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Status, crop losses, epidemiology, variability, and disease management of cumin blight : A review

Laxman Prasad Balai*[1], S M Khardia[2], Navab Singh[1], Indu Bala Sethi & Sachin Sharma[1]
Sri Karan Narendra Agriculture University, Jobner (Jaipur)[1], Agriculture University, Kota[2]
**Email: laxman.ppath@sknau.ac.in*

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Abstract

Cumin (*Cuminum cyminum* L.) is a spice crop native to the eastern Mediterranean area and is now cultivated worldwide, especially in South Asia, North Africa, and Latin America. The most significant and destructive disease affecting cumin is blight caused by the pathogen *Alternaria burnsii*. This disease progresses after flowering, particularly during seed formation, and is exacerbated by cold, moist, and consistently gloomy weather. The pathogen grows to its maximum temperature of 28±1°C. The disease intensity has been found to range from 11.34 to 80.00 percent, depending on the climate. Symptoms of the disease manifest as small, isolated, whitish necrotic spots on aerial plant parts. These spots gradually enlarge and merge, causing the plant to turn purple, then brown, and ultimately black. Under ideal circumstances, the contagion quickly spreads to the plant's stem and flowers, killing the viable leaves and flowers, which are typically non-viable and may not appear withered. It is essential to investigate blight, focusing on its symptoms, signs, biology, status, epidemiology, cultural variation, morphological, pathogenic, and molecular variability. Developing effective disease management technologies and improved resistance screening techniques are necessary to recognize the changes in disease scenarios in climate fluctuations. This review updates current knowledge regarding the pathogen symptomology, status, variability, and source of resistance and identifies management options and the genetic basis of resistance as future research priorities.

Keywords: Blight, molecular, variability, resistant, intensity, growth, management

Introduction

Cumin (*Cuminum cyminum* L.) is one of the most widely grown spice crops globally, second only to chili, with significant production in South Asia, North Africa, and Latin America. Its native habitat is in the eastern Mediterranean and the region close to the east of the world. Typically, the crop is irrigated on sandy loam to clay soils with a pH range of 6.8 to 8.3 during winter. It is sown from October to December and harvested from February to April in Gujrat, Rajasthan, Madhya Pradesh, Uttar Pradesh, Maharashtra, Haryana, and a few other Indian states. India is the world's largest producer, consumer, and exporter of cumin seed, covering

11.87 million hectares. The country produces 8.60 million tons annually, with an average yield of 647 kilograms per hectare, accounting for 70% of global cumin production (DASD, 2024). However, cumin productivity in India lags behind other countries due to the limited adoption of advanced production techniques and technologies for plant health management. Several factors affect yield, including biotic stresses such as blight, powdery mildew, wilt, aphids, and mites, as well as abiotic stresses like drought, frost, heat, and salinity.

Cumin blight, caused by *Alternaria burnsii* (Uppal *et al.* 1938), is a major concern in arid and semi-arid areas. This disease affects all above-ground parts of the plant, including seeds, which are susceptible to this disease. It can also cause a decline in quality and quantity and destructive disease, especially in arid and semi-arid regions. Blight disease has been recorded as having a percentage disease intensity (PDI) ranging from 11.34 to 80.00 in cumin-growing areas. The pathogen lives in crop debris and seeds. The spores of these polyphagous fungi occur normally in the atmosphere (air) on seeds and soil. The ideal conditions for disease development include prolonged cloudy, humid, cool weather, and rainfall during the reproductive, fruiting, and harvesting stages. The pathogen spreads rapidly in moist conditions, aided by wind circulation, eventually causing infected fields to develop brown patches, particularly during the flowering to seed formation stage. The subsequent review summarizes the pathogen's causes, symptoms, biology, status, epidemiology, cultural, morphological characteristics, pathogenic and molecular variability. Additionally, it explores the improvement of resistance screening methods and the advancement of disease management strategies to adapt to shifts in the landscape brought about by climate change.

Historical perspective of the pathogen

The genus *Alternaria* is a commonly encountered fungus of the Dictyosporae (Gr. Diction = net and spores = seed, spore). Taxonomically, *Alternaria* belongs to the Domain; Eukaryota, Kingdom; Fungi, Phylum; Ascomycota, subdivision; Pezizomycotina, class; Dothediomycetes, subclass; Pleosporomycetidae, order; Pleosporales, family; Pleosoraceae, genus; *Alternaria,* and species; *burnsii* (Kirk *et al.* 2008). The conidia of *A. burnsii* are large, multicellular, and dark-pigmented, producing chains or branched ones with horizontal and oblique septa. They are broader near the bottom and taper to form an elongated beak (muriform). The conidia are elliptic to oblong, beaked, and light brown to dark brown, measuring 27.35-92.0×8.0-27.35 μm (with a beak) and 12.0-52.0×8.0-27.35 μm (without beak), and are formed singly or in chains of two to seven. It was found that each beaked conidium had thick walls, septate (1-6 vertically and 1-3 longitudinally), and a bulbous apex. As the conidium matures, its body color transitions from pale brown to dark olive green. Conidiophores of *A. burnsii* vary in size and sporulation patterns, occurring either solitarily or in chains. They can be branched or unbranched, and are thick-walled, septate, with rounded tips and measuring 13.66-54.70×2.4-5.9 μm. The conidiophores are also erect, straight, occasionally irregularly bent, geniculate, 3-5-celled, light-colored, and septate. Blight disease caused by *Alternaria* species was first reported in the Mumbai region (Uppal, 1933). The pathogen was later accurately identified as *Alternaria burnsii* (Uppal *et al*.1938) from the Khaira district of Gujarat, India. Over time, the disease has been detected in several cumin-growing regions, including Rajasthan, India (Joshi, 1955), Turkey (Kocaturk, 1988; Ozer and Bayraktar, 2015), Pakistan (Shakir *et al.* 1995), and Iran (Kamkar *et al.* 2011).

Symptomology of disease

The symptoms of the disease can be observed in the cumin plant from the young leaf stage to maturity. Initially, small, isolated, whitish necrotic spots appear on the aerial parts of the plant, particularly on young leaves. Over time, these spots enlarge, merge, and gradually

change color from purple to brown, and finally to black. This is due to a fungus that produces an acidic substance, leading to necrosis in the leaves and stems. Some researchers have also noted symptoms of blight. Shekhawat *et al.* (2013a) described that symptoms occur in all the aerial parts of the plant: stems, leaves, inflorescences, and seeds are affected. Under favorable conditions, the infection spreads rapidly to the stem and flowers, causing the succulent leaves and blossoms to wither, potentially preventing seed formation. Even if seeds develop, they are often shriveled, dark-colored, lightweight, and typically non-viable. Blight becomes particularly severe after the flowering stage, as the fungus thrives in low-sugar conditions, and the levels of maltose and sucrose decline as the plant matures. The incidence of blight increases with prolonged leaf wetness and rainfall (Rana *et al*. 2018).

Survey and prevalence of blight

Some researchers have reported on the survey and prevalence of blight. In a field survey by Sharma *et al.* (2013a), the arid and semi-arid districts of Rajasthan and Gujarat, India, were studied from Rabi from 2007-08 to 2011-12, and blight disease intensity was observed at 0 to 80 percent in moderate to severe forms. Mali *et al.* (2014) surveyed and reported that blight incidence ranged from 28.25 to 63.81 PDI in arid Northern Gujarat. Kakraliya (2017) surveyed the arid and semi-arid districts of Rajasthan and found blight PDI to be in the range of 11.34 to 51.47. Negi (2020) reported disease severity ranging from 12.2 to 35.44 percent in Gujarat from 2016-17 to 2018-19. Similarly, Rathod *et al*. (2022) documented 12.02 to 35.55 percent in arid areas of Gujarat from 2016-17 to 2018-19. Yadav *et al.* (2022a) conducted surveys in the Jodhpur district of Rajasthan in Rabi 2021 and 22, and found that blight ranged from 42.83 to 70.0 percent and 40.2 to 60.16 percent, respectively.

Assessment of yield losses

Yield losses due to blight in cumin have been reported by several researchers. The disease consistently accounts for ten to twenty percent of crop losses. However, in cases of severe infection, losses can reach up to 80% (Gemawat and Prasad, 1972). Singh *et al.* (2015) reported disease incidence from 62 to 68 %, whereas in Bangladesh, severity as high as 98 and 88 percent were also recorded (Wadud *et al.* 2021).

Variability of isolates

Variation within the *Alternaria* genus is an important phenomenon that indicates the presence of many pathotypes. It is crucial to keep track of changes in populations and individuals. This variation can be observed in spore form, color, size, growth, sporulation, pathogenicity, and other aspects.

Cultural variability of isolates

Cultural characteristics of the pathogen has been well documented by several researchers. When mycelium was young, the *Alternaria burnsii* culture on Potato dextrose agar (PDA) was hyaline; however, on maturity, the colour changed from an olive green to brownish black. The hyphae varied in diameter from 1.5 to 7.1 µm. The hyphae are branched, septate, and hyaline (Uppal *et al.*1938). Pipaliya and Jadeja (2008) found that the colony color, colony type, and growth habit of the pathogen varied depending on the culture. Thirty-two isolates with dark brown to black coloured colonies, nineteen isolates with characteristic black colonies, twenty isolates with olive green-coloured colonies, and nine isolates with dirty white-coloured colonies were among the tested isolates. Singh *et al.* (2016a) exhibited whitish brown, brownish black, greenish-dark black, grey-black, and dark blackish colors, and they displayed diverse circular growth with plain or fluffy zoning, regular or irregular radial growth, and occasional joining. The maximum radial growth of 50.5 mm occurred on the fourth day of incubation at 28±1°C, while on the seventh day of incubation, the maximum radial growth reached 76.5 mm. The mycelium displayed diverse colors ranging from greenish to black,

greenish to grey, and dirty white to black (Mali *et al.* 2017). The PDA and Czapek Dox Agar media supported excellent growth and spore formation in the *A. burnsii* isolates. The fungus displayed first as light green, sometimes white, septate mycelial growth, then developed into a fluffy radial growth, plain irregular radial growth, a fluffy joining growth pattern on the media, and a grey-to-black colony boundary that appeared dirty white to brownish (Sawant and Parmar, 2019a).

Morphological variability

The morphology of spores (conidia), including their size, color, dimensions, septa wall ornamentation, type of conidial beak, and size, has been used to classify *Alternaria*. Some researchers have described *A. burnsii* as having specific morphological characteristics. According to Sharma and Pandey (2012), three isolates of *A. burnsii* were labeled as Ab-1, Ab-2, and Ab-3. The conidia of the isolates were found to be varied in length, width, colony color, number of septa, and average radial growth. Singh *et al.* (2016a) reported that the conidia and beak size varied in length, width, and septa (longitudinally 0-3 to 0-5 and vertically 0-1 to 0-2). The highest sporulation frequency recorded was 1.24×10^5/ml. Singh *et al.* (2016b) described conidiophores in the isolates as branched, erect, straight, irregularly bent, and geniculate. The conidia of the isolates varied in size, septa, beak length, and sporulation frequency. The largest conidial size observed in the isolates of UDP Ab-1 was 88-111×26-32 µm (with beak) and 30-38×14-18 µm (without beak). The smallest conidial size observed in the isolate of JLR Ab-1 was 70-88×25-32 µm (with beak) and 31-39×15-19 µm (without beak). Mali *et al.* (2017) found that the conidia length ranged from 25.00-51.80 µm and breadth ranged from 11.60-17.60 µm. The length of the conidia beaks ranged from 8.52-11.76 µm, and the breadth of the conidia beaks ranged from 7.20-8.68 µm. The conidia longitudinally septa l-3 or 3-7 and vertically septa 0-3 were found. Singh *et al.* (2018) described the conidia length as 44.92-63.28 µm, and the width of the conidia was 10.84-24.36 µm. The conidia beak length was 20.34-47.85 µm, and the sporulation frequency was recorded. According to Sawant and Parmar (2019a), the average conidial length ranged from 50.89-63.76 µm, and the breadth from 20.24-25.47 µm, with a beak length of 28.73-47.33 µm. The conidia had 1 to 6 septa longitudinally and 0 to 3 septa vertically. Negi (2020) described the difference in the conidial size, beak length, septa, and width, indicating the presence of variability in the pathogen.

Pathogenic variability

Pathogenic variability has been documented by several researchers. The three isolates of the pathogens confirmed pathogenic variability. The GC-4 cultivars showed a 46.17 PDI when exposed to artificial inoculation with Ab-3 (43.72%) and Ab-2 (37.39%) of *A. burnsii*. The Ab-1 isolates were highly pathogenic. There was a low similarity index (0.54) between Ab-1 and Ab-2, while the similarity index was higher (0.18) between the Ab-2 and Ab-3 isolates (Sharma and Pandey, 2012); 24.2 to 65.4 PDI was observed by Shekhawat *et al.* (2013a); the highest PDI (31.4) was with the isolates of Ab-08 (Singh *et al.* 2016a). Disease intensity ranging from 35.09 to 55.41 percent was recorded by Mali *et al.* (2017).

Molecular variability

Some researchers have reported molecular variability in *Alternaria*. In a study by Sharma and Pandey (2012), molecular variability revealed two major clusters. The first cluster included Ab-1, while the second cluster contained Ab-2 and Ab-3. The highest level of polymorphism was observed in primer OPE-14 and OPE-10. Based on genetic distance, the dendrogram formed two clusters: one with isolates Ab-1 and Ab-2, and another with isolate Ab-3. Ozer *et al.* (2014) found phylogenetic variation within the *A. burnsii* and *A.* spp. groups. Nine RAPD primers were used to analyze molecular variability; each primer exhibited polymorphism. Primers OPB-20, OPC-2, and OPG-17 produced a maximum

of ten bands with PIC values of 0.31, 0.34, and 0.33, respectively. Seventy-six amplified bands were found, with forty-one being polymorphic. Singh *et al.* (2016b), noted that the primers OPC-2 (80%) and OPA-19 (25%) showed the highest and lowest percent of polymorphism, respectively. According to Singh *et al.* (2016a), gel electrophoresis of fungal isolates amplified ITS gene sequences, generating a band of around 1200bp. These sequences of the fungal isolates of Ab-01 to Ab-10 were exposed to a parallel search using NCBI-Blast and multiple sequence alignment. The multiple sequence alignments reflected many additions, deletions, and substitutions in the nucleotide sequences of the isolate. The analysis of rDNA-ITS sequences by Bayraktar *et al.* (2017) showed that all tested isolates belonged to a single group and were genetically distinct from isolates of *A.* species groups. The phylogenetic classification based on ITS gene sequences using MEGA5.6 revealed two separate groups (Singh *et al.* 2018). Group I comprised highly pathogenic isolates that developed quickly, while individuals in group II had longer conidia beaks, a grey-black color, a light brown colony edge, and an uneven growth pattern. Sawant and Parmar (2019b) used fifteen random decamer primers from the OPA and OPE series in a PCR to examine molecular variability in the genomic DNA isolated from each *A. burnsii* isolate. The ten RAPD primers resulted in 84 loci and 622 bands, with seventy-seven loci being polymorphic at an average polymorphism rate of 91.51 percent. The average polymorphism information content was 0.8473. Out of the ten primers, OPA8, OPA9, OPA18, OPA4, OPA13, and OPA10 showed one hundred percent polymorphism. OPA 10 and OPE 7 primers exhibited eighty-three percent polymorphism, while OPE 7 showed the minimum polymorphism at 66.66 percent. The molecular weights of the amplicons varied from 139.79 to 2312319.40 bp. Feng *et al.* (2021) constructed and sequenced the first genome of *A. burnsii* CBS 0.38. Wadud *et al.* (2021) reported genetic variation in the identified *A.* species isolates. The draft genome provides a foundation for further investigation of related pathogens and comparative genomics of *A. burnsii*. The pathogen was identified as *A. burnsii* based on morphological characters and ITS sequencing.

Detection of pathogen

Some researchers have reported that blight has been detected in seeds. Uppal *et al.* (1938) identified two *A.* species as internally or externally seed-borne or combined. *A. burnsii* specifically correlated with cumin seeds, and it was observed that seed-borne pathogens could persist in crop debris. The standard blotter paper method was more reliable than the agar plate method for identification. Characteristic colonies can be confidently identified either macroscopically or microscopically, and the impact of sunlight on the growth of conidia was thoroughly examined. Furthermore, Bayraktar *et al.* (2016) reported that PCR tests could swiftly and accurately determine the fungal pathogen *A. burnsii* by comparing the Alt al gene sequences. The Ab35/ab326 primers robustly amplified a single PCR band of 291 bp from *A. burnsii*, and the primer pairs' specificity was unequivocally confirmed by PCA analysis of DNA from other fungal species related to cumin. The primers were able to reliably verify the presence of pathogen DNA in infected cumin seeds, demonstrating the efficacy of the described PCR technique for detecting and identifying the pathogen.

Epidemiology of pathogen

Alternaria burnsii grows at a rate nearly comparable to spore germination, and this growth is affected by temperature. The optimal temperature for both is between 26 and 27°C. Conidia germination and growth are significantly reduced below 4.5°C and above 37.5°C (Uppal *et al.* 1938). Gemawat and Prasad (1972) suggested that humid and moist climates are more favorable for blight. When the humidity level exceeds ninety percent, the disease rapidly spreads in the field parallel to the wind direction. Additionally, they pointed out that cumin crop is susceptible to blight

following a flow. For the disease to develop, there must be high relative humidity (90 percent) for three days, a temperature between 23-28°C, and moisture in droplets for at least two hours. This is because conidia can form and penetrate the plant tissue through the hyphae. If excessive humidity persists after infection and spreads in the direction of the wind, then the severity becomes evident. Mycelium and conidia are present in plant debris, soils, and seeds, which are the primary sources of infection. As the disease progresses, the quantity of spores increases and is at its maximum in the morning. Mali *et al.* (2014) observed that the pathogen can thrive over a wide pH range from 4.5 to 7.5 and can sporulate. The pathogen exhibited maximum growth of 89.00 mm on PDA media. Bayraktar *et al.* (2017) examined pathogens on seven different types of media under two distinct incubation conditions. It was discovered that the V88 media with varying light and temperature resulted in maximum sporulation. The study also noted that temperature significantly influenced the growth of pathogens, with the highest growth observed at 25°C.

Disease management strategies

Date of sowing

The key points for achieving high crop yields include using effective methods to minimize the impact of fungal diseases and selecting the right sowing dates. The weather patterns in February and March, specifically cloudy and humid conditions, coupled with a maximum temperature between 20 to 35.3°C, the minimum temperature between 3.9 to 10°C, and humidity between 47.5 to 73.5 percent, create a scenario where 18.3 mm rainfall can exacerbate conditions conducive to Alternaria blight disease development. According to Uppal *et al.* (1938) morning relative humidity ranging from 73.40 to 86.10 percent, with few hours' sunshine (8.73) and cloudy conditions for two to three days, were advantageous for infection and the spread of blight intensity. Deepak *et al.* (2008a) found that cumin plants aged between 20 to 75 days showed that the blight initiated and spread more readily ten weeks after sowing. The crop sown in December had the lowest incidence of blight with a relative humidity of 75.00 percent. Meanwhile, the crop sown in October had the highest blight severity with a relative humidity of 65.00 percent. Sharma and Pandey (2013) discovered that the survival rate of *A. burnsii* on seeds was 100 percent in April and May but decreased to 70 percent in October and November under laboratory conditions (25°C temperature and 40-50 percent relative humidity). They also found that the disease developed most when the temperature ranged from 29-35°C, the minimum temperature was 9.6-19.7°C, the average afternoon relative humidity was over 60.00 percent, wind speeds were 2.1-4.8 km/hr, and there were 8-10.4 hours of bright sunshine. According to Patel *et al.* (2018) cultivars JC-2000-28 & JC-95-102 are suitable for late-sown conditions which showed decreased incidence of disease and increased yield by 64.27 and 44.31 percent, respectively.

Varietal screening for resistance

An inexpensive, safe, and efficient way to manage any disease is through host plant resistance. As the pathogen can spread through the air, it becomes difficult to manage using plant extract, biocontrol, and chemical means. Using a resistant cultivar is a reliable and practical way to control disease. No cumin cultivar has been observed to have a high host resistance to *A. burnsii* worldwide. A few researchers have mentioned encountering some degree of resistance.

Plant extracts

Different plant extracts and herbal products have been found to have an inhibitory effect on the conidial germination of *A. burnsii.* Jadeja and Pipliya (2008) tested fourteen plant extracts for their ability to inhibit the growth of *A. burnsii* under laboratory conditions at five and ten percent concentrations. It was found that *Allium sativum* cloves and *Zingiber officinale*

Table 1. Source of resistance to the blight of cumin

Resistant cultivars	Moderately resistant	References
EC-109635, EC-243373	EC-China, ED-Syria, EC-Turkey, EC-243375, EC-270954, & EC-279081	Vihol (2004)
-	AC-167, RZ-209, UC-198, UC-216, & JC-11	Sunder (2005)
-	CUM-11, GC-4 & RZ-209	Singh (2014)
-	JC-91-262	Negi (2020)
-	CN026, CN028, CN031 & CN038	Wadud *et al.* (2021)
-	MCU-7, MCU-11, MCU-22, & MCU-23	Varma *et al.* (2021)
-	UC-223, UC-224, UC-234, UC-239, UC-247, UC-256, UC-258, UC-260, UC-267, UC-270, UC-280, UC-291, UC-310, UC-326, UC-336, UC-341, UC-343, & UC-346	Kumawat *et al.* (2022)

were the most effective, with mean inhibitions of 78.52 percent and 72.96 percent, respectively. Additionally, Gangopadhyay *et al.* (2010) found that five plant extracts (*Azadirachta indica* leaves, *A. indica* NSKE, *Aloe vera, Calotropsis procera,* and *Eucalyptus globulus*) significantly inhibited the mycelial growth and conidial germination of *A. burnsii* in both *In vitro* and *In vivo* conditions. Shekhawat *et al.* (2013) observed that the neem formulation of Azadirachtin was effective in the laboratory. Shekhawat *et al.* (2016) also described that treating seeds with 5.0 percent NSKE, and spraying NSKE at 5.0 percent resulted in lowest blight incidence (5.90 PDI) and the highest benefit-cost ratio. Piliwal *et al.* (2017) reported that *Curcuma longa* (70.55%), *Z. officinale* (62.79%), and *A. sativum* (67.45%) at ten percent prove the most effective for growth inhibition of pathogens in the laboratory. Shelar *et al.* (2017) reported that *Datura stramonium* extract showed (58.52%) inhibition of mycelial growth which was more effective than by *Jatropha curcas* (50.74%) and *Vachellia nilotica* (49.63%). The disease intensity recorded at 60 DAS, indicated a significant decrease of 24.39 percent with *M. piperita* extract at 0.2 percent followed by *C. nardus* at 0.2 percent and *T. vulgaris* oil at 0.2 percent when compared to control (. Jagani *et al.* (2023), found that *A. indica* exhibited the highest inhibition (78.15%) at a concentration of fifteen percent, followed by *Mimuspos elengi* (67.75%). *Annona reticulata* showed 43.48 percent inhibition at the same concentration, while *Aloe barbadensis* Miller exhibited the least inhibition at 40.24%. Varma and Kumar (2023) analyzed plant extracts at concentrations of 5, 10, 15, and 20 percent using the food poisoning technique in the laboratory. Among the plant extracts, NSKE, and *A. indica* extracts were the most effective, resulting in mean growth inhibition of 48.88 and 45.85 percent, respectively. The least mean growth inhibition of 13.14 percent was recorded with *Eucalyptus globulus.* Makawana *et al.* (2024a) observed highest inhibition by *Ocimum tenuiflorum*, *Calotropis gigantea,* and *A. sativum* extracts at ten percent concentration, which recorded at 73.76, 70.63, and 70.09 percent inhibition, respectively.

Biocontrol agents

The inhibitory properties of different bacteria, actinomycetes, fungi, and various biocontrol agents are suggested to manage the diseases. *Trichoderma harzianum* was found to have the strongest inhibitory effect (85.45%) on the mycelial growth of *A. burnsii* (Deepak *et al.* 2008b). For sustainable disease management, treating with *T. harzianum* for blight under both circumstances at 24g/6m^2 or 40 kg/ha appears promising. According to Jadeja and Pipliya (2008), the two most efficient strains that inhibited *A. burnsii* in the lab were *T. viride*

and *T. harzianum*. Sharma and Pandey (2013) evaluated the effectiveness of four bioagents and found that *T. harzianum* was the most successful in inhibiting the growth of the test fungus, with 82.02 percent growth suppression rate. According to Pipliwal *et al.* (2013), *T.* isolate-11 cultural filtrate showed the lowest rate of pathogen spore germination, followed by *T.* isolate-19. El-Deeb *et al.* (2016) reported that foliar application of *T. album* biocide dramatically reduced blight disease compared to control. According to Kakraliya *et al.* (2022), treatment combination of *T. harzianum* + *P. fluorescens* was most effective against the pathogen. Four bio-agents were evaluated against the pathogen, and *T. harzianum* demonstrated the highest level of pathogen suppression, with a growth inhibition of 69.63 percent (Varma and Kumhar 2023). Singh *et al.* (2024) found that four biocontrol agents (*T. afroharzianum, Aneurinibacillus aneurinilyticus, P. laluanensis,* and *B. licheniformis*), when used individually or in consortium, were effective in reducing disease severity, promoting plant growth, and enhancing defense responses in cumin plants infected with *A. burnsii*. They reported that the bioagents were compatible and led to minimum disease severity. In a recent study by Aziz *et al.* (2021), the effectiveness of nano silicon (NSi) and potassium silicate (PS) as antagonists against Alternaria blight fungus was investigated. The chemicals were tested at various concentrations (50, 100, 200, 300, and 400 ppm for PS and 1.5, 2.0, 2.5, 3.0, and 3.5 mM for NSi) in laboratory conditions.

Fungicides

The above mentioned methods likewise adjust the date of sowing, varietal screening, use of plant extract, and application of bioagents have been effectively managing the disease, but these approaches have limitations because their effects are slow and take a long time to achieve their potential outcome. Consequently, chemical management (fungicide) has proven to be both effective and the cheapest. Several studies have evaluated the efficacy of various fungicides against *Alternaria burnsii,* highlighting differences in their effectiveness under laboratory and field conditions. Vihol *et al.* (2004) reported that Mancozeb at a concentration of 500 ppm completely inhibited fungal mycelium growth. However, Tridemorph, at 250 or 500 ppm, reduced the mycelial growth by 83.00 percent. Among the various fungicides tested, the most effective field management of the disease was achieved with Mancozeb (0.20%), followed by Copper-Oxychloride (0.25%) and Thiophanate Methyl (0.02%). Bhatnagar and Tak (2008) reported that Difenoconazole @ 0.05 percent significantly decreased the disease severity. According to Pipliya and Jadeja (2008), among the five fungicides tested, Mancozeb (0.25%) was found most effective in decreasing the disease severity. Regular spraying of Mancozeb (0.25%) or Cymoxanil (0.1%) at ten-day intervals after blooming was found to be effective for blight management in field conditions. In laboratory studies, Polra and Jadeja (2011) observed that Hexaconazole, Tebuconazole, and Mancozeb were the most effective fungicides. Sharma *et al.* (2013b) found that Propiconazole lowers PDI compared to Carbendazim, Iprodione, and Chlorothalonil. Shekhawat *et al.* (2013b) noted that Tebuconazole most effectively inhibited *A. burnsii* mycelial growth under laboratory conditions, followed by Azoxystrobin, Carbendazim, and Mancozeb. Moreover, foliar application of Tebuconazole in pot culture was found to be highly effective. Hexaconazole and Tebuconazole were shown to be the most efficient in reducing the spore germination of the blight pathogen, according to Pipliwal *et al.* (2015). El-Deeb *et al.* (2016) reported that Mancozeb reduced the linear growth of *A. burnsii* more effectively than Thiophanate Methyl, and Mancozeb was most effective in reducing blight severity when applied as a foliar spray. In pot condition, Rovral 50 (0.2%) exhibited the lowest disease severity (Khalequzzaman 2016). Patel *et al.* (2017) found the lowest PDI with Kresoxim-methyl 44.3 SC @ 0.1 percent. Pipliwal *et al.* (2017) observed complete inhibition of the pathogen *in vitro* using Hexaconazole, Mancozeb, Propiconazole, and Tebuconazole. Wadud

et al. (2017) tested eight different fungicides, with Azoxystrobin + Difenoconazole, Metiram + Pyraclostrobin, Carbendazim + Mancozeb, Tricyclazole, Metalaxyl + Mancozeb, Iprodione, Fluazinam, and chlorothalonil. Among tested fungicides, Azoxystrobin + Difenoconazole sprayed plots had the lowest PDI (6.24), while the control plots had the highest PDI (78.81). Tebuconazole 50 percent + Trifloxystrobin 25 percent WG formulation @ 350 g/ha was proven to be effective against blight (Amin *et al.*, 2018). Jat *et al*. (2019) demonstrated effective blight management with Tebuconazole 18.3 percent + Azoxystrobin 11 percent. According to Negi (2020), field applications of Mancozeb 0.2 percent, Kresoxim-methyl 0.20 percent, Chlorothalonil 0.20 percent, Propiconazole 0.02 percent, Azoxystrobin 18.30 percent + Difenoconazole 11.40 percent all demonstrated to have an impact on blight in the field. Verma *et al.* (2020) described that the minimum PDI and increased yield using Captan 70 percent + Hexaconazole 5 percent WP at 750 grams per hectare. Kakraliya *et al.* (2021) found Azoxystrobin to be very effective, next to Propiconazole, in both laboratory and field conditions while Difenoconazole was the least effective, with a PDI of 21.90. Sawant *et al.* (2022) reported that zink nanoparticles (ZnNPs) inhibited fungal mycelium growth, with inhibition directly proportional to concentration. Yadav *et al.* (2022b) noted that Tebuconazole at 25.9 EC @ 1 ml/litre resulted in the lowest PDI (6.00 percent) of blight. However, Carbendazim 12 + Mancozeb 63 percent at 2 g/litter showed a higher PDI of 39.00%. According to Varma and Kumhar (2024), the fungicide that exhibited the highest inhibition (76.94%) for controlling blight was Tebuconazole + Trifloxystrobin (70.00%), followed by Tebuconazole (65.05%) and Pyraclostrobin + Epoxiconazole (50.75%). Makawana *et al.* (2024b) reported that Captan, Chlorothalonil, and Mancozeb were the most effective with 95.67, 95.62, and 94.86 percent mycelial growth inhibition, respectively. In contrast, Hexaconazole was most effective in systemic fungicides with 99.98 percent inhibition, followed by Tebuconazole with 87.40 percent. Further, Makawana *et al*. (2024c) found that the most effective field conditions were Azoxystrobin 11+Tebuconazole 18.30 percent SC at a concentration of 0.04 percent, which achieved the least mean disease intensity (14.76%). This was followed by Metiram 55 + Pyraclostrobin (5%), 0.18 percent WG (18.27%). Sharma *et al.* (2024) confirmed the superior efficacy of Tebuconazole 25 percent WG at 750 g/ha, with the lowest PDI at 8.89% and 12.11% after the first and second foliar sprays, respectively. A combination of Pyraclostrobin 133 g/litre + Epoxiconazole 50 g/litre @ 750 ml/ha and Tebuconazole 25 percent WG at 500g/ha also effectively managed blight. However, Thiophanate-methyl 70% WP (750 and 1000 g/ha), Azoxystrobin 23% SC (500 and 750g/ha), and Mancozeb 75 percent (1000 g/ha) were among the least effective.

Reclamation of soil

Soil sterilization and soil solarization before sowing can effectively kill harmful fungal spores and plant debris. For optimal growth of cumin, it is recommended to utilize well-drained sandy or loamy soil that is abundant in organic matter and maintains a pH level within the range of 6.0 to 8.3. (Didwania, 2019). Good soil drainage is essential as cumin crop can be severely damaged by standing water and excessive wetness. High pH or calcareous soils are not ideal for optimal crop growth and yield. Meena *et al.* (2010) reported that cumin can tolerate the highest levels of salinity and soil electrical conductivity (EC) of 14.0 dSm^{-1}. It is recommended to use the right amount of nitrogen, as an excessive dose can lead to succulence in the crop, making it more susceptible to blight.

Integrated disease management

Information available on the integrated disease management (IDM) of cumin blight is scanty. Dhakad *et al.* (2015) reported that using Mancozeb 0.25 percent with five sprays resulted in the lowest disease intensity (19.07 percent). This was followed by three sprays

of Mancozeb 0.25 percent and two sprays of *T. harzianum* 0.2 percent, resulting in disease intensity of 21.19 percent and 24.10 percent, respectively. Additionally, Chhata *et al.* (2017) discovered that a combination of seed treatment with *T. harzianum* at 8 g/kg seed, along with three foliar sprays of *Azadirachtin* at 2ml/lit at specific intervals (45-60, 60-75, and 90-100 DAS), was more effective in managing blight and also resulted in the lowest disease intensity. Jadon *et al*. (2020) found that a successful IDM strategy involved a single foliar spray of Mancozeb, two tons of vermicompost per hectare, four milliliters of *T. viride* used as seed dressing, and the incorporation of neem cake into the soil mixture.

Research gap and future prospects

The current standards for seed production are inadequately developed, posing challenges for farmers in obtaining high-quality seeds. It is imperative to prioritize the identification of resistance sources from germplasm for blight in the existing cumin cultivars. Cumin, primarily cultivated in arid and semi-arid regions, is a minor crop. Scientific knowledge about the genetics and inheritance of complex factors such as pests, diseases, and yield in this crop surpasses that of major crops. The manual broadcast method for cumin sowing is not tailored to cumin seeds, resulting in a significant waste of seeds. Cultivation in arid and semi-arid regions necessitates the adoption of recommended technology, encompassing high-yielding cultivars, sandy soil, line sowing method, recommended seed rate, fertilizer dose, effective weed control, plant protection measures, and mechanized harvesting methods.

Conclusion

The major challenge in dealing with cumin blight is the scarcity of resistant genotypes worldwide. The pathogen is airborne, making it difficult to manage the disease. The cumin crop typically matures within 125 to 130 days, with seed germination requiring 14 to 16 days. Delaying harvesting and improper post-harvest practices, such as prolonged sun-drying, lead to the loss of volatile oil content in cumin seeds. This not only lower seed quality but also reduces market value and overall revenue returns for farmers. The cumin blight generally occurs in the field in mid-February, when the temperature ranges from 25 to 28°C, with cloudy weather, 2.5 mm of rainfall, afternoon relative humidity above 60.00 percent, wind speeds of 2.1-4.8 km/h, and 8-10.4 hours of bright sunshine. Traditionally, cumin growers have heavily relied on mancozeb to manage blight, but this has led to significant fungicide residues in cumin seeds, particularly affecting cumin seed export potential. In future, it is important to intensify research efforts in a collaborative way to develop induced resistance or incorporate resistance genes using modern biotechnological approaches. It is also essential to optimize crop duration to reduce the seed germination period to 14-16 days instead of 7-8 days and shorten the total cumin crop maturity period to 125-130 days from 105-110 days by developing short-duration varieties. IDM remains the cornerstone of effective blight management. This pathogen requires a multifaceted approach that includes the use of resistant varieties, plant extracts, organic soil amendments, and biocontrol agents with proven efficacy in reducing disease severity and yield losses. New methods can be employed to manage this pathogen effectively. Additionally, application of novel fungicides such as Difenoconazole, Azoxystrobin, Pyraclostrobin, Epoxiconazole, and Tebuconazole should be considered, especially in rotation or combination with other IDM practices to prevent resistance build up and enhanced disease management. In conclusion, the management of cumin blight requires a comprehensive strategy. This includes the development of short-duration, disease-resistant varieties, optimized sowing times, harvesting practices, plant extracts, organic amendments, biocontrol agents, and the judicious use of advanced fungicides for managing cumin blight. By intensifying collaborative research efforts and refining

IDM practices, the cumin industry can achieve improved yields, better quality, and enhanced market competitiveness.

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