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Assessment of genetic diversity in linseed germplasms for Alternaria blight resistance under natural conditions

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Abstract

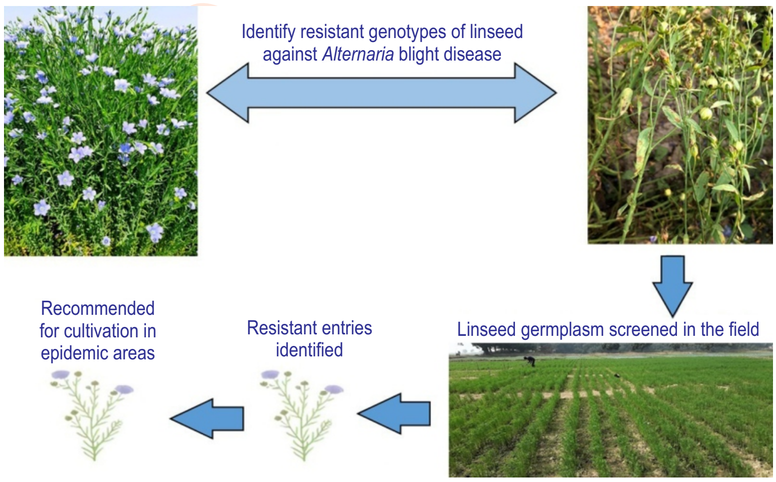
Aim: The aim of the present study was to identify the resistant varieties/entries of linseed against *Alternaria* blight disease and recommend them for cultivation in epidemic areas.

Methodology: A total of 144 linseed germplasms were field-screened for resistance to *Alternaria* blight at Bihar Agricultural University, Sabour, during the *Rabi* seasons of 2020–21, 2021–22 and 2022–23. Standard non replicated field trials with controls were conducted, and disease response was assessed at multiple growth stages. Entries were classified as resistant, moderately resistant, moderately susceptible, or highly susceptible based on their disease reaction.

Results: Out of 144 linseed germplasm screened, seven entries were found to be resistant to *Alternaria* blight: CI 1552, GS 440, H 40, LC 2945, PKDL 167, Priyam and RL 15561. Additionally, 22 entries exhibited moderate resistance, while 60 entries showed moderate susceptibility to the disease. Remaining entries were either susceptible or highly susceptible to *Alternaria* blight.

Interpretation: The identified resistant and moderately resistant linseed entries can be recommended for cultivation in *Alternaria* blight-prone areas to mitigate disease impact. Their use can help minimize yield losses, reduce reliance on chemical control, and support sustainable linseed production. Susceptible varieties should be prioritized for genetic improvement using resistant gene pools.

Key words: Disease resistance, Genotype screening, Linseed, Natural condition



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Introduction

Linseed (*Linum usitatissimum* L.), commonly known as flax, is one of the oldest cultivated oilseed crops that holds significant agronomic and economic importance in India and globally (Kumar and Kumar, 2022; Kauser *et al.,* 2024). Linseed has a long and illustrious history, almost as long as civilization itself. According to Vavilov, the small-seeded type, which is grown primarily for oil purposes, appears to have originated in South Western Asia, including India, Afghanistan and Turkey, while the bold seeded type, which is grown primarily for fiber purposes, appears to have originated in the Mediterranean region, including Asia Minor, Egypt, Algeria, Spain, Italy and Greece (Singh *et al.,* 2020). It is primarily grown for its oil-rich seeds, which are an excellent source of Omega-3 fatty acids, dietary fiber, and high-quality protein. The oil is widely used in both food and industrial applications, including manufacture of paints, varnishes, linoleum, printing ink, and soaps (Woodfield and Harwood, 2017).

In India, linseed is cultivated mostly during the *Rabi* season, next only to rapeseed and mustard in terms of area and production, with major growing states being Madhya Pradesh, Maharashtra, Chhattisgarh, Uttar Pradesh, Bihar, and Odisha. India stands as the fifth-largest producer, contributing approximately 0.154 million tonnes to the global linseed production of 3.4 million tonnes (Dhiman *et al.,* 2025). Despite its nutritional and industrial value, this crop is ravaged by a number of diseases and insect pests at various phases of its growth which reduce the crop yield and quality. Amongst diseases, *Alternaria* blight caused by *Alternaria lini* is a major biotic stress, limiting crop yield in hot and humid environment (Amisha *et al.,* 2022). The disease is characterized by dark brown lesions on leaves, stems, and pods, leading to premature defoliation, seed shriveling, and significant losses in seed yield and oil content. Under favourable environmental conditions particularly high humidity and moderate temperatures *Alternaria* blight can cause yield losses ranging from 18% to over 70% depending on disease severity (Kumar and Kumar, 2022; Kaur *et al.,* 2023). The increasing frequency and severity of *Alternaria* blight outbreaks in India have raised serious concerns about the sustainability of linseed cultivation.

Effective disease management is essential to protect both crop productivity and seed quality. Therefore, there is an urgent need to develop and implement comprehensive management strategies including the use of resistant cultivars, effective fungicidal applications, and integrated disease management approaches to ensure the long-term viability and profitability of linseed production (Kauser *et al.,* 2024). Traditional methods of managing *Alternaria* blight, such as use of chemical fungicides, have proven to be both expensive and environmentally damaging. Furthermore, the frequent application of fungicides may not always provide long-term control, making it essential to explore alternative, sustainable disease management strategies (Amisha *et al.,* 2022). One of the most effective and economical approaches is the use of resistant or tolerant varieties of linseed. By selecting the varieties that are naturally resistant to *Alternaria* blight, farmers can reduce their reliance on chemical treatments, thus lowering production costs and minimizing environmental impact (Yadav *et al.,* 2021; Paliwal *et al.,* 2024). Additionally, resistant varieties can help ensure a more stable yield even in regions prone to disease outbreaks, thereby securing the livelihoods of farmers.

The present study aims to screen a diverse set of linseed germplasms for resistance to *Alternaria lini* under field conditions. By identifying resistant or moderately resistant varieties, research aims to offer practical recommendations for cultivating these varieties in the disease-prone areas for *Alternaria lini* include Eastern India, particularly Bihar and West Bengal, where warm and humid conditions favour disease development. In these regions, disease severity can reach up to 60–80% under conducive conditions, often resulting in significant yield losses making the crop highly prone to epidemics. Such an approach could significantly contribute to the sustainable agricultural practices, as it would not only provide a natural defence against disease but also reduce the need for chemical control measures. The present study, therefore, holds promise for improving linseed production and disease management, benefiting both farmers and the environment.

Materials and Methods

It is an established fact that the use of resistant variety is the most effective and economical measure for the management of disease in plants, which can be achieved by testing promising varieties/entries and also by locating sources of resistance through screening against diseases. Therefore, to develop resistant varieties and to identify the source of resistance, an experiment was conducted in non-replicated trial during the *Rabi* seasons of 2020–21, 2021–22, and 2022–23 at the Research Farm of Bihar Agricultural University, Sabour (coordinates 25°15'40"N, 87°02'42"E; 52.73 m above mean sea level).

The biological experimental materials comprised 144 diverse linseed lines, selected based on the morphological and unique traits from a germplasm collection of exotic and indigenous accessions obtained from the AICRP on Linseed, Department of Genetics and Plant Breeding, Bihar Agricultural University, Sabour, Bhagalpur (Bihar). The climatic conditions are classified as subtropical, characterized by hot summers, a distinct monsoon season, and mild winters. The region receives an average annual rainfall of approximately 1100–1300 mm, the majority of which occurs during the south-west monsoon period (June to September). The *Rabi* season remains largely dry, requiring supplemental irrigation for crop cultivation, while relative humidity is higher during the monsoon and lower in winter. For effective plant growth, experimental plot was managed by following recommended package of practices excluding fungicides application for the management of diseases. Each genotype was sown in three rows, each measuring 3 m in length. The row-to-row and plant-to-plant spacing were maintained at 45 cm and 10 cm, respectively, to facilitate uniform plant growth and accurate data collection. Sowing was performed on 15th November of the year 2020, 2021 and 2022 under optimal agronomic conditions. The intensity of disease in the field was estimated from five randomly selected plants which were tagged with labels. Each plant was scored visually in the field and plants were rated in 0-5 scale where, 0- Immune, 1- resistance, 2- moderately resistance, 3- moderately susceptible, 4- susceptible and 5- highly susceptible. The disease assessment per plant was determined by observing the intensity of lesions on the leaves. Plants with a disease rating of < 2 were considered resistant, while those with a rating > 2 were deemed susceptible. The observations were recorded based on disease reactions and were conducted three times at 10-day intervals, starting from the appearance of the first disease symptoms. The Percent Disease Index (PDI) was assessed using the Standard Evaluation System (SES) for *Alternaria* blight, based on a 0–5 disease rating scale (Kumar and Tripathi, 2018) as described below: The percent disease index (PDI) was calculated using Wheeler's (1969) formula:

$$\text{PDI (\%)} = \frac{\text{Sum of all numerical ratings} \times 100}{\text{Total no of leaves x Maximum grade}}$$

All recommended package of practices was followed, except for the application of plant protection chemicals, to allow maximum natural inoculation of *Alternaria* blight. Environmental factors such as humidity, temperature, and light can influence the development of disease, possibly explaining the differences in disease severity scores. The screening process aimed to identify genotypes with varying levels of resistance to *Alternaria* blight. Disease assessments were conducted regularly throughout the crop's growing period, recording the severity of symptoms across different genotypes. Visual observations of disease symptoms like leaf lesions, chlorosis, and necrosis, were documented. Based on the observed severity, genotypes were categorized into different resistance groups. This methodological approach enabled a comprehensive evaluation of resistance levels in linseed germplasm under natural field conditions and is expected to contribute valuable insights toward the identification of resistant varieties suitable for cultivation in *Alternaria* blight-prone areas.

Results and Discussion

In modern crop production, the use of resistant varieties is a cornerstone for sustainable crop production. Resistant varieties not only boost productivity, but also reduce disease pressure significantly, minimizing the need for chemical inputs. In this study, 144 linseed germplasms screened in non-replicated trial for resistance against *Alternaria* blight under the natural field conditions at Bihar Agricultural University, Sabour, Bhagalpur, Research Farm during *Rabi* season of the year 2020-21, 2021-22 and 2022-23. Genotypes were evaluated based on their reaction to disease, and data collected were categorized into different resistance groups. The detailed results are presented in Table 1 and Fig. 1, 2. The findings indicate significant variation in the resistance level of the tested genotypes against *Alternaria* blight. None of the genotypes were found to be completely free from disease; however, seven genotypes, namely CI 1552, GS 440, H 40, LC 2945, PKDL 167, Priyam, and RL 15561 were identified as resistant based on the disease severity rating. These genotypes exhibited the least disease symptoms and considered promising candidates for cultivation in *Alternaria* blight-prone area. Moreover, 22 genotypes, BAU14-11, BRLS101, BRLS103-1, BRLS105-1, BRLS106, BRLS108-1, BRLS109-1, CI1597, CI1622, CI1663, Deepika (RLC78), Divya, EC 104397, GS202, GS232, GS51, H49, KL134, RL13165, RLC 167, NP 123 Yellow, UP type 367, were found to be moderately resistant.

These genotypes demonstrated moderate disease symptoms, indicating some level of tolerance and potential for integrated disease management strategies. A larger portion of genotypes (60), including Baner (KL224), BRLS102-1, BRLS103, BRLS104, BRLS105, BRLS106-1, BRLS106-2, BRLS107-2, BRLS108-3, BRLS110-2, BRLS110-3, BRLS111-1, BRLS111-3, BRLS112-2, BRLS112-3, BRLS118, BRLS119, BRLS120, BRLS121, BRLS121-1, CI2057, CI2229, EC22784, EC322672, EC517 M,EC541222, GS206, GS397, EC1529, RLC117, H23, IC15888, H34, LBR6, LCK1702, LCK1707, LCK1812, LCK9436, LCP146, LMS2015-27, LW9-828, Meera (RL 933), NDL 2006-10, NDL 2005-24, NL315, NP123, NP123 Brown, OL09-286-23, Parvati, RL15580, RL27005, RLC165, RLC168, RLC173, SLS117, SLS118, TL145, TL99, UP1 and Sabour Tisi-1 were classified as moderately susceptible. These genotypes/entries showed a higher incidence of the disease; however, they still exhibited some level of resistance, which may be beneficial in regions with lower disease pressure or when integrated disease management practices are implemented.

The study also revealed that 43 genotypesAce-1456, BRLS102, BRLS107-1, BRLS109-2, BRLS115, BRLS116, BRLS116-1, EC22684, EC282827, EC322688, EC399582, EC6160, GS337,GS376, Kartika (RLC76), KL248, LC2023, LCK 89512, LMS2015-31, LMS2016-1-2, LMS2016-1-5, LMS63-6, Lus 2007-1, NDL2015-03, Neelam, NL260,OL 10-15, OL 98-13-1, Padmini AC, Polf 23, RL15553, RL903, RLC174, Sharda, SJKO37, SJKO40, SJKO5, SLS123, SLS71, SLS72, T22, Suyog 1-2 and Trans local, were classified as susceptible. These genotypes/entries exhibited significant disease symptoms under natural conditions, making them less desirable for cultivation in *Alternaria* blight prone areas. Finally, 12-genotypes, BRLS108-4, BRLS110-1, BRLS110-4, BRLS111-2, BRLS122, EC1424, LCK7035, RMLS11,SHA4, T 397, Shekhar and Tikamgarh were highly susceptible, showing severe symptoms of disease and should be avoided for planting in epidemic-prone areas. Quantitative analysis of screening data revealed a wide range of responses among the tested genotypes to *Alternaria* blight.

Out of the total genotypes evaluated, only 4.86% were categorized as resistant, demonstrating minimal disease symptoms and a high level of tolerance under natural field conditions. A slightly larger proportion, 15.28%, exhibited moderate resistance, showing limited disease development that could be effectively managed with minimal intervention. The majority of genotypes (41.66%) were classified as moderately

Table 1: Grading of germplasm/entries based on reaction group against Alternaria blight disease of linseed

Reaction group	Score	Germplasm/Entries	Total
Disease Free (Immune)	0	Nil	0
Resistant (R)	1	CI1552,GS440,H40,LC2945,PKDL167,Priyam, RL 15561.	7
Moderately Resistant (MR)	2	BAU14-11, BRLS101, BRLS103-1, BRLS105-1, BRLS106, BRLS108-1, BRLS109-1, CI1597, CI1622, CI1663, Deepika (RLC78), Divya, EC104397,GS202, GS232, GS51, H49, KL134, RL13165, RLC 167, NP 123Yellow, UP type 367.	22
Moderately Susceptible (MS)	3	Baner (KL224), BRLS102-,BRLS103,BRLS104, BRLS105, BRLS106-1, BRLS106-2, BRLS107-2, BRLS108-3,BRLS110-2,BRLS110-3,BRLS111-1,BRLS111-3, BRLS112-2, BRLS112-3, BRLS118, BRLS119, BRLS120, BRLS121, BRLS121-1,CI2057,CI2229, EC22784,EC322672, EC517M,EC541222, GS206, GS397, EC1529, RLC117, H23, IC15888,H34, LBR6, LCK1702, LCK1707,LCK1812, LCK9436, LCP146, LMS2015-27, LW9-828, Meera(RL 933), NDL 2006-10, NDL 2005-24, NL315, NP123, NP123 Brown, OL09-286-23,Parvati, RL15580, RL27005, RLC165, RLC168,RLC173, SLS117, SLS118, TL145, TL99, UP1,Sabour Tisi-1.	60
Susceptible (S)	4	Ace-1456,BRLS102,BRLS107-1,BRLS109-2, BRLS115,BRLS116,BRLS116-1,EC22684, EC 282827, EC322688, EC399582, EC6160,GS337, GS376, Kartika (RLC76), KL248, LC2023,LCK 89512,LMS2015-31, LMS2016-1-2, LMS2016-1-5,LMS63-6,Lus2007-1, NDL2015-03,Neelam, NL260,OL 10-15,OL 98-13-1,Padmini AC,Polf 23,RL15553,RL903, RLC174,Sharda,SJKO37,SJKO40,SJKO5,SLS123,SLS71,SLS72,T22,Suyog1-2, Trans local.	43
Highly Susceptible (HS)	5	BRLS108-4, BRLS110-1, BRLS110-4, BRLS111-2, BRLS122, EC1424, LCK7035, RMLS11, SHA4, T 397, Shekhar, Tikamgarh.	12

susceptible, indicating noticeable disease incidence, yet with some degree of tolerance that might be exploitable under low disease pressure or with integrated management practices. Furthermore, 29.86% of the genotypes were found susceptible, displaying significant disease symptoms and suggesting limited utility in disease-prone regions without robust control measures. Notably, 8.33% of the genotypes were highly susceptible, suffering from severe disease symptoms, and are therefore unsuitable for cultivation in areas endemic to *Alternaria* blight without advanced disease mitigation strategies. These results suggest that while a significant proportion of germplasms exhibited varying degrees of resistance to *Alternaria* blight, there is still considerable scope for improving the disease resistance of linseed varieties through breeding programs. A similar observation was made by Ram *et al.* (2007), who noted comparable trends, with only a few genotypes exhibited moderate resistance, while the majority of genotypes were found to be susceptible or highly susceptible. These findings highlight the importance of ongoing research into genetic resources to identify and effectively utilize resistant germplasm. Kailash *et al.* (2007) screened 440 linseed genotypes and 3-check varieties (Neelam, T 397, Kiran) for resistance to *Alternaria* blight.

Among them, 140 genotypes exhibited lower disease intensity than the check varieties. Genotypes A-364, A-202, A-66, A-232, A-184, A-226, A-75, and A-225B exhibited the lowest disease intensities, ranging 12.67 to 25.00%, and also demonstrated better seed yield response. Chauhan *et al.* (2008) evaluated 250 linseed varieties for resistance to *Alternaria* blight. They identified 6 genotypes-NDL-2004, NDL-2005-03-02, EC-22704, EC-41623, NDLS-169, and NDLS-164-as resistant to the *Alternaria* blight. Remaining genotypes exhibited varying degrees of moderate resistance or susceptibility. Singh and Singh (2011) evaluated 200 genotypes under artificially inoculated conditions and found no genotypes completely free of disease. Among them, 10 were resistant, 15 moderately resistant, 29 moderately susceptible, 59 susceptible, and 98 highly susceptible. Kumar *et al.* (2012) assessed 54 linseed genotypes (including 10 lines, 4 testers, and 40 crosses) for resistance to *Alternaria* blight under artificial epiphytotic conditions in field. Among these, 28 genotypes were classified as resistant, 23 as moderately resistant, and 3 as moderately susceptible to disease. Reddy *et al.* (2012) assessed linseed genotypes for their resistance to bud fly, *Alternaria* blight, and powdery mildew. Their findings showed that the pest and disease incidence varied, with bud fly ranging 11.4 (EC544) to 59.54% (ES44), and *Alternaria* blight ranging from 5.34 (Neelam) to 17.7% (ES44).

Amongst the hybrid crosses, Padmini x Ayogi and PKVNL-260 x EC9825 were identified as resistant to *Alternaria* blight. Nayak *et al.* (2014) conducted an experiment and found that forty-two genotypes namely BAU-20-08, LCK-9022, LMS-2007, RL-27010, RLC-123, SLS-73, SLS-81, SLS- 82, Neela, Meera, Sharda, BAU-16-8, JLT-202, LMS-31-7, LMS-2009-173,LSJ-46, LSJ-2009-77, LMS-2009-083, LMS-2009-173, LSJ-103,NDL-2009-21, PKDL-91, PKDL-111, PKDL-114,PCL-46,RL-27033, RL-28003, RL-28006, RL-29202, RLC-132, SLS-86, LC-54, Padmini, Parvati, R-552, Shekhar, Sheela, 7397, NDL-2007-3, NDL-2007-5 showed high resistance against bud blight. Singh *et al.* (2015) evaluated 46 linseed varieties for resistance to *Alternaria* blight and found that only 2 were resistant, 20 were moderately resistant, 15 were moderately susceptible, and 3

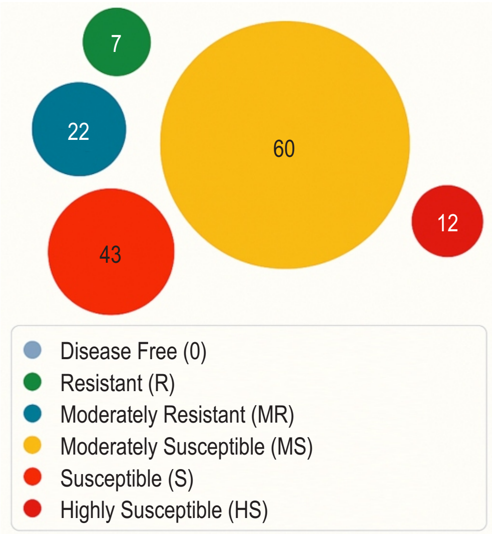

Fig. 1: Number of germplasms showing different reaction to *Alternaria* blight disease of linseed.

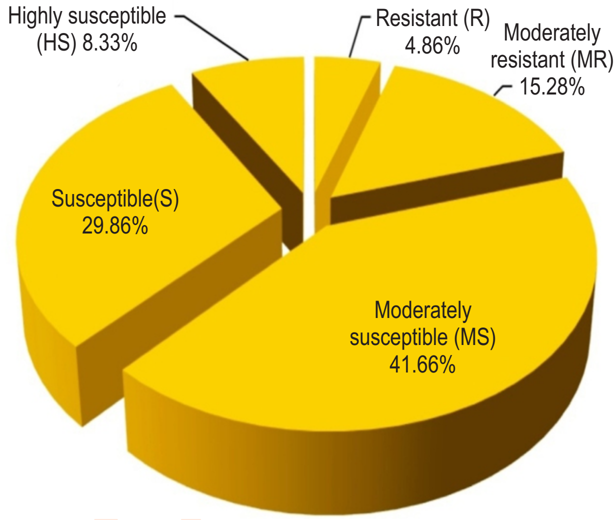

Fig. 2: Percentage of germplasms showing different reaction to *Alternaria* blight disease of linseed.

were susceptible. The study highlighted the importance of utilizing resistant lines in breeding programs to improve disease resistance in linseed. This broad spectrum of resistance is consistent with the findings of Das *et al.* (2016), who observed high susceptibility in several linseed genotypes and highlighted the influence of environmental factors and pathogen aggressiveness on disease expression, which helps explain variability in resistance.

Singh *et al.* (2017) conducted an experiment in which they screened out 95 genotypes against *Alternaria* blight of linseed and found that 15 genotypes (KL-31, KL- 229, Polf-2, LCK-11, H-22, KL-168, KL-225, KL-221, KL-220, SJKO-17, H-12, H-15, H-43, H-5 and Ayogi) showed resistant reaction, 37 genotypes reacted as moderately susceptible and 13 genotypes showed susceptible reaction. Kumar and Tripathi (2018) screened 200 linseed genotypes for resistance to *Alternaria* blight, revealing that none were completely disease-free or highly susceptible. Of these, seven genotypes were resistant, 66 were moderately resistant, 102 were moderately susceptible and 25 were susceptible to disease. Ajithkumar *et al.* (2020) screened a total of 258 linseed genotypes for evaluation of major foliar diseases under epiphytotic conditions. None of the genotypes were free of *Alternaria* blight and powdery mildew infection. Only two genotypes, 19801 and 20216 showed resistant to both *Alternaria* blight and powdery mildew. The remaining genotypes were moderately susceptible, susceptible or highly susceptible. Subedi *et al.* (2023) reported significant variability in resistance levels among linseed genotypes against *Alternaria* leaf blight.

About 19% of the evaluated genotypes showed moderate resistance, with promising lines such as ACC# (5-ICLI-2001-5), ACC#96-001, ACC#7622, ACC#96-004, TN#04, ACC#(9-ICLI-2001-9), ACC#(1-ICLI-2001-1), and TN#08 identified as potential sources of resistance for future breeding programs. Sahu *et al.* (2024), screening of 30 linseed genotypes for *Alternaria* blight over two *Rabi* seasons revealed no resistant or highly resistant genotypes in 2021–22. However, in 2022–23, three genotypes—IC-0525919, IC-0498517, and IC-0498872 exhibited high resistance, while IC-0597268, IC-0499201, and IC-0498795 showed a resistant reaction. These findings highlight the role of environmental variation in disease expression and underscore the importance of multi-season evaluation for reliable resistance identification. Paliwal *et al.* (2024) evaluated 92 linseed genotypes for resistance to *Alternaria* blight. None of the genotypes were found to be either completely free off disease or extremely susceptible.

The study identified six genotypes LMS-2015-42, LMS-2014-20, IC0498675, IC0498724, IC0498761, and IC0424878 as highly resistant. Additionally, seven genotypes, including IC0525920, IC0498538, IC0498768, IC0526514, IC0305053, IC0385383, and IC0499156, were categorized as resistant. Furthermore, 21 genotypes were found moderately resistant, 42 moderately susceptible, and 16 susceptible, reflecting a broad range of genetic variability in response to the disease and offering promising candidates for resistant linseed breeding programs. A similar observation was made by Paliwal *et al.* (2024), who screened linseed genotypes and identified a similar proportion demonstrating moderate resistance to *Alternaria* blight. These findings collectively indicate that moderate resistance is attainable and could provide a basis for developing resistant varieties. On the basis of disease severity index, none were found to be highly resistant. Only five varieties JRF-3, A-202, EC-41590, Gaurav and Meera appeared to be resistant against the *Alternaria* blight on both leaf and bud. Recently, Prasad *et al.* (2025)

conducted a comprehensive multi-environment screening of 2,579 linseed accessions from India's National Gene bank to identify sources of resistance against *Alternaria lini,* the causal agent of *Alternaria* blight. The study revealed significant genetic variability among the accessions, indicating the presence of valuable traits for resistance breeding. From the initial screening, a focused subset of 256 genotypes, representing both resistant and susceptible reactions, was shortlisted for further evaluation. These findings underscore the importance of large-scale germplasm screening in identifying stable and diverse resistance sources for the development of *Alternaria* blight-resistant linseed cultivars. The outcome of this study hold significant practical implications for developing and implementing effective strategies to manage *Alternaria* blight in linseed. The identification of resistant and moderately resistant genotypes provide farmers with valuable options for selecting varieties/germplasm that are better suited for cultivation in areas where *Alternaria* blight is prevalent. By focusing on these resistant and moderately resistant varieties, pressure from disease can be minimized, leading to higher and more stable yields, reducing need for chemical intervention, promoting sustainable agriculture.

In conclusion, this study demonstrates the importance of screening linseed genotypes for disease resistance. Identified resistant and moderately resistant varieties hold promise for enhancing productivity in *Alternaria* blight-prone regions, offering a cost-effective and environmentally friendly solution for managing this devastating disease. Future breeding efforts should aim to further pyramid the resistant genes into high-yielding varieties to further mitigate the impact of *Alternaria* blight on linseed production.

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