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Alternaria blight of linseed (*Linum usitatissimum* L.) and its chemical management: A comprehensive review

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Abstract
Alternaria blight is an important disease of Linseed (*Linum usitatissimum* L*)* that hampers its productivity and oil content. Symptoms first appears on lower leaves as black point that gradually increased in size to become circular to oval or irregular in shape. During severe infections, spots coalesce and cover the large area of the leaves. The pathogen also attack on the other foliar part of the plant. *Alternaria linicola* Groves & Skolko and *Alternaia lini* Dey are two fungi known to cause Alternaria leaf blight in linseed. Studies of relative dominance of pathogens associated with the diseased tissue revealed the dominance of *Alternria linicola* in infected tissue in comparison to *A.lini*. Evaluation of genotypes against Alternaria leaf blight under artificial epiphytotic condition revealed that resistance and tolerance is present in the linseed germplasm. Various number of plant protection chemicals were tested during the past years and Rovral @ 0.2% and mancozeb @ 0.2% was found most effective in many experiments. propiconazole @ 0.1% and hexaconazole @ 0.1% were found effective to combat against the Alternaria blight. Iprodione, Propiconazole, Hexaconazole, Difenconazole, Carbendazim 0.10%, Capton 0.20%, Carbendazim 12% + Mancozeb 63% and iprobenphos have been noted to manage the disease economically. Early sowing was also found effective for reduction of Alternaria. Aqueous leaf extracts of *Azadirachta indica* and *Lawsonia inermis* was also found suppressive to disease. Spray of Salicylic acid and Benzoic acid was reported to reduce the disease by enhancing the immunization in the linseed plant.

Keywords: *Alternaria linicola, Alternaria lini,* Alternaria leaf blight, resistance, linseed, *Linum usitatissimum* L.

Introduction
Linseed (*Linum usitatissimum* L.) commonly known as flax is belonging to the genus *Linum* and family Linaceae is one of the oldest cultivated oilseed crop in the world. This crop has 30 diploid chromosomes (Tammes, 1928; Tutin *et al*., 1980) [53, 55]. This is an important crop grown in temperate climatic areas for production of either fiber (fiber linseed) or oil (oilseed linseed). The oil of linseed seed is enriched in α-linolenic acid (ALA) which is also recognized as a good source of ALA for the human diet. Linseed seed contains 33-47% oil, 5.5% Linolenic acid, 20.3% protein, 38% fat, 29% carbohydrate, 4.8% fiber, and 2.4% ash in different varieties. Linseed is also a good source of calcium and phosphorus (Aykroyd, 1966) [3]. The linseed oil is also used in the process of cementing of roads in the U.S.A. (Walsh, 1965) [58] and in antibiotics (Anonymous, 1968) [1]. Linseed is listed for medicinal use in Indian pharmacopeia. The important linseed growing countries are India, Canada, China, USA and Ethiopia in the world. Globally its production was 19.23 lac tones from 22.18 lac ha with an average yield of 867 kg/ha.

Linseed production is constantly suffering from plethora of threats instigated by various plant pathogens leading to huge economic losses. Diseases are one of the major hurdles that limit the productivity of linseed. Fungi causing blight, powdery mildew, rust and wilt are important pathogens affecting the linseed crop. *Alternaria linicola* (Groves and Skolko, 1944) [13] and *Alternaria lini* Dey inciting Alternaria blight in linseed are commonly occurring pathogens in India. Plant pathogenic species of *Alternaria* exhibit a necrotrophic life style resulting in severe necrotic diseases in crops. During host pathogen interaction, Necrotrophic pathogens

actively kill host tissue as they colonize and thrive on the contents of dead or dying cells (Stone, 2001) [52]. The pathogens are responsible for a range of symptoms on its host including leaf spots and necrotic lesions on the capsules, which can result in yield loss and reduction in oil quality. Alternaria blight of linseed has assumed greater importance in different parts of country, especially mid-eastern India. In the last few years, *A. linicola* infection has been the main reason for the failure of the linseed seed. Alternaria leaf blight causes 18 to 60 per cent annual yield losses depending upon the severity of the disease in different cultivars (Chauhan and Srivastava, 1975; Singh *et al.*, 2003, Singh and Singh 2004[a]) [5, 42, 45]. This review describes the pathogens, epidemiology, resistance sources and management of the Alternaria blight of linseed.

Historical development of genus Alternaria and Alternaria blight of linseed

The genus *Alternaria* was described by Nees von Esenbeck in 1816 with *Alternaria tenuis* as the type species but has suffered from considerable taxonomic uncertainty and flux since its inception. In 1832, Fries wrote his monumental work titled Systema Mycologicum in which he did not recognize Nees' description of *A. tenuis* and cited it as a synonym of *Torula alternata*, complicating the taxonomy of *Alternaria* from an early date. In 1912, Keissler reevaluated both Nees' and Fries' descriptions and synonymized both specimens with *Alternaria alternata*, which is now the recognized type for the genus. The defining characteristics of *Alternaria* include dark multicelled conidia with transverse and longitudinal septa (phaeodictyospores) that occur in chains (catenulate) or borne singly and possess an apical beak or tapering apical cells (Elliott 1917, Wiltshire 1933, Neergaard 1945, Joly 1964, Simmons 1967) [7, 59, 27, 18, 36].

There are several reports from outside India regarding association of *Alternaria* spp. with linseed (Badayeva, 1930; Tervet, 1937; Rost, 1938; Flor, 1940) [4, 10, 33, 54]. Ruschmann and Bartram (1940) [34] and Johnson (1942) [16] reported *Alternaria tenuis* Nees on flax straw which had been dew-wetted. Groves and Skolko (1944) [13] isolated an *Alternaria* spp. from the seed of linseed, which they named *Alternaria linicola*. Johnson (1943) [17] earlier reported association of *A. solanai* with flax plants. Johnson's material was further examined by Neergard (1945) [27] who found it similar to the fungus of Groves and Skolko. Moore (1946) [23] also isolated *A. linicola* Gr. and Sk. from black end cotyledons, dark leaf spot and pale brown streaks of stem of linseed. Mercer and Martin (1994) [22] have also reported *Alternaria linicola* from U.K as seed borne pathogen.

A thorough screening of literature on the Alternaria blight disease of linseed in India showed that there is only sporadic occurrence of this disease. A disease of linseed caused by *Alternaria* spp. was first observed on the Government Research Farms of Kanpur and Gorakhpur (Dey, 1933) [6]. Dey (1933) [6] identified it as a new fungus and named it *A. lini* sp. nov. Since 1933, there were no further reports of any Alternaria disease of linseed for another nineteen years till Arya and Prasada (1952) [2] recorded a severe outbreak of a blight disease in the linseed crop in Delhi, in the month of March and April, 1949. They also isolated an *Alternaria* spp. from the blighted plants that were showing symptoms somewhat similar to that reported by Dey. They identified their causal fungus as *Alternaria brassicae* (Berk) Sacc. Var. *microspora* Braun. This fungus was earlier reported to be Synonym of *A. brassicicola* (Wiltshire, 1947) [60]. Later, Siddiqui (1963) [35] reported the occurrence of Alternaria blight on linseed cultures grown in the farms of Indian Agricultural Research Institute, Delhi and in other parts of the countries. He thoroughly studied his fungus along with 2 sub cultures of *A. lini* Dey (1933) [6], obtained from IARI, New Delhi and C.B.S., Holand. Considering the size and other morphological characters of the three isolates, he found all of these belong to *Alternaria tenuis* auct. Chauhan and Srivastava (1975) [5] also reported the prevalence of this disease in the country. Narain (1982) [26] reported cotyledonary leaf blight caused by *Alternaria linicola* on *Linum grandiflorum* and leaf spot and black bud caused by *Alternaria alternata* (Garg, 1982) [12] causing losses to some of the susceptible promising lines. Singh *et al.* (2003) [42] also reported the prevalence of disease, causing 18.2 to 35.8% loss in yield of different commercially grown varieties from Faizabad.

Symptomatology

Alternaria blight Symptoms first appears on lower leaves of linseed as black point that gradually increased in size to become circular to oval or irregular in shape (Fig-3a & b). Blighting of the leaves from leaf margins are also common. During severe infections, spots coalesce and covers the large area of the leaves (Fig.1b). The affected leaves ultimately get dried up and curled. Target board like spots are not found in Alternaria leaf spot of linseed. Symptoms on floral parts first appears near the calyx on pedicel as minute dark brown spots. They enlarge, and spread all over passing into pedicel. The infected pods become distorted, blighted and discolored (Fig.1d). Sometime partially filled capsules can be seen in disease affected plants. Symptoms on stem appears as light brown linear spot with darker margin of varying size which later become more linear and darker in colour.

Characteristics of pathogens of Alternaria blight of linseed

Alternaria blight of linseed is known to be caused by two species of namely *Alternaria linicola* Groves & Skolko and *Alternaia lini* Dey. The proportion *Alternaria linicola* conidia in the infectied area is high due to its high infection potential (Yadav, 2017) [61]. The morphological and cultural characteristics of the *Alternaria linicola* and *Alternaria lini* are as follows:

Alternaria linicola

The mycelium of *A. linicola* on Potato dextrose medium are septate, brown to brownish grey in colour. The conidiophores are dark, septate, arise in fascicles, measuring 18-56×2-5µm. Conidia are brownish black, obclavate, borne singly or sparingly in chains of 2-4, muriform with long beak and the overall conidial size ranges between 90-145 × 12-19 µm with 3-7 transverse and 1-6 longitudinal septa (Fig.1e and g).

Alternaria lini

The mycelium of *A. lini* are septate, olive grey to grayish black in colour. The conidiophores are olivaceous, septate, branched measuring 26-80 µm in length and 3-7 µm in width. Conidia are dark, cylindrical to oblong, muriform without beak measuring 42-60 µm in length and 3-7 µm in width with 2-7 transverse and 1-4 vertical septa (Fig.1f).

Toxins of *A. linicola*

Evans *et al.* (1997) [8] reported that *Alternaria linicola* produces non-host specific phytotoxins tenuazonic acid, alternariol monomethyl ether, tentoxin and two destruxin-type

compounds which closely resembled destruxin A and destruxin B.

Yield loss

The disease appear on all the aerial parts of the plant, resulting a leaf and bud blight and ultimately causes substantial losses in yield from 18 to 43.9% (Singh and Singh, 2007) [40]. Singh *et al*. (2014) [44] reported the yield losses in linseed due to Alternaria blight caused by *A. linicola* and *A. lini*. They reported maximum yield loss (58.44%) was recorded in cultivar Neelum followed by Parvati (55.56%), Meera (55.56%) and Chambal (51.72%), respectively while minimum loss was recorded in Kiran (19.92) and Jeevan (22.22%).

Source of inoculum and environmental conditions

Vloutoglou *et al*. (1995) [56] reported that *A. linicola* survived as thick-walled chlamydospores in hyphal or conidial cells on infected linseed stem debris, either on the soil surface or buried in the soil. Conidia produced on these debris under favorable conditions were not only viable but also pathogenic to young linseed seedlings. Infected stem debris increased the incidence of infected seedlings which merged from infected seed (Incidence of *A. linicola* 1%-28%), especially if the debris was on the soil surface rather than buried. *A. linicola* was more effectively transmitted from infected seeds to seedlings at temperatures 15-25 ºC than at 10 ºC. The incidence of the disease on seedlings at which emerge from infected seed was positively correlated with the amount of seed borne inoculum, whereas the proportion of the seedlings which emerged was negatively correlated with the incidence of *A. linicola* on the seed. Vloutoglou *et al*. (1995) [56] reported that numbers of conidia in the air above linseed crops were greatest between 1200 h and 1300 h, when the relative humidity was lowest. Although numbers of conidia collected decreased with increasing height within and above the crop canopy, air born *A. linicola* conidia were present up to 80 cm above the crop canopy. Conidia of *A. linicola* were transported by wind up to at least 40 m downwind from an artificial line inoculum source, but their numbers decreased with increasing distance from the source. In 1991, 1992 and 1993, the dispersal of *A. linicola* conidia above linseed crops followed a seasonal periodicity which was influenced by weather conditions and cultural practices. The greatest number of conidia were collected during July, August and early September and coincided with periods favorable for sporulation and with an increase in the incidence of the disease in the senescent crop. In 1992 and 1993, the disease was first detected downwind from the sources, but by the end of growing seasons, it had spread in all directions and up to 20 m and 60 m from the sources, respectively.

Vloutoglou *et al*. (1999) [57] studied the effects of inoculum density, temperature, leaf wetness and light regime on the infection of linseed by *A. linicola*. The percentage cotyledons and leafs with symptoms and the disease severity increased linearly with the inoculum density increased from $1x10^3$ to $1x10^5$ conidia ml^{-1}. The first symptoms appeared on cotyledons and leafs 4 and 6 days after inoculation, respectively. 8 hours of leaf wetness were found sufficient to initiate the disease at 25 ºC but not at 15 ºC, when 10-h period of leaf wetness were required. Percentage leaf area with symptoms was lower at 15 ºC than that at 25 ºC irrespective of the leaf wetness periods tested. Interruption of a continuous leaf wetness period by a 12-h dry period, occurring at any time between 1 and 18-h after inoculation, decreased the percentage cotyledons with symptoms and the disease severity, with the greatest reduction (60 and 100%, respectively) being observed when the dry period began 6-h after inoculation. *A. linicola* conidia were able to exploit successive 12-h periods of leaf wetness cumulatively to infect linseed plant. Disease incidence and severity were positively correlated with dark period following inoculation, but they were negatively related to the length of initial light period.

Research on host resistance

Very little information is available on varietal reaction of linseed germplasm promising lines against this disease. Singh *et al.* (2004a) [45] screened 450 genotypes of linseed and reported eight genotypes *viz.,* Acc No. 2883, Acc. No. 2921, Ayogi, Cherapuram, ES-44, KL-31, and RI-50-3 as resistant to the disease during the year 1991-92 to 1993-94. Evans *et al*. (1995) [9] studied the levels of resistance in linseed and Linum accessions to *A. linicola* using an *in vitro* detached cotyledon bioassay. The response of four marketed varieties to seven isolates showed that differences between the isolates accounted for the majority of the variance. There was no significant interaction between varieties and isolates so that levels of response to the isolates showed a consistent trend. In a more comprehensive studies, 102 different linseed and Linum accessions were challenged with an aggressive and a non-aggressive isolate. The response of a sub- set of tested material to the two isolates in a whole plant assay was positively correlated to the scores achieved in the in vitro bioassay. Since large isolate line interaction with respect to resistant scores were not observed in either test, resistance appears to be polygenically determined. The result suggested that an improvement in the resistant of linseed to *A. linicola* would be possible and beneficial.

Evans *et al*. (1997) [8] studied the multivariate analysis of variance (MANOVA) and canonical variants analysis (CVA) to examine differences in host plant resistance and pathogen behavior in interactions between *A. linicola* and three genotypes of *Linum usitatiassimum*, previously identified as susceptible, modestly resistant and resistant to the pathogen. Significant differences in pathogen development were found among the Linum successions at 18, 24 and 40 h after inoculation. At 18 h after inoculation attempt penetration by the pathogen was relatively rare on all three essences and canonical variants analysis revealed that over all differences among accession resulted from large differences with respect to a small number of variables associated with successful penetration on the most susceptible accession. Pant *et al.* (2001) [30] screened 30 linseed cultivars for the resistant to *Alternaria alternata* and reported 9 cultivars as resistant (1-1.5% infection) and 9 moderately resistant (5.1-10% infection). Singh (2004) [38] evaluated 4965 germplasm under field condition against Alternaria blight during 1996 and reported 37 lines as resistant against the disease. Gupta (2004) [14] evaluated 49 linseed genotypes against the natural infestation of Alternaria blight (*A. lini*) during 5 consecutive *Rabi* season 1997-98 to 2001 in Madhya Pradesh. The genotypes 5610, EC-1392, RLC-29, JLT-84-12-1, LMH-43 and LCK-93-24 were reported as highly resistant against the disease by him. Singh and Singh (2004^a) [45] screened 200 genotypes and reported 6 resistant genotypes against the disease. Singh and Prasad (2005) [41] screened 200 germplasm of linseed under artificial inoculation condition during 2000-01 to 2002-03 and reported few genotypes resistant to *Alternaria lini*. Srivastava and Singh (2007) [51] screened 440 linseed germplasm lines accessions and three improved check

varieties to identify promising genotypes at the yield level against Alternaria blight. Of these germplasm lines, one hundred forty lines were identified with significantly lower disease intensity of *Alternaria* blight on leaves than checks varieties. Ram *et al*. (2008) [31] evaluated 440 lines of linseed against Alternaria blight severity and reported 14 lines significantly superior over checks in respect of less disease severity on leaves. Evans *et al.* (1997) [8] reported that Linum leaf material infected with conidia of *A. linicola* and blastospores of *Melampsora lini* contained a number of compounds which were fungitoxic to *Cladosporium cladospiroides* and, to a lesser extent, *Alternaria brassicicola*. They found that the quantitative differences in the amount of the fungitoxic compounds produced between the inoculated and uninoculated resistant and susceptible host genotypes. They suggested that the production of fungitoxic compounds was greater in response to attempted colonization. On this basis, they proposed that the phytoalexin production is a component of the resistance reaction. The results from these investigations are discussed in relation to recent research on the ecology of the pathogen and the possible roles of phytotoxin production by the pathogen and phytoalexin production by the host on disease development. Singh and Singh (2011) [43] evaluated 200 genotypes against alternaria blight under artificial inoculated condition and found none was free from the disease. Only ten genotypes were recorded resistant, 15 moderate resistant, 29 moderately susceptible, 59 susceptible and 98 as highly susceptible. Kumar *et al.* (2012) [21] evaluated fifty-four genotypes against Alternaria blight disease in field under artificial epiphytotic conditions. Out of which 28 genotypes were found resistant, 23 moderately resistant and 3 moderately susceptible against Alternaria blight. Reddy *et al*. (2012) [32] evaluated linseed genotypes for resistance to bud fly, Alternaria blight and powdery mildew. The results revealed that the pest and diseases ranged from 11.39 (EC544) to 59.54 (ES44) and 5.34 (Neelum) to 17.68 (ES44) for budfly and Alternaria blight. Among the hybrids Padmini x Ayogi and PKVNL-260 X EC9825 were found resistant to Alternaria infestation. Singh *et al.* (2015) [49] evaluated the forty six varieties against *Alternaria lini* and reported that only two were resistant, twenty cultivars were moderately resistant, fifteen were moderately susceptible and three were susceptible.

Management

Use of chemicals has been a practical method for controlling the disease and in some cases it has become the principal method to check the losses in yield. Singh *et al.* (1995) [48] found that 2-3 sprays of Rovral @ 0.2% as most effective followed by Indofil M-45 @ 0.25% in reducing the disease severity and increasing the seed yield. Singh *et al*. (2001) [37] tested the efficacy of Mancozeb + Thiophanate – methyle, Indofil Z-78, Copper sulphate, Carboxin, Phentin, Hydrooxide and Oxycarboxin 0.2% and Carbendazim (0.1%) against the Alternaria blight and found significant reduction in disease intensity in comparison with control. Amongst the treatments, Mancozeb + Thiophana te- methyle was the most effective in controlling the disease. Singh (2002) tested 4 fungicides namely Rovral 0.2%, Mancozeb 0.25%, Calixin 0.2% and Thiovit/ Wettable sulfur 0.25% against the foliar diseases of linseed and reported that Rovral was most effective followed by Indofil M-45. Khan *et al.* (2004) [20] tested the efficacy of Indofil M-45 0.20%, Carbendazim 0.10%, Capton 0.20%, Thiram 0.20%, Baycor 0.20%, Topsin M- 0.20% Vitavax 0.10%, Indofil Z-78 0.20%, Benlate 0.20% and Ridomil MZ 0.20% against Alternaria blight of linseed and reported higher efficacy of Inofil M-45.

Singh and Singh (2004[a]) [45] tested the efficacy of Indofil M-45@ 0.25%, Rovral @0.20%, Foltof @ 0.20%, Kavach @ 0.20%, Ridomil MZ @ 0.25% and Blitox-50 @0.30% against Alternaria blight. They reported lowest foliar blight intensity along with highest test weight and seed yield with foliar spray of Rovral 50 WP (0.2%) followed by Mancozeb 75 WP (0.25%). Maximum net return was recorded with Rovral while maximum cost – benefit ratio was recorded with Mancozeb.

Singh and Singh (2004[b]) [46] reported that 2 and 3 sprays of mancozeb and Iprodione significantly reduced the disease severity and enhanced the seed yield over the check. Three and two spray of Iprodione gave highest disease control and yield increase followed by 3 and 2 sprays of Mancozeb and one spray of Iprodione. Singh and Chandra (2005) [39] reported that Iprodione was superior over Mancozeb and 2 to 3 sprays of both the fungicides were significantly superior over one spray in controlling the disease and enhancing the seed yield. Singh *et al.* (2009) [47] conducted an experiment for the management of Alternaria blight of linseed by using carbendazim 12% + mancozeb 63%WP (0.125%), mancozeb 75WP (0.25%), propiconazole 25 EC (0.10%), hexaconazole 5 EC (0.10%), difenconazole 25 EC (0.05%) and iprobenphos 48 EC (0.10%) reported that all the treatment were significantly effective against the disease. Amongst them carbendazim 12% + mancozeb 63% (companion) application resulted in lowest leaf blight intensity of 32.15% and 28.25%, bud damage of 14.66% and 12.50%, highest 1000-seed weight of 4.90 and 4.97 g and seed yield of 1400.00 and 1462.50 kg/ha, respectively, in the first and second year. Propiconazole (tilt) 25 EC 0.10%, hexaconazole (contaf) 5 EC 0.10%, difenconazole (score) 25 EC 0.05% and iprobenphos (kitazin) 48 EC 0.10% have been noted to manage the disease economically.

Singh *et al*. (2007) [40] developed an economic spray schedule of mancozeb 75 WP 0.25% to identify most spray-responsive crop growth stage. Three sprays of the fungicide, one each, at maximum branching, flowering and capsule formation resulted in least leaf blight of 14.4 and 11.6%,and bud damage of 14.1 and 8.1%, respectively, in the first and second year. It also resulted in highest 1000-seed weight of 7.8 and 8.0g and seed yield of 1500 and 1510 kg/ha. It was followed by the schedule with first spray at flowering and second at capsule formation, which was at par with it in reducing bud damage in the first year and increasing 1000-seed weight and seed yield during both the years. The latter gave a net return of Rs. 3620/ha and benefit-cost (B:C) ratio of 3.2 as against a net return of Rs. 3682 and B:C ratio of 2.5 in case of former. A single spray at flowering stage with B:C ratio of 4.3, however, proved most economical. Flower stage, singly or in combination with maximum branching and/or capsule formation, proved most responsive to protection by way of contributing to higher yields.

Singh *et al*. (2007) [40] evaluated the aqueous leaf extracts (2.0%) of 15 locally available plants against *Alternaria lini*. Maximum inhibition was recorded with *Azadirachta indica* (67.7%) followed by *Lawsonia inermis* (63.0%), *Dhatura metel* (39.2%), *Calotropis procera*, *Lantana camara* (36.6%) and *Citrus medica* (28.1%), Others including *Odium sanctum*, *Eucalyptus citriodora*, *Acacia nilotica*, *Aegle marmelos*, *Parthenium hysterophorus*, *Clerodendrum inerme*, *Bougainvillea* sp., and *Pongomia glabra* had either low or no fungitoxic effect. The inhibitory effect was higher (97.7 to

50.2%) at higher (5.0%) concentration. Singh *et al*. (2014) [44] conducted experiment to manage the Alternaria blight of linseed with the integration *Trichoderma viride*, fungicides (mancozeb, thiophenole methyle) and plant extract (Neem leaf extract, garlic bulb extract), and reported that seed treatment with *T. viride* (4g/kg seed) followed 2 sprays of mancozeb (0.25%) was better in reducing the disease severity and increasing the seed yield. Singh *et al*. (2014) [44] reported maximum disease control (69.74%) with seed treatment by vitavax power + 2 foliar spray of Saaf followed by spray propiconazole (0.2%). Maximum mean seed yield (1440 kg/ha) was obtained with seed treatment with vitavax power + 2 foliar spray of Neem leaf extract followed by seed treatment with vitavax power + 2 foliar spray of Saaf (1378 kg/ha). Holi and Meena (2015) evaluated *in vitro* and *in vivo* efficacy of fungicides *viz*. Rovral, Copper oxychloride, Dithane M-45, Propiconazole, Difienoconazole, Carbendazim and Topsin. *In vitro* evaluation of Propiconazole (0.1%) completely inhibited the growth of *Alternaria lini* and was found significantly superior over the rest of fungicides. The fungicide Dithane M-45 (0.2%) was found most effective showing disease control up to 44.06% and 12.54% disease incidence followed by Rovral (0.2%) which showed disease control 42.50% and 12.89% disease incidence respectively. The highest yield was obtained by the treatment of Dithane M-45 (0.2%) 722 kg/ha followed by Rovral (0.2%) 674 kg/ha. Singh *et al*. (2015) [49] studied the effect of different date of sowing on the disease severity of Alternaria leaf blight and reported that highest incidence (35.90%) of disease was on first sowing date i.e. 28th October, which was gradually reduce in subsequent sowing dates. They found the minimum disease severity in crop sown on 9th December (6.87%). However, the significantly highest grain yield (547.6 kg/ha) was obtained in crop sown on 18th November followed by 8th November and 28th October. Singh *et al*. (2020) [50] studied the effectiveness of different resistance inducing chemicals *viz*. Benzoic acid, Napthelic acetic acid, Salicylic acid, Phosphoric acid, Isonicotinic acid at 0.05 and 0.1% concentration along with fungicide Mancozeb @ 0.25% were tested against the Alternaria blight. They found the minimum disease (28.40%) severity with maximum yield (724.16kg/ha) with spray of Salicylic acid @ 0.10% followed by the same chemical @0.05% and Benzoic acid @ 0.10% respectively. But maximum benefit cost ratio was recorded with Benzoic acid @ 0.05%.

Conclusion

Alternaria lini and A. linicola are opportunistic foliar pathogens that cause destruction of host tissue through the reduction of photosynthetic potential by inciting spots and blights in linseed. The disease also cause reduction in the oil content and quality of the fiber of crop. The higher dominance of *A. linicola* in the diseased samples indicates that *A. linicola* is most aggressive and predominant necrotrophic pathogen during all the growth stages of plants. The research on the evaluation of genetics stocks indicates that resistance and tolerance is available in the germplasm of linseed against Alternaria blight. Since the disease is air borne, hence the most appropriate method of the disease management is the use of suitable fungicides and resistant inducing chemicals. Neem based fungicides can also be used as non-chemical method of disease management. Use of seed treatment by chemicals and bio-agents, use of resistant varieties, change in the time of sowing of the crop and better agronomic practices could be useful for the management of the disease.

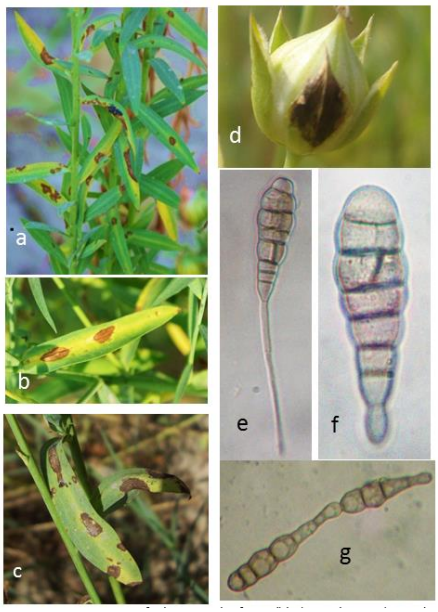

Fig 1: Symptoms of Alternaria leaf spot/blight on leave (a to c) and pods (d). Conidium of Alternaria linicola (e), Alternaria. linl (f) on linseed leaves and formation of conidia of Alternaria linicola on corn meal agar medium

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