured seeds having an elliptical shape with a black-coloured hilum. MACSNRC 1898 is without KTi and Lox2 genes and with 92% genome of therecurrent parent genome content (RPGC). The genotype MACSNRC 1898 is useful in further breeding for the soybean varieties suitable for food use.

Keywords: Kunitz Trypsin inhibitor, Marker-assisted, Null allele, Null lipoxygenase-2 gene, Soybean

Soybean (*Glycine max* [L.] Merr.) is one of the nutritionally rich and globally accepted commodities being rich in quality protein (38-40%) and edible oil (18-20%). An increase in domestic and industrial uses elevated soybean as one of the most important crops in agriculture and other agro-based allied industries (Tiwari and Tiwari, 2023; Mondal *et al.,* 2023). Even though its several uses and health benefits are known to the masses, its direct consumption as food is limited. This is attributed to the presence of some undesirable compounds like protein inhibitor Kunitz trypsin inhibitor (KTI) and off-flavour generating lipoxygenases (Lox2 gene). These antinutritional/undesirable factors can be removed/nullified by thermal treatment but it's a time-consuming process and incurs cost. Hence, it is imperative to eliminate these two factors genetically from the prevailing high-yielding soybean varieties using biotechnological tools like marker-assisted backcross breeding techniques.

Keeping this in view, an investigation was undertaken during 2016-2022 to eliminate the off-flavour generating lipoxygenase-2 gene from Kunitz trypsin inhibitor-free (null KTi) soybean genotypes developed in the background of the popular variety JS 93-05 using molecular markers. For this purpose, two Kunitz trypsin inhibitor-free (Null allele) genotypes developed earlier were selected (one in MACS 450 background and another in JS 93-05 background) to eliminate the off-flavour generating lipoxygenase-2 gene. Hybridization with Null lipoxygenase-2 gene germplasm line PI 596540 was carried out to develop null KTi and lipoxygenase-2 gene-free soybean varieties using a marker-assisted back cross-breeding method (Kumar *et al.,* 2021). The parental lines were screened for Null lipoxygenase-2 gene using an SNP-based gene-specific primer and the background of MACS 450 and JS 93-05 were screened using SSR markers (Kumar *et al.,* 2014). The developed lines were evaluated for yield under field conditions during *kharif* 2021-2022 and for quality under laboratory conditions during *kharif* 2023. The line developed in the background of JS 93-05 was promising in yield and its attributes and was named MACSNRC 1898.

Agronomically, MACSNRC 1898 has a semi-determinate plant type and semi-erect type growth habit with pointed ovate leaves. The plant grows to an average height of 65-69 cm, bears purple-coloured flowers in 35 days, and matures in 95 days after sowing. It bears three seeded pods with medium-sized yellow-coloured seeds having an elliptical shape with a black-coloured hilum. MACSNRC 1898 is without KTi and Lox2 genes and with 92% genome of the recurrent parent genome content (RPGC). It gives an average yield of 2460 kg/ha. The

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genotype MACSNRC 1898 is useful in further breeding for the soybean varieties suitable for food use and would be one more addition to the food grade type of soybean category.

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INDIAN SOCIETY OF OILSEEDS RESEARCH

Instructions to Authors for Preparation of Manuscript for Journal of Oilseeds Research

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This part of the text should comprise the materials used in the investigation, methods of experiment and analysis adopted. This portion should be self-explanatory and have the requisite information needed for understanding and assessing the results reported subsequently. Enough details should be provided in this section to allow a competent scientist to repeat the experiments, mentally or in fact. The geographical position of soil site or soils used in the experiment or site of field trial should be identified clearly with the help of coordinates (latitude & longitude) and invariably proper classification according to Soil Taxonomy (USDA), must be indicated to the level of Great-group, Suborder or Order as far as possible. Specify the period during which the experiment(s) was conducted. Send the article after completion of the experiment(s) not after a gap of 5 years. Instead of kharif and rabi use rainy and winter season respectively. Please give invariably the botanical names for local crop names like raya, bajra moong, cholam etc. Botanical and zoological names should confirm to the international rules. Give authorities. Go through some of our recent issues and find out the correct names. Give latest correct names from authentic source. For materials, give the appropriate technical specifications and quantities and source or method of preparation. Should a product be identified by trade name, add the name and location of the manufacturer or a major distributor in parenthesis after the first mention of the product. For the name of plant protection chemicals, give popular scientific names (first letter small), not trade names (When trade name is given in addition, capitalize the first letter of the name). Known methods of analysis should be indicated by referring to the original source, avoiding detailed description. Any new technique developed and followed should be described in fair detail. When some specially procured or proprietary materials are used, give their pertinent chemical and physical properties. References for the methods used in the study should be cited. If the techniques are widely familiar, use only their names in that case.

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This section should discuss the salient points of observation and critical interpretation thereof in past tense. This should not be descriptive and mere recital of the data presented in the tables and diagrams. Unnecessary details must be avoided but at the same time significant findings and special features should be highlighted. For systematic discussion, this section may be divided into sub-sections under side-heading and/or paragraph side heading. Relate the results to your objectives. While discussing the results, give particular attention to the problem, question or hypothesis presented in the introduction. Explain the principles, relationships, and generalizations that can be supported by the results. Point out any exceptions. Explain how the results relate to previous findings, support, contradict or simply add as data. Use the Discussion section to focus on the meaning of your findings rather than recapitulating them. Scientific speculation is encouraged but it should be reasonable and firmly founded in observations. When results differ from previous results, possible explanations should be given. Controversial issues should be discussed clearly. References to published work should be cited in the text by the name(s) of author(s) as follows: Mukherjee and Mitra (1942) have shown or It has been shown (Mukherjee and Mitra, 1942)..... If there are more than two authors, this should be indicated by et al. after the surname of the first author, e.g., Mukherjee et al. (1938).

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Physical Symbol for SI Unit Symbol Remarks quantity physical quantity for SI Unit

Primary Units					
length	l		time	t	
metre	m		second	s	
mass	m		electric current	I	
kilogram	kg		ampere	A	
Secondary Units					
plane angle	radian	rad	Solid angle	steradian	sr
Unit Symbols					
centimetre	cm		microgram	µg	
cubic centimetre	cm^3		micron	µm	
cubic metre	m^3		micronmol	µmol	
day	d		milligram	mg	
decisiemens	dS		millilitre	mL	
degree-Celsium	°C [=(F-32)x0.556]		minute	min	
gram	g		nanometre	nm	
hectare	ha		newton	N	
hour	h		pascal	Pa	
joule J	(=10^7 erg or 4.19 cal.)		second	s	
kelvin	K (=°C+273)		square centimetre	cm^2	
kilogram	kg		square kilometre	km^2	

kilometre	km	tonne	t
litre	L	watt	W
megagram	Mg		

Some applications along with symbols

adsorption energy	J/mol (=cal/molx4.19)	leaf area	m^2/kg
cation exchange capacity	cmol (p+)/kg (=m.e./100 g)	nutrient content in plants (drymatter basis)	µg/g, mg/g or g/kg
Electrolytic conductivity	dS/m (=mmhos/cm)	root density or root length density	m/m^3
evapotranspiration rate	m^3/m^2/s or m/s	soil bulk density	Mg/m^3 (=g/cm^3)
heat flux	W/m^2	specific heat	J/kg/K
gas diffusion	g/m^2/s or m^3/m^2/s or m/s	specific surface area of soil	m^2/kg
water flow	kg/m^2/s (or) m^3m^2s (or) m/s	thermal conductivity	W/m/K
gas diffusivity	m^2/s	transpiration rate	mg/m^2/s
hydraulic conductivity ion uptake	m/s	water content of soil	kg/kg or m^3/m^3
(Per kg of dry plant material)	mol/kg	water tension	kPa (or) MPa

While giving the SI units the first letter should not be in capital i.e cm, not Cm; kg not Kg. There should not be a full stop at the end of the abbreviation: cm, not cm. kg, not kg.; ha, not ha.

In reporting the data, dimensional units, viz., M (mass), L (length), and T (time) should be used as shown under some applications above. Some examples are: 120 kg N/ha; 5 t/ha; 4 dS/m etc.

Special Instructions

I. In a series or range of measurements, mention the unit only at the end, e.g. 2 to 6 cm2, 3, 6, and 9 cm, etc. Similarly use cm2, cm3 instead of sq cm and cu m.

II. Any unfamiliar abbreviation must be identified fully (in parenthesis).

III. A sentence should not begin with an abbreviation.

IV. Numeral should be used whenever it is followed by a unit measure or its abbreviations, e.g., 1 g, 3 m, 5 h, 6 months, etc. Otherwise, words should be used for numbers one to nine and numerals for larger ones except in a series of numbers when numerals should be used for all in the series.

V. Do not abbreviate litre to` l' or tonne to `t'. Instead, spell out.

VI. Before the paper is sent, check carefully all data and text for factual, grammatical and typographical errors.

VII. Do not forget to attach the original signed copy of `Article Certificate' (without any alteration, overwriting or pasting) signed by all authors.

VIII. On revision, please answer all the referees' comments point-wise, indicating the modifications made by you on a separate sheet in duplicate.

IX. If you do not agree with some comments of the referee, modify the article to the extent possible. Give reasons (2 copies on a separate sheet) for your disagreement, with full justification (the article would be examined again).

X. Rupees should be given as per the new symbol approved by Govt. of India.

Details of the peer review process

Manuscripts are received mainly through e-mails and in rare cases, where the authors do not have internet access, hard copies of the manuscripts may be received and processed. Only after the peer review the manuscripts are accepted for publication. So there is no assured publication on submission. The major steps followed during the peer review process are provided below.

Step 1. ***Receipt of manuscript and acknowledgement***: Once the manuscript is received, the contents will be reviewed by the editor/associate editors to assess the scope of the article for publishing in JOR. If found within the scope of the journal, a Manuscript (MS) number is assigned and the same will be intimated to the authors. If the MS is not within the scope and mandate of JOR, then the article will be rejected and the same is communicated to the authors.

Step 2. ***Assigning and sending MS to referees***: Suitable referees will be selected from the panel of experts and the MS (soft copy) will be sent to them for their comments - a standard format of evaluation is provided to the referees for evaluation along with the standard format of the journal articles and the referees will be given 4-5 week time to give their comments. If the comments are not received, reminders will be sent to the referees for expediting the reviewing process and in case there is still no response, the MS will be sent to alternate referees.

Step 3. ***Communication of referee comments to authors for revision***: Once the referee comments and MS (with suggestions/ corrections) are received from the referees, depending on the suggestions, the same will be communicated to the authors with a request to attend to the comments. Authors will be given stipulated time to respond and based on their request, additional time will be given for attending to all the changes as suggested by referees. If the referees suggest no changes and recommend the MS for publication, then the same will be communicated to the authors and the MS will be taken up for editing purpose for publishing. In case the referees suggest that the article cannot be accepted for JOR, then the same will be communicated to the authors with proper rationale and logic as opined by the referees as well as by the editors.

Step 4. ***Sending the revised MS to referees***: Once the authors send the revised version of the articles, depending on the case (like if major revisions were suggested by referees) the corrected MS will be sent to the referees (who had reviewed the article in the first instance) for their comments and further suggestions regarding the acceptability of publication. If only minor revisions had been suggested by referees, then the editors would look into the issues and decide take a call.

Step 5. ***Sending the MS to authors for further revision***: In case referees suggest further modifications, then the same will be communicated to the authors with a request to incorporate the suggested changes. If the referees suggest acceptance of the MS for publication, then the MS will be accepted for publication in the journal and the same will be communicated to the authors. Rarely, at this stage also MS would be rejected if the referees are not satisfied with the modifications and the reasoning provided by the authors.

Step 6. ***Second time revised articles received from authors and decision taken***: In case the second time revised article satisfies all the queries raised by referees, then the MS will be accepted and if not satisfied the article will be rejected. The accepted MS will be taken for editing process where emphasis will be given to the language, content flow and format of the article.

Then the journal issue will be slated for printing and also the pdf version of the journal issue will be hosted on journal webpage.

Important Instructions

- Data on field experiments have to be at least for a period of 2-3 years
- Papers on pot experiments will be considered for publication only as short communications
- Giving coefficient of variation in the case of field experiments Standard error in the case of laboratory determination is mandatory. For rigorous statistical treatment, journals like Journal of Agricultural Science Cambridge, Experimental Agriculture and Soil Use and Management should serve as eye openers.

SPECIAL ANNOUNCEMENT

In a recently conducted Executive Committee meeting of the Indian Society of Oilseeds Research, it was decided to increase the scope of the Journal of Oilseeds Research by accommodating vibrant aspects of scientific communication. It has been felt that, the horizon of scientific reporting could be expanded by including the following types of articles in addition to the Research Articles, Shor Communications and Review Articles that are being published in the journal as of now.

Research accounts (not exceeding 4000 words, with cited references preferably limited to about 40-50 in number): These are the articles that provide an overview of the research work carried out in the author(s)' laboratory, and be based on a body of their published work. The articles must provide appropriate background to the area in a brief introduction so that it could place the author(s)' work in a proper perspective. This could be published from persons who have pursued a research area for a substantial period dotted with publications and thus research account will provide an overall idea of the progress that has been witnessed in the chosen area of research. In this account, author(s) could also narrate the work of others if that had influenced the course of work in authors' lab.

Correspondence (not exceeding 600 words): This includes letters and technical comments that are of general interest to scientists, on the articles or communications published in Journal of Oilseeds Research within the previous four issues. These letters may be reviewed and edited by the editorial committee before publishing.

Technical notes (less than 1500 words and one or two display items): This type of communication may include technical advances such as new methods, protocols or modifications of the existing methods that help in better output or advances in instrumentation.

News (not exceeding 750 words): This type of communication can cover important scientific events or any other news of interest to scientists in general and vegetable oil research in particular.

Meeting reports (less than 1500 words): It can deal with highlights/technical contents of a conference/ symposium/discussion-meeting, etc. conveying to readers the significance of important advances. Reports must

Meeting reports should avoid merely listing brief accounts of topics discussed, and must convey to readers the significance of an important advance. It could also include the major recommendations or strategic plans worked out.

Research News (not exceeding 2000 words and 3 display items): These should provide a semi-technical account of recently published advances or important findings that could be adopted in vegetable oil research.

Opinion (less than 1200 words): These articles may present views on issues related to science and scientific activity.

Commentary (less than 2000 words): This type of articles are expected to be expository essays on issues related directly or indirectly to research and other stake holders involved in vegetable oil sector.

Book reviews (not exceeding 1500 words): Books that provide a clear in depth knowledge on oilseeds or oil yielding plants, production, processing, marketing, etc. may be reviewed critically and the utility of such books could be highlighted.

Historical commentary/notes (limited to about 3000 words): These articles may inform readers about interesting aspects of personalities or institutions of science or about watershed events in the history/development of science. Illustrations and photographs are welcome. Brief items will also be considered.

Education point (limited to about 2000 words): Such articles could highlight the material(s) available in oilseeds to explain different concepts of genetics, plant breeding and modern agriculture practices.

Note that the references and all other formats of reporting shall remain same as it is for the regular articles and as given in Instructions to Authors

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