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Integrated Disease Management of Leaf Spot of Brinjal Caused by *Alternaria alternata*: A Review

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ABSTRACT

Brinjal, eggplant or aubergine (*Solanum melongena* L.) is a major vegetable crop of India after potato. It is grown in all seasons and almost in all the parts of India except on higher altitudes. Leaf spot of disease were appears in two phases leaf spot and fruit rot caused by *Alternaria alternata* (Fr.) Keissler. It is mainly an outdoor whose spores disseminate in warm, dry air, so in temperate climate, their count peacks in the summers. Pathogen on crop plants reason huge yield losses, reduce the economic value of the crop plants in conventional production system and are very difficult to manage. Survey conducted in Brinjal fields in the different climatic condition was recorded the disease intensity of leaf spot (*A. alternata*). The maximum leaf spot disease intensity 39.01% was recorded in old plants, whereas, it was minimum disease intensity recorded in 9.20% in newly plant in areas surveyed. Fruit rot disease incidences was recorded more than 50%. In leaf spot symptoms is as small, circular, brown, necrotic spots with a chlorotic halo. They gradually emerged and coalesced are causing withering and shedding of the leaves. There are concentric rings with a deep greenish blue growth of the fungus. Lower leaves are first attacked than upper leaves and fruit. The fungus is isolated from infected leaves and found to be pathogenic as seed and spore cum myceial suspension under artificial inoculation condition. Microscopic observations of the isolated fungus revealed that the mycelium is septate, with dark brown hyphae and conidia, when observed singly and irregularly branched, measuring 2.7-4.4 µm in width. The conidiophores are dark brown in color, septate, branched and measured 34.0-93.0 µm in length and 3.4-9.0 µm in width. The conidia are dictyospores and transversely septate. The environmental factors during the crop season play and important role in disease development because temperature and relative humidity are two important external factors, which is influence the growth of pathogen as well as it pathogenesis. Maximum disease occurred when temperature are ranged from a maximum of 28.7-32.2^{o}C to a minimum of 15.5-20.3^{o}C and relative humidity from 62.74 % to 32.46%. Management of leaf spot and fruit rot are fungicides like Indofil Z-78, Vitavax, Benlate, Thiram, Karathane, Calaxin, Ridomil, Miltox, Plantvax, Captan, Brestan-60, Dithane M-45, Difolatan, Cuman L, carbendazim+mancozeb, copper oxychloride, iprodione, thiophanate methyl, Zineb, propecanazole and hexacanazole gave satisfactory management, but are dangerous to the ecosystem. Other methods are managing alternaria

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pathogens like use of bio-agents such as *Trichoderma harzanuim*, *T. viridi* and *Aspergillus niger* was found good result. Medicinal plants and various plant products have some potential. To find out possibilities of replacing fungicides with other ecofriendly product, plant extract of garlic, NSKE, onion, bitter melon and beal are tested *in vitro* against the mycelial growth of pathogen. The found of pathogen management are *in vitro* as well as *in vivo* condition. Use of disease resistant as well as agronomically superior variety is an important accomplishment of present era for the disease management and obtained high yield. Use of resistant variety against specified disease is not only a full-hardy and most economical adaptive measure, but also renders atmosphere free of pollution, which might have been polluted due to use of pesticides. This review is an effort to through some light on the different eco-friendly strategies for the management of leaf spot of Brinjal under different agro-climatic conditions.

Keywords Brinjal, Alternaria, Temperature, Relative humidity, Bio-agents.

INTRODUCTION

Brinjal (*Solanum melongena* L.), eggplant or aubergine is a major vegetable crop of India after potato. It is grown in all seasons and almost in all the parts of India except on higher altitudes. Its centr of origin is in the Indo-Burma region (Zeven and Zhukovsky 1975). It belongs to family, Solanaceae. It has many medicinal properties. It is a common belief that white Brinjal are good for diabetic patients. It can also cure toothache if fried, Brinjal fruit cooked in Sesamum oil acts as an excellent remedy for those suffering from liver complaints (Chauhan 1981). The bitter taste in Brinjal fruit is due to glycoalkaloids. Brinjal have very good nutritional value, per 100 g of edible portion contain 92.7 g moisture, 6.4 g carbohydrate, 1.3 g protein, 0.3 g fat, 1.3 g fiber, 124 IU vitamins A, 0.09 mg nicotinic acid, 120 mg vitamin C, 200 mg potassium, 18 mg calcium, 16 mg magnesium, 47 mg phosphorus, 0.9 mg iron, 18 mg oxalic acid, 0.74 mg beta carotene, 0.04 mg thiamine and caloric value is 24 (Aykroyd 1963). Brinjal is highly productive and usually finds its place as the poorman's crop. This crop is extensively grown in warm area of India, Bangladesh, Pakistan, China and Philippines. The total area under Brinjal cultivation in the world is 1864.32 thousand hectares with annual production and productivity of 49782.16 thousand metric tonnes and 26.70 MT per hectare respectively (Anonymous 2015). In India, Brinjal is a mainly grown in the states like West Bengal, Odisha, Gujarat, MP, Bihar, Maharashtra, Andhra Pradesh and Karnataka with an area of 730.00 thousand hectare and production of 12, 801.00 thousand metric tonnes and productivity of 18.5 MT per hectare (Anonymous 2018-19). A principle limiting factor in profitable cultivation of this crop in different climatic location is attack of several disease mainly caused by fungi, which take heavy loss of the crop at all the stage of growth right from sowing to harvest and during storage. Fungal, bacterial, viral and phytoplasmal diseases like leaf spot (*Alternaria alternata* (Fr.) Keissler), Damping off (*Pythium aphanidermatum* (eds.) Fitz; *Phytophthora spp*.; *Rhizoctonia spp*.), Phomopsis blight (*Phomopsis vexans* Sacc. and Syd.) Harter, Cercospora leaf spot (*Cercospora solani melongenae* Chupp., C. *solani*.), Verticillium wilt (*Verticillium dahliae Kleb*), Fusarium wilt (*Fusarium solani* (Mart.) App and Wollenw), Bacterial wilt (*Ralstonia solanacearum* Smith), little leaf (Phytoplasma.), Mosaic virus, Root-knot nematodes (*Meloidogyne javanica* (Treub) Chitwood) during various growth stages, which reduce yield and quality of fruits. *Alternaria alternata* was first known as *Alternaria tenuis*. Christian Gottfried Daniel Nees Von Esenbeck in 1817 placed the *Alternaria tenuis* as species under genus Alternaria. After that Karl Von Keissler is an Austrian lichenologist and mycologist in 1912 continued the study of *A. tenuis* and replaced the name with *A. alternata*. The designation Keissler was allotted to the name of the fungus due to recognition of his work. The taxonomically it's belong to Kingdom: Fungi, Class dothideomyctes, order: Pleosporaces is a family: Pleosporaces, genus Alternaria and species *Alternaria alternata*. Pleosporaceae is a family of black pigmented molds having in and rapid growing colonies with color range from dark gray to olive brown (Woudenberg *et al.* 2013) Alternaria comprises of different saprophytic as well as endophytic species and well known for its notoriously destructive plant pathogen members. Kustrzeba *et al.*

(2014) stated that *A. alternata* is an outdoor fungus of temperate climate, which like to sporulate under warm dry air conditions and may also be sporulate under moisture conditions. These spores could be the organic constituent of soil while during spring to autumn become airborne to cause saprophytic contamination. The necrotrophic nature of *Alternaria alternata* (Fr.) Keissler first reported by Kapoor and Hingorani (1958) at new Delhi leaf spot and fruit rot of Brinjal typically leads to extensive damage of the plant and harvest product, with seedlings seldom surviving an attack. Singh (1987) reported that *A. alternata* survives in the plant debris for up to one year, when kept at room temperature (25-28ºC) under lab. Conditions, but it survived only up to 6 months when buried in soil. Infected aubergine seeds yielded a pathogenic culture of *A. alternata.* Infected soil, plant debris and seed served as the source of primary infection. The important factor that occurs and develops in the epidemic form of the disease under the combination of a number limit the productivity in different climatic region is likewise, used of contaminated seed, susceptible host cultivar, along with non-adoption of improved cultivation practices and favorable environment condition. Alternaria temperature range of 15-30ºC, relative humidity >90%, wind velocity of 2-5 km/h and intermittent rains are the most abiotic conducive conditions for development of leaf spot under field conditions. In addition, high nitrogen application without phosphorus or potash resulted in severe infection (*A. alternata*) on Brinjal in a field, while high phosphorus and potash helped to decrease incidence (Singh 1988). It such as crop rotation by farmers which results in poor seed germination and in vision of various disease including leaf spot (*A. alternata*) during crop development in field as well as in storage. The crop suffers from leaf spot and fruit rot during harvesting stage (*A. alternata*), which is account for huge losses to farmer. In India, the disease Alternaria leaf spot and fruit rot of Brinjal. This disease is severe and appears regularly, causing heavy losses in fruit yield. When the environmental conditions are favorable, the fruit rot incidence can be up to 50% and this can result serious economic losses. The fruit infection takes place during fruit formation just some days prior to the harvest of the crop. This infection becomes severe at the time of harvesting to marketing. Some farmers are found using available fungicides indiscriminately and unscientifically in different location in Brinjal, leaf spot and fruit rot management. It is no single method or approaches in current use is feasible, viable, stable effective and economical in reduce with any host pathogen system. Therefore, it is necessary to integrated all the methods of plant disease management. Which are available, including host plant resistance, efficacy of fungicides, botanicals and bio-agents for the effective management of leaf spot and fruit rot Brinjal is taken under review Singh and Shukla (1985, 1986) Bochalya *et al.* (2012) Balai and Ahir (2010, 2013) Balai *et al.* (2010, 2013) Premila (2014) Kumar (2017) Raina *et al.* (2018) Shafique *et al.* (2021). This review is an attempt to collate available information on integrated disease management practices of *A. alternata* for enhancing the agricultural productivity in Indian soils under different agro-climatic conditions.

Survey of disease

Pucci (1947) reported that planting of Brinjal in the vicinity of La Plata, Argentina, were severely attacked by a species of Alternaria, which formed ashen-grey lesion on the leaves and stems and yellow brown to black ones (scabbed in the case of Brinjal) on the fruit. Danger and Singh (1985) observed maximum disease intensity (33.87 and 34.31%) was observed during second and first fortnight November of 1979 and 1980, respectively in Kanpur (UP). Singh and Shukla (1986) observed maximum disease intensity (39.12%) was recorded in 120 days old plant and minimum disease intensity (13.06) of Brinjal infected with leaf spot (*A. alternata*) at Kanpur (UP). Balai and Ahir (2013) survey conducted in Brinjal fields near Jobner (Jaipur) during *rabi* season 2006-07 to estimate the disease intensity of leaf spot (*A. alternata*). The maximum disease intensity 25.32% was recorded in Bagru whereas; it was recorded minimum disease intensity in Phulera 9.20% in the area surveyed. The disease first makes its appearance in young seedling but intensity is less. It attacks leaves and then spreads to fruits, which subsequently rot and become unfit for consumption (Bochalya *et al.* 2012). Premila (2014) recorded 9.5 to 29.5% intensity of leaf spot disease on Brinjal in Manipur. An extensive survey was conducted in Kashmir revealed that disease was prevalent disease intensity 30.76% maximum and 9.77% minimum, respectively was noted by Raina *et al.* (2018).

Symptomology of disease

Kapoor and Hingorani (1958) at IARI, New Delhi in 1952-53, reported that *Alternaria tenuis* (= *Alternaria alternata*) was the cause of this disease of Brinjal believed to be a new host record. During the rainy season, it affected young seedlings, which become blight, charred and died. In September small, circular, brown, necrotic leaf spots with a chlorotic halo were formed, which gradually enlarged and coalesced causing withering and shedding of the leaves. Fruit lesions were small (+ ½ cm), concentric, dark brown and sunken, becoming olivaceous due to spore formation, coalescing and sometimes covering the entire surface. Balai (2007) found that most recognizable symptoms were appeared as small, circular, brown, necrotic spots with a chlorotic halo. They gradually emerged and coalesced causing withering and shedding of the leaves. There were concentric rings with a deep greenish blue growth of the fungus. The purified culture of the pathogen based on cultural and morphological characters. Further the identification was got confirmed from Division of Plant Pathology IARI, New Delhi and pathogen was identified as *Alternaria alternata* (Fr.) Keissler. Sidhdapara *et al.* (2016) reported that disease produced small, necrotic, circular brown spots on leaves, with a purplish halo and expands to about 1 cm diameter. The center becoming grey and cracked, Finally, the spots enlarge in size which later on resulted defoliation of leaves. Kumar (2017) reported that disease symptoms were observed as small, circular, brown colored, necrotic spot, which gradually in large in size, concentric rings. Lower leaves are first attacked than upper leaves. Leaf spot of Brinjal (*A. alternata*) a fungal pathogen responsible for developing small, circular, concentrated, brownish, dark necrotic spots that spread and cause senescence in the leaves. Necrotic spots are enlarged and sporulated under favorable conditions that damage the leaves and then spread through fruits that cause rotting of the fruit reported by Haider (2020). Shafique *et al*. (2021) reported that symptoms were small, circular, brown, necrotic spots uniformly distributed on leaves. The spots gradually enlarged and coalesced into large, nearly circular of irregularly shaped spots that could be upto 3 cm in length. The center of the spots was light tan, surrounded by a dark brown ring and a chlorotic halo and it tended to split in the later developmental stage.

Morphological characters of pathogen

Pandey and Vishwakarma (1999) described the size of conidia and conidiophores of *Alternaria alternata* was much larger on Brinjal host growing under natural conditions and drastically reduced, when isolated either on host extract or on potato dextrose agar (PDA) medium. The conidial chain arrangement on the conidiophores has been illustrated by new method named as "Slide coating technique". The germination of conidia started after 2 hr and germ-tube elongation continued only up to 9 hr of incubation. Balai (2007) reported that microscopic observations of the isolated fungus revealed that the mycelium was septate, with hyaline hyphae when observed singly and irregularly branched, measuring 2.7-4.4 µm in width. The conidiophores were dark brown in color, septate, branched and measured 34.0-93.0 µm in length and 3.4-9.0 µm in width. Conidia were slightly brown in color spindle shaped with round base and tapering apex measuring 21.8-95.9 µm in length and 8.0-17.0 µm in width having 0-2 longitudinal and 2-6 transverse septa. Conidia were mostly in chains of 3-12 conidia. The colony was spreading, hairy and gray brown to black in color, mycelium was branched, septate, dark colored with tints of olive brown whereas conidiophores were septate, short, simple, straight or flexuous dark colored and conidia were long beaked, muriform, dark colored, borne in chains, both longitudinal and transverse septa in mature conidia. Conidia were borne singly or in short chains and were pyriform to clavate 29. 48× 13.25 2.78 µm with zero to three longitudinal and two to six transversal reported by Shafique *et al.* (2021).

Pathogenicity

In the *Alternaria alternata* was isolated from leaf spot infected leaves of Brinjal and found to produce typical, symptoms of leaf spot on Brinjal plant after

10 days inoculation. The test fungus (*A. alternata*) was used as seed and spore cum mycelium inoculation to test pathogenicity. In seed inoculation, technique 18.50% disease incidence (seedling mortality) was observed with spore cum mycelial suspension (1×103 spore/ml) technique 56.25% disease intensity was observed. It was reported by (Kapoor and Hingorani 1958, Balai 2007, Kumar (2017), Shafique *et al*. 2021) workers that the fungus *A. alternata* was found pathogenic on Brinjal.

Mycelial Growth on Different media

Bochalya *et al.* (2013) *in vitro* studies were carried out in SKN College of Agriculture, Jobner, Jaipur. Six different solid growth media viz., Potato dextrose agar (PDA), Oatmeal Agar, Corn meal Agar, Czapeck's dox, Martins medium and Richards's medium were tested for mycelial growth and sporulation of *A. alternata*. The maximum mycelial growth and excellent sporulation were observed on PDA (47.70 and 84.28 mm) followed by Richards' medium (38.28 and 76.70 mm) after 4th and 7th days of incubation at 25±1°C. Minimum mycelial growth of the fungus was observed on Martin's medium (20.20 and 38.70 mm) and showed fair sporulation after 4th and 7th days of incubation. Jakatimath (2016) reported that suitable medium for the growth and sporulation of the fungus, nine solid media viz., Asthana and Hawkers Agar, Commeal Agar, Czapecks dox Agar, Potato Dextrose Agar (PDA), walks man Agar, malt Agar, Oat meal Agar, Rchards Agar and Sabouraud's. Among nine solid medium PDA, oatmeal Agar, Rchards Agar, and Sabouraud's proved best for mycelial growth and sporulation of the pathogen. Kumar (2017) reported that maximum mycelial growth and sporulation of the fungus was observed at PDA followed by Oatmeal medium, whereas minimum was observed at martin medium in *in vitro* condition.

Disease development in relation to environment condition

The environmental factors during the crop season play an important role in disease development because temperature and relative humidity are two important climatic factors, which is influence the growth of pathogen as well as it pathogenesis. For each fungus, there is certain of temperature and relative humidity for growth with three cardinal point viz., minimum, maximum and optimum. Wolf and Wolf (1947) observed that most of the parasitic fungi survive with in the temperature range of 0 to 40ºC. Dingar and Singh (1985) reported that disease *Alternaria alternata* development on aubergine reached a peak during the last week of October and 1st weeks of November when mean temperature was 24-26ºC and RH was 47-52%. Scanty rains and a long dry spell affected disease development more adversely than intermittent rainfall. Singh and Shukla (1986) while working at Kanpur studied that during 1979 and 1980 *A. alternata* appeared on aubergine in the 1st half of July and infection increased until November. There was a decline in severity with the lowering of temperature and relative humidity upto December. Maximum disease occurred in mid-October to mid-November when temperature ranged from a maximum of 28.7-32.2ºC to a minimum of 15.5-20.3ºC and relative humidity from 62.74 % to 32.46 %. The maximum disease was recorded on 120 days old plant and minimum on 15 days after Brinjal planting. In general, it is known that temperature either low or near frizzing, slow down fungal development. It was also known that relative humidity enhance the fungal growth and disease development in plants. Bochalya *et al*. (2012a) reported that temperature (i.e., 15, 20, 25, 30 and 35ºC) for the radial growth of fungus. Maximum mycelium growth 86.00 mm and excellent sporulation was observed at 25ºC. A gradual decrease in mycelial growth and sporulation was observed at 30ºC and 35ºC. Minimum mycelial growth i.e., 10.00 and 16.00 mm and fair sporulation was observed at 15ºC temperature. The effect of relative humidity was a studied by exposing the fungus at different levels viz., 60, 70, 80, 90 and 100% and incubated at 25±1°C for 7 days. Maximum mycelial growth (82.44 mm) and excellent sporulation was recorded at 90% relative humidity closely followed by 100% (78.42 mm and excellent sporulation) relative humidity. Balai and Ahir (2013) observed the role of temperature and relative humidity on Brinjal pathogen (*A. alternata*) under *in vitro* conditions. The mycelial growth of *A. alternata* is very much affected by temperature. Maximum mycelial growth was observed at 25ºC. A gradual decrease in mycelial growth was observed at 30ºC and 35ºC, whereas minimum mycelium growth was observed as 10ºC. The effect of relative humidity was studied by exposing the fungus at different levels viz., 50, 60, 70, 80, 90 and 100% and incubated at 25+1ºC for 7 days. Maximum mycelial growth was recorded at 100% relative humidity, which was closely followed at 90.0% relative humidity. Minimum mycelial growth was observed at 50% relative humidity. It can be concluded that high relative humidity favors the growth of the pathogen. Kumar (2017) reported that maximum mycelial growth and sporulation of the fungus was observed at 90% followed by 100% relative humidity in *in vitro* condition. Maximum mycelial growth and sporulation of the fungus was observed at 30ºC temperature followed by 25ºC whereas minimum was observed at 15ºC temperature in *in vitro* conditions.

Sporulation of inoculum and inoculum development: Bochalya *et al.* (2013a) mycelial growth and sporulation were tested under *in vitro* condition. The maximum disease incidences (15.90 and 18.26) was observed on four days old fruit at 4th and 7th day after incubation inoculated with 10 days olds inoculum and with 106 inoculum load (spores/ml) at 25±1°C temperature.

Integrated disease management of leaf spot

Management practices directed of the disease occurrence could be exclusion, eradication of the pathogen, to reduce its inoculum. The varied nature of pathogen involved, evolving resistant varieties has so far proved to be the best bet, although other conventional chemical, cultural methods and biological control have also yielded good results. Leaf spot of Brinjal can be managed using resistant cultivar, plant extract, bio-agents and conventional fungicidal seed treatment and foliar spray management have good results. The use of leaf spot resistant cultivar/varieties is cheap and easily adoptable methods in managing leaf spot of Brinjal. Developing and releasing leaf spot resistant cultivar is the major objective of the every vegetable breeder.

Bio agents

To circumvent pollution hazard due to indiscriminate use of agrochemical and also to avoid development of resistance in pathogenic fungi, use of biocontrol agents for the management of plant diseases has increased in recent years and has proved to be very effective against plant diseases. Keeping in view the antagonistic properties of various fungi, bacteria and actinomycetes, the use of various bio-control agents is being encouraged. Another important reason of their increased application is the fact that they are eco-friendly too. No commercial biological control agents that directly attack leaf spot of pathogens are currently available. However, potential biological agents have been identified for the management of leaf spot of Brinjal. Bora (1977) found *in vitro* condition the effects of *Aspergillus niger*, *Myrothecium verrucaria* and *Trichoderma viride* isolated from soil against *Alternaria alternata* isolated from eggplant and *Aspergillus niger* showed the greatest antagonism. The antagonistic potential of *T. harzianum*, *T. viride* and *A. niger* against *A. alternata* was evaluated by dual culture plate method on PDA medium. *T. harzianum* and *T. viride* inhibited the growth of the pathogen. *T. harzianum* was the most effective (inhibition zone of 7.3 mm), followed by *T. viride* (6.2 mm). Aubergine seeds were inoculated with the fungal antagonists (1.0 × 104 cfu [colony forming units] / ml), inoculated with *A. alternata* and then treated with 10-day-old cultures of the fungal antagonists before sowing. At 60 days after sowing, the pathogen was inoculated to plants. The fungal antagonists reduced seedling mortality and leaf spot intensity. Seedling mortality and disease intensity were lowest (9.3 and 38.5%, respectively) in plants treated with *T. harzianum* reported by Balai and Ahir (2011). Bochalya *et al.* (2012) mycelial growth and sporulation were tested under *in vitro* condition. Tricoderma viride was found most effective biocontrol agent and produced a clear inhibition zone followed by *T. Harzianum* and *Sporidiobolus pararoseus*. Jakatimath (2016) found that bio-control agent tested *in vitro*, *T. harzianum*-p and *T. harzianum*-21 were found effective. The efficacy of various bio-agents was carried out *in vitro* and *T. harzianum* showed highest inhibition among bio-agents showed maximum mycelial growth inhibition. Sidhdapara *et al*. (2016) reported that biocontrol agents are potential alternative to chemical agents that are hazardous to the environment. Therefore efforts was made to screen the different biocontrol agents against test fungus, Biocontrol agents viz. *Trichoderma* spp. have worked very well during their bioassays against the leaf spot pathogen and best performance was received with *T. harzianum*-I followed by *T. harzianum*-II to reduced the radial growth of the leaf spot pathogen in dual culture method. Eco-friendly disease management in the field with most effective bio-agents was evaluated *in vivo* showed that seed treatment with *T. harzianum*. Three foliar spray could be effectively manage the disease with lowest disease incidence of 19.13% and highest fruit yield of 197.80 q/ha, as compared to control plot showing highest disease incidence of 65.51% and intensity of 34.51% respectively with lowest fruit yield of 106.46 q/ha reported by Khursheed *et al.* (2021).

Plant extract

In view of environmental pollution and associated health hazards as well as the development of fungicidal resistant strains of the pathogen. The application of plant extract for the managements of plant disease increased in recent years because these cause no health hazard or pollution and proved to be very effective against plant disease. To find out possibilities of replacing fungicides with other ecofriendly product, plant extract of garlic (*Allium sativum*), NSKE (*Azadirachta indica*), onion (*Allium cepa*), bitter melon (*Citrullus colocynthis*) and beal (*Aegle marmelos*) were tested *in vitro* against the mycelial growth of *Alternaria alternata*. Balai and Ahir (2011) work done the antifungal properties of neem seed extract and onion, garlic, bael and bitter melon extracts at various concentrations (5, 10 and 15%) were evaluated against pathogen by poisoned food technique. The efficacy of the extracts in the inhibition of mycelial growth increased with the increase in extract concentration. The garlic extract was the most inhibitory among the extracts (mean inhibition of 73.7%). Bochalya *et al.* (2012) mycelial growth and sporulation were tested under *in vitro* condition. Garlic extract at 15 % concentration inhibited mycelial growth and sporulation of the fungus followed by Neem and onion in poisoned food technique. Jakatimath (2016) tested garlic bulb extract onion bulb extract and kokum fruit extract were found most effective @ 5 and 10% concentration in inhibition of mycelial growth of the pathogens. Kumar (2017) reported that plant extracts tested by poisoned food technique garlic clove extract was most effective in inhibiting the mycelial growth and sporulation of pathogen by NSKE. The aqueous extracts of commonly available eleven plant species belonging to ten different families were evaluated *in vitro* for their inhibitory effect on the mycelial growth and spore formation by *A. alternata*. The results revealed that all the phyto-extracts tested were significantly superior over the control in checking the growth of the pathogen. The rhizome extract of turmeric (54.42%) was found significantly superior in inhibiting mycelial growth over the rest. The next best in order of merit was garlic (50.67%). The sporulation was inhibited by all the phyto extracts as compared to control. Thus, extract of turmeric, garlic and neem proved most effective phyto-extracts in inhibiting mycelial growth as well as in preventing spore formation reported by Rajput and Chaudhari (2018). Haider (2020) work done in phyto-extracts of the plants tested included *Zingiber officinale, Curcuma longa, Allium sativum, Azadirachta. indica, Dahtura stramonium, Allium cepa, Eucalypttus globulus, Lawsonia inermis, Menthra piperita* and *Bouganvillea glabra*. Aqueous extracts of *Z. officinale, C. longa* and *A. sativum* expressed to be very effective under in vitro conditions against *A. alternata* 5%, 10% and 15% concentrations. However, in *In-vivo* conditions these three most effective phyto-extracts applied individually and in combinations against leaf spot of Brinjal. All extracts showed promising results while combination of *Z. officinal* + *A. sativum* + *C. longa* showed best results among all other combinations without any phytotoxic effects at given concentrations. The efficacy of various plant extracts was carried out *in vitro* showed highest inhibition among plant extracts garlic bulb extract showed maximum mycelial growth inhibition.

***In vivo* condition**

Yadav *et al*. (1998) reported that three spray *Allium sativum* extract (2%) were found statistically at par in terms of control efficacy. Balai and Ahir (2011) work done the antifungal properties of pot experiment, aubergine seedlings were inoculated with *A. alternata*, and then sprayed with neem seed extract and onion, garlic, bael and bitter melon of the extracts at 48 h after inoculation and 10 days after inoculation. The plant extracts reduced the disease incidence (seedling mortality) and disease intensity (leaf spot), with the garlic extract being the most effective (mean reduction of 6.6 and 30.7%, respectively). Kumar (2017) reported that in field condition, plant extract garlic clove extract was found most effective followed by NSKE against leaf spot. Nagaraju *et al.* (2020) four plant extracts (Turmeric, Neem, Tulasi and Alovera) were evaluated against *Alternaria alternata* under *in vitro* condition by using the poison food technique method at different concentration levels of (2.5%, 5% and 7.5%). Among the four plant extracts, tulasi and turmeric showed most efficacious and successful in inhibiting the mycelial growth of *A. alternata*, whereas alovera showed lowest inhibition of pathogen causing leaf spot of Brinjal. Disease management in the field with most effective plant extracts evaluated in vivo showed that seed treatment along with three foliar spray with garlic clove extract could effectively manage the disease with lowest disease incidence of 19.13% and intensity of 9.02% respectively and highest fruit yield of 197.80 q/ha. Whereas to control plot showing highest disease incidence of 65.51% and intensity of 34.51% respectively with lowest fruit yield of 106.46 q/ha reported by Khursheed *et al*. (2021).

Chemical management

One of the most effective measures and cheapest to control the disease (*Alternaria alternata*) is the effective application of fungicides.

***In vitro* condition**

Singh and Rai (2003) conducted an experiment *in vitro* to determine the effect of 0.2% Indofil M-45, 0.2% Indofil Z-78, 0.1% Vitavax, 0.2% Kavach, 0.2% Bavistin, 0.2% Benlate, 0.2% Thiram, 0.2% Karathane, 0.2% Calaxin, 0.2 Ridomil, 0.2% Blue copper-50, 0.2% Miltox, 0.2% plantvax and 0.2% captan on the growth of *Alternaria alternata* infecting Brinjal using poisoned food technique. Indofil M-45, indofil Z-78, vitavax and kavach appeared most efficacious in reducing the mycelial growth were statically superior amongst all the other fungicides tested against the pathogen. Balai *et al.* (2010) tested six fungicides systemic and non Systemic namely mancozeb (Indofil M-45), copper oxychloride (Blitox-50) carbendazim (Bavistin), iprodione (Rovral 50 WP) thiophanate methyl (Topsin M) and carbendazim + mancozeb (Companion) at 100, 250 and 500 ppm concentrations were tested against the culture of *A. alternata* in poisoned food technique. Mancozeb was found most effective followed by copper oxychloride and mancozeb + carbendazim. Carbendazim and thiophanate methyl was least effective against mycelial growth of the pathogen. Increase in concentration of fungicides was more effective in inhibiting the mycelial growth of the pathogen. Bochalya *et al.* (2012) mycelial growth and sporulation were tested under *in vitro* condition against the pathogen. Mancozeb (1000 ppm) was found most effective in inhibiting mycelial growth and sporulation of *A. alternata* followed by copper oxychloride and iprodione (1000 ppm). Jakatimath (2016) reported that fungicides tested *in vitro*, tebuconazole @ 0.1%, carbendazim @ 0.1% and propiconazole @ 0.1% were found most effective in inhibiting the mycelial growth of the pathogen. Kumar (2017) tested fungicides by poisoned food technique propiconazola was most effective in inhibiting the mycelial growth and sporulation of pathogen by heaxaconazole. Hassan *et al.* (2013) tested the pyrimidine derivative (4,6-dimethyl-N-phenyldiethyl pyrimidine, DPDP) as a foliar spray fungicide at 50 mg l-1 for protection of Brinjal from spot disease. Varied concentrations of DPDP (10–50 mg l-1) differentially inhibited mycelial growth, conidial count and conidial germination of pathogen growth *in vitro*; the magnitude of inhibition increased with increasing concentration.

***In vivo* condition**

Singh and Shukla (1984) tested nine fungicides sprayed on inoculated brinjal plants in plots tests, Brestan-60, Dithane M-45, Difolatan, Cuman L, Zineb, Bavistin, blue copper-50, captan and kitazin gave the best control of this disease and increased yields. Brestan-60 followed by Dithane M-45 was most effective against leaf spot of Brinjal. Yadav *et al*. (1998) reported that three spray of captaf (0.25%), blitox-50 (0.35) and indofil m-45 (0.25%) at 20 days interval were significantly superior to other treatments in reducing disease severity (*Alternaria alternata*) and increasing the yield of aubergine in field. Three sprays of carbendazim (0.05%) was found statistically at par in terms of control efficacy. Patel *et al*. (2000) conducted a field experiment at the vegetable research farm near Mai Parvat Faizabad, UP, India, during 1991 and 1992 to assess the effectiveness of eight fungicides viz., Dithane M-45, Bavistin, Dithane Z-78, Bliotox-50, Sulfex (sulfur), Carbendazim, Captaf and Bordeaux mixture for the control of leaf spot of Brinjal. All the fungicides reduced leaf spot disease incidence and significantly increased yield. Singh and Rai (2003) fungicides that proved effective *in vivo* condition against leaf spot of Brinjal, three sprayings of each fungicides such as Indofil M-45, Vitvax, Indofil Z-78, Kavach and Bavistin were given at 15-day intervals. Indofil M-45 was most effective in controlling *A. alternata* (84.5%) followed by Indofil Z-78 (78.0%), Vitavax (75.5%), Kavach (73.6%) and Bavistin (42.4%). Balai *et al.* (2010) tested six fungicides systemic and non-systemic (carbendazim, carbendazim+mancozeb, copper oxychloride, iprodione, mancozeb and thiophanate methyl) at their respective does were further tested in pot conditions (*In vivo*) as seed treatment and foliar spray against leaf spot of Brinjal. Mancozeb was found most effective in reducing the disease incidence (seedling mortality) and disease intensity followed by copper oxychloride and carbendazim + mancozeb, respectively. The maximum disease incidence and disease intensity was observed with thiophanate methyl followed by carbendazim, respectively. Hassan *et al.* (2013) conducted an experiment under pot conditions using four treatments i.e., control, *A. alternata* alone, DPDP alone and combination of DPDP and *A. alternata*. In this experiment, 10-day-old eggplant seedlings were inoculated, DPDP or their combination one week later. The intensity of disease was obvious in infected leaves but withdrawn by DPDP. They were found relationships between incidence and severity, greater in plant leaves infected pathogen alone and diminished with the presence of DPDP. Furthermore, the infection resulted in reductions in growth, decreases in contents of anthocyanins, chlorophylls, carotenoids and thiols as well as inhibitions in activities of superoxide dismutase (SOD), glutathione peroxidase (GPX) and glutathione-S-transferase (GST). However, the application of DPDP at 50 mg led to a recovery of the infected eggplant; the infection-induced deleterious effects were mostly reversed by DPDP. However, treatment with DPDP alone seemed with no significant impacts. Due to its safe use to host and the inhibition for the pathogen, DPDP could be suggested as an efficient fungicide for protection of eggplant to control pathogen. Kumar (2017) reported that in field condition, propiconazole was most effective against leaf spot of Brinjal followed by hexaconazole.

Host resistance

Use of disease resistant as well as agronomically superior variety is an important accomplishment of present era for the disease management and obtained high yield. Use of resistance variety against specified disease is not only a full hardy and most economical adaptive measure, but also renders atmosphere free of pollution which otherwise might have been polluted due to use of pesticides. Most of the resistant varieties have been found to be susceptible after some years because of breakdown in their resistance and evolution of variability in the pathogen. Singh and Shukla (1984) found on 30 Brinjal cultivars tested under conditions of artificial epiphytotic infection by *A. alternata*, only 5 cultivar were resistant and 7 moderately resistant and the rest were moderately susceptible to susceptible. Balai *et al*. (2013) reported that fourteen varieties/genotypes of Brinjal were evaluated for resistance against leaf spot (*A. alternata*) of Brinjal. The variety Pant Smrat, Pusa Ankar and Pant Rituraj showed moderate resistance (MR) reaction whereas nine genotypes / variety showed moderate susceptible, two varieties were showed susceptible reaction and none found resistance. Therefore, the genotype /varieties Pant Smart, Pusa Ankar and Pant Rituraj, which showed moderate resistance reaction as against leaf spot of Brinjal can be useful for these areas where leaf spot is a severe problem. Jakatimath *et al.* (2013) who used 60 Brinjal genotypes against leaf spot disease under field conditions none of the genotypes found to be immune. Two genotypes CBB-3 and CBB26 showed resistant response whereas, 31 genotypes expressed as moderately resistant reaction. Haider (2020) work done in ten Brinjal varieties / cultivars assessed against Alternaria leaf spot in RCBD under field conditions in University of Agriculture, Faisalabad. Kalash black and HBR-330 showed a resistance response with disease incidence of 8.6%

and 10.6% respectively, whereas HBR-321 was highly susceptible, HBR-331, HBR-312 moderately resistant, Global round and HBR-320 moderately susceptible.

CONCLUSION

From the above studies, it is concluded that *Alternaria alternata* is a very destructive pathogen causing a widespread destruction in Brinjal crops. The utilization of advanced techniques, it becomes easier to management of this pathogen. Substantial integrated disease management strategies are the only solution to maintain plant health, including minimum use of chemicals for checking the pathogen population, encouragement of useful, plant extract, bio-agents to reduce pathogen inoculum and use of resistant varieties. In the future, the program should have to give more attention on development of other management's practices and multiple resistant variety, amendments of plant extract and bio-agents as integrated disease management components, proving of resistant line under field condition in controlled environments. Race analysis for molecular, pathogenic and biochemical variability was studies, periodically survey for its' incidence and intensity level prevalence, strengthen the disease screening techniques both in main season and irrigation based and over location verification of released variety against the existing races. Every year temperature will be increased and more air borne disease occurrence. Review are conclude that fourth generation chemical are more studies well be required for leaf spot of Brinjal disease management.

REFERENCES

Anonymous (2015) Food Agriculture Organization Statistics. Food Agriculture Organisation of United Nations, Rome, Italy . http://faostat.fao. org/default.aspx, pp 567.

Anonymous (2018-19) Indian Horticulture Database. Ministry of Agriculture. Government of India.

Aykroyd WR (1963) ICMR special series, 42.

Balai LP (2007) Integrated disease management of leaf spot Brinjal (*Solanum melongena* L.) caused by *Alternaria alternata* (Fr.) Keissler SKN COA, Jobner (SKRAU, Bikaner) *MSc* (P. Patho) thesis.

Balai LP, Ahir RR (2011) Evaluation of plant extracts and biocontrol agents against leaf spot disease of Brinjal. *Ind Phytopath* 64 (4): 378-380.

Balai LP, Ahir RR (2013) Role of temperature relative humidity on mycelial growth of *Alternaria alternata* infecting Brinjal. *Trends Biosci* 6: 307-308.

Balai LP, Ahir RR (2013) Survey occurrence of leaf spot of Brinjal caused by *Alternaria alternata* (Fr.) Keissler in Jaipur District. *Adv Life Sci* 2(1):71-72.

Balai LP, Ahir RR, Singh RB, Singh RK (2010) Chemical control of leaf spot of Brinjal caused by *Alternaria alternata. Ind J Pl Patho* 24 (1 and 2): 109-113.

Balai LP, Ahir RR, Yadav SM (2010) Varietal screening of Brinjal genotypes against leaf spot of disease caused by *Alternaria alternata. Environ Eco*. 31: 1276-1278.

Bochalya MS, Shekhawat KS, Kumar A, Singh R, Chohan PK (2012) Management of *Alternaria alternata* causing Alternaria fruit rot of Brinjal (*Solanum melongena*) under *in vitro* condition. *Biopesti Int* 8 (2): 131-137.

Bochalya MS, Shekhawat KS, Kumar A, Singh R, Chohan PK (2012a) Effect of meteorological parameters on growth and sporulation of *Alternaria alternata* causing alternaria fruit rot of Brinjal. *J Agromete* 14(2): 187-189.

Bochalya MS, Shekhawat KS, Kumar A, Singh R, Chohan PK (2013) Studies on mycelial growth cultural characteristics of *Alternaria alternata* causing alternaria fruit rot Brinjal on different solid media. *Ann Bio* 29(3) 428-430.

Bochalya MS, Shekhawat KS, Singh R, Chohan PK (2013a) Studies on age of fruit, age of inoculum and inoculum load on development of Alternaria fruit rot of Brinjal caused by *Alternaria alternata. Ann Agri Bio Res* 18: 388-390.

Bora T (1977) *In vitro and in vivo* investigation on the effect of some antagonistic fungi against the damping off disease of eggplant. *J Turkish Phytopath* 6 (1):17-23.

Chauhan DVS (1981) Vegetable production in India (3rd ed). Ram Prasad Sons, Agra, India, pp.

Dingar SM, Singh M (1985) Role of weather in development of leaf spot disease of Brinjal. *Ind Phytopath* 38 (4): 721-726.

Haider E (2020) Assessment of phytoextracts against leaf spot of Brinjal caused by *Alternaria alternata* (Fr.) Keissler University of Agriculture, Faisalabad. MP (P. Patho) thesis.

Hassan NM, Abu-Doubara MI, Waly MA, Nemat Alla MM (2013) Efficacy of a pyrimidine derivative to control spot disease on *Solanum melongena* caused by *Alternaria alternata. J Adv Res* 4: 393–401.

Jakatimath S (2016) Etiology management of fruit rot of Brinjal (*Solanum melongena* L.) caused by *Alternaria alternata, Colletotrichum melongenae* and *Phomopsis vexans* UHS, Bagalkot MSc thesis.

Jakatimath SP, Mesta RK, Biradar IB, Mushrif SK, Ajjappalavar PS (2017) *In vitro* evaluation of fungicides, botanicals bio-agents against *Alternaria alternata* causal agent of fruit rot of Brinjal. *Int J Curr Microbiol Appl Sci* 6:495-504.

Kapoor JN, Hingorani MK (1958) Alternaria leaf spot fruit rot of Brinjal. *Ind J Agri Sci* 28: 109-114.

Khursheed Z, Wani TA, Bhat NA, Rather RA, Ahanger SA, Chasti F (2021) Eco-friendly management of Alternaria leaf spot disease of Brinjal in Kashmir. *J Pharmaco Phytoche* 10(1): 100-105.

Kumar P (2013) Management of Alternaria leaf spot Brinjal (*Solanun Melongena* L.) caused by *Alternaria alternata* (Fr.) Keissler, SKNAU, Jobner. *MSc* (P. Patho) thesis.

Nagaraju K, Mishra JP, Prasad R, Sekhar JC, Reddy VP, Kumar S

(2020) Isolation *in vitro* evaluation of different botanicals on mycelia growth of *Alternaria alternata* (Fr.) Keissler causing leaf spot of Brinjal. *J Pharmaco Phytoche* 9(4): 889-891.

Pandey A, Pandey B (2001) Fungal diseases of Brinjal in Bareilly region. *Adv Pl Sci* 14:99 –104.

Pandey KK, Vishwakarma SN (1999) Morphological symptomatological variation in *A. alternata* causing leaf blight in Brinjal. *J Myco Pl Path* 29 (3): 350-354.

Patel KK, Yadav FD, Shivani S (2000) Efficacy of fungicides spraying on control of leaf spot disease of Brinjal var muktakesi in Faizabad. *J Living World* 6 (6): 16-18.

Premila A (2014) Leaf spot disease of Brinjal: Epidemiological aspects traditional management in Manipur. *Int J Inno Res Devel* 3(2): In press.

Pucci A (1947) A serious atlernariousis on chilli eggplant in the Argentine Republic. *Pub Tec Direc Agropec, B. Aires* iv 2, 7, pp 2.

Raina ZK, Rather RA, Bhat SA, Wani TA, Bhat NA, Dorjey S (2018) Severity of alternaria leaf spot of Brinjal caused by *Alternaria alternata* in Kashmir, India. *Int J Curr Microbiol App Sci* 7(5): 322-328.

Rajput RB, Chaudhari SR (2018) Evaluation of various botanicals against *Alternaria alternata* (Fr.) Keissler *In vitro* condition. *J Pharmacogn Phytochem* 7(4):1306-1309.

Shafique MS, Amrao L, Saeed S, Ahmed MZ, Ghuffar S, Anwaar HA, Sheikhh UAA, Khan MA, Qadir A, Abdullah A (2021) Occurrence of leaf spot caused by *Alternaria alternata* on Eggplant (*Solanum melongena*) in Pakistan. *Pl Dis* 105 (4): 1224.

Sidhdapara KM, Lathiya SV, Anadani VP (2016) Evaluation of biocontrol agent against *Alternaria alternata* incitant of Brinjal (*Solanum Melongena* L.) leaf spot. *Adv life Sci* 5(4): 1308-1309.

Singh K, Rai M (2003) Evaluation of chemicals against Alternaria leaf spot of Brinjal. *Ann Pl Prot Sci* 11 (2): 394-395.

Singh M (1987) Survival perpetuation of *Alternaria alternata* causing leaf spot fruit rot of Brinjal. *Farm Sci J* 2(2): 116-119.

Singh M (1988) Effect of interaction of nitrogen, phosphorus potash on *Alternaria* leaf spot fruit rot of Brinjal. *Farm Sci J* 3(1): 21-23.

Singh M, Shukla TN (1984) Chemical control of Alternaria leaf spot fruit rot of Brinjal caused by *Alternaria alternata. Ind J Myco Pl Phytopath* 14 (1): 81-83.

Singh M, Shukla TN (1985) Evaluation of Brinjal germplasm against *alternaria* leaf spot fruit rot diseases. *Ind J Myco Pl Phytopath* 14 (3): 299-300.

Singh M, Shukla TN (1986) Epidemiology of *Alternaria* leaf spot and fruit rot of Brinjal. *Ind Phytopath* 39 (1): 119-120.

Wolf FA, Wolf FT (1947) The fungi viii john Willey sons inc, new Delhi, pp 16.

Woudenberg J, Groenewald J, Binder M, Crous P (2013) Alternaria redefined. *Studies in Myco* 75: 171-212.

Yadav BP, Rashmi, Ojha KL (1998) Management of leaf spot blight of Brinjal using fungicides plant extracts. *J App Bio* 8 (2): 57-60

Zeven A, Zhukovsky P (1975) Dictionary of cultivated plants their centers of diversity. Wageningen: Center for agricultural publishing documentation (pp 219).