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Review

A WAY FORWARD TOWARDS THE MANAGEMENT OF CHILLI ANTHRACNOSE - A REVIEW

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Abstract

Chilli anthracnose is the most ravaging biotic stress to chilli that adversely degrades chilli production across the globe. For efficient disease management, accurate taxonomic data is required. In the Colletotrichum patho-system, various Colletotrichum species can be linked to anthracnose in the same host. Although various Colletotrichum spp. have been described as causative agents of this disease globally, interactions of species associated to the disease are poorly understood. Despite extensive research on the disease management, commercial cultivars of Capsicum annuum that are resistant to the pathogenic fungus causing chilli anthracnose have not yet been developed. The main aim of the present manuscript is to throw light on pathogen profile, symptomology, epidemiology, and strategies for disease management.

1. INTRODUCTION

Chilli is a very essential and lucrative crop that belongs to family Solanaceae. Its origin is South and Central USA (Thakur et al., 2019). Globally, chilli crop is grown on an area of 1860 thousand hectares with 4.6 million tons of production. In Pakistan, chilli covers an area of 158 thousand ha with 143 million tons of production (Ali, 2020). Its contribution is 1.5 % of GDP of Pakistan (Arin, 2019). New Mexico is regarded to be the home of chilli. Before 1585, the Portuguese transported chills from Brazil to the Indo-Pak subcontinent (Hussain and Abid, 2011). Capsicum (bell pepper) has been recognized in the Western Hemisphere since the dawn of civilization. It has been a component of the human diet since 7500 BC. Between 5200 and 3400 BC, Native Americans grew chilli plants. It is one of the first crop to be cultivated in America. (Perry and Flannery, 2007).

Chilli is said to be helpful in reducing asthma, migraines, blood pressure, and diabetes complications. Heart disease, atherosclerosis, and heart attacks are all conditions that can lead to death. They have a high fiber content, which helps to reduce gallstone formation. Consumption of whole grains is beneficial to one's health. Preventing insulin resistance and heart disease are just a few of the benefits (Deshpande et al., 2015). According to research, that capsaicin changes the pattern of energy usage by bodily cells by inhibiting ATP hydrolysis. Scoville heat units (SHU) are a measure of how much chilli extract must be diluted in order for a panel of tasters to be unable to identify the heat when it is added to

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sugar syrup. The higher the amount of dilution required to achieve this goal, the higher the SHU. (Ganguly et al., 2017). Chilies are extensively utilized in the preparation of processed foods, used as coloring agent in salad dressings, cosmetics and even textiles (Saxena et al., 2016).

Chilli is used as a spice, a condiment, a vegetable, a culinary additive, a medicinal, and a decorative plant. Capsicum's pungent chemical principle is fruit-specific capsaicin, which has been reported to help with a variety of pain issues, including arthritis, pruritis, contact allergy, post-mastectomy syndrome, urticaria, post-surgical neuromas, psoriasis, and diabetic neuropathy (Hasan et al., 2015). Numerous diseases and pests pose serious threat to chilli crop. Various insects such as mites, leaf hoppers, pod borers, aphids, crickets, thrips, cut worms, ear wigs, flea Beatles, root grubs and other insects damage or destroy the crop. Pathogens such as fungi, bacteria, viruses, nematodes, and others pose a severe threat to the chilli crop in addition to pests. Bacterial wilt, bacterial canker and bacterial spot are among of the most frequent bacterial diseases. There are around 17 viruses that cause diseases in the chilli plant. Alfalfa mosaic, Pepper Gemini Virus, Leaf curl and Tobacco mosaic are some of the most common viral diseases. Root knot nematodes are more damaging have a wider host range than other nematodes. Meloidogyne spp. attack on the roots of the chilli plant and restricted the flow of nutrients and water in the plant system, causing the plants to wilt and eventually die. Frequently, fungal diseases are more severe than those carried by other pathogens. Fusarium wilt, Damping-off root rot, Choanephora blight (wet rot), Anthracnose, Cercospora (frogeye) leaf spot and Charcoal rot are some of the pre-harvesting fungal pathogens. Gray leaf spot, grey mould, Southern blight, Phytophthora blight, Powdery mildew. Chilli crop is grown for Verticillium wilt and White mould (Hussain and Abid, 2011).

One of the most common chilli diseases is anthracnose. Chilli anthracnose is common disease in tropical and subtropical regions around the world. It is airborne, seed-borne, water-borne and soil-borne, it can cause damage to seedlings and aerial sections of plants (Saxena et al., 2016). This disease is mostly appears on mature fruits, resulting in yield losses of up to 50% (Prathibha et al., 2013). Colletotrichum spp. is one of the world's ten most ravaging biotic stress, responsible for massive crop losses across the globe. Colletotrichum is asexual fungi imperfect genus that belongs to the phylum Ascomycetes and class Coeleomycetes. When optimum conditions are available, distinctive symptoms appear as sunken circular or angular lesions on the ripe chilli fruit. Orange to pink conidial masses may be observed on the fruit surface. Whenever the lesions fully mature, they typically appear as concentric rings of black colored dots. Small depressed greyish brown dots with a black border occur on stems and leaves (Saxena et al., 2016).

2. Pathogen Profile

Colletotrichum was first identified as Vermicularia in 1790, and the name *Colletotrichum* was first used in 1831. Colletotrichum was recently classified as the world's eighth most important pathogenic fungus genus (Mongkolporn and Taylor, 2018). *C. gloeosporioides* (straight conidia with obtuse ends), *C. truncatum and* C. *acutatum* (straight conidia with acute ends) were previously identified as *Colletotrichum* spp. producing chilli anthracnose in Asia (falcate conidia). However, multigene phylogenetic analysis revealed that *C. acutatum* is a acutatum complex made up of thirty four related species, seven of which are known to cause anthracnose in chilli peppers (de Silva *et al.*, 2019). B.D.Halsted first reported it in 1890 from New Jersey, USA, naming the causative agents *Gloeopsorium piperatum* and *Colletotrichum nigrum.* Different Colletotrichum spp. complexes, like *C. gloeosporioides, , C. coccodes, C. capscii, C. acutatum, C. truncatum and C. boninense* are known to cause disease (Sonawane and Shinde, 2021). It is an economically important pathogen because it can survive on a variety of hosts, including fruits, vegetables, ornamental plants and major staple food crops. The species of this genus have been found to have an impact on more than 121 plant genera from 45 distinct plant families. It also causes post harvest rots and aerial plant blights. In tropical and subtropical countries, infection of basic items including grains, beans, sorghum, cassava, and bananas could cause significant economic loss. Many *Colletotrichum* spp. can infect a single species or a single host, or a single species can infect multiple hosts (Saxena *et al.*, 2016).

3. Taxonomic status and biology of pathogen

Pathogenic fungus (*Colletotrichum* spp.) causing anthracnose disease belongs to the Kingdom Fungi, Phylum Ascomycota, Class Sordariomycetes, Order Phyllachorales, and Family Phyllachoraceae (Banya *et al.*, 2020). The morphological or molecular characteristics of *Colletotrichum* species can be used to distinguish them. Conidia strains have blunt pointy ends and are sub-cylindrical, fusiform, ellipsoid, oblong, and ellipsoid. It creates falcate conidia, which are conidia with two pointy ends. Black acervuli produce conidia. The mycelium starts out white, then turns brownish orange as it matures, producing black setae from acervuli (Anggrahini *et al.*, 2020).

Conidia range in length and width from 1742–3407 m and 32–73 m, respectively. Colony produces cottony mycelial growth and orange-colored conidial masses in large numbers. Some colonies give profuse mycelial growth with brownish color conidial masses(Saxena *et al.*, 2014). On PDA fungus colony colour changes from white to grey-dark brown over time. Acervuli with numerous black setae generate light to dark grey cottony growth on mycelium (Ali *et al.*, 2016).

4. Symptomology, epidemiology, mode of survival and spread

When favorable conditions are met, the ripe chilli fruit develops typical symptoms, appearance of sunken angular or circular lesions. At maturity, the lesions are typically characterized by black coloured dots in concentric rings. On the fruit surface, conidial masses ranging in colour from orange to pink may initially be observed. The dark dots visible under a microscope are acervuli structures with setae hairs that capture the conidia of the pathogen. Small depressed greyish brown spots with dark borders emerge on stems and leaves, with acervuli developing in concentric rings (Saxena *et al.*, 2016). The round or angular depressed lesions are coated with concentric rings of wet, gelatinous spores from salmon-colored fungal fruiting bodies (acervuli) at advanced stages of infection. These spores have many black spines and a salmon colour (setae) (Ali *et al.*, 2016).

The severity and spread of any disease are heavily influenced by environmental factors. Disease spreads due to a combination of favorable host, pathogen, and meteorological conditions. The disease spreads more easily in hot, humid environments (Saxena *et al.*, 2016). Critical environmental factors that influence the severity of the disease include rainfall intensity and duration, humidity, leaf surface moisture, and light. Due to the pathogen's greater establishment in terms of germination, adhesion, and penetration into host tissues, leaf surface wetness has been directly linked to disease severity. The most favorable circumstances for successful disease establishment have been reported as approximately 27°C with 80% relative humidity. The disease's progression is also influenced by the host cultivar's resistance to the infection(Banya *et al.*, 2020)

Other studies have found that temperatures between 20 and 25 degrees Celsius encourage colony formation and sporulation, and that relative humidity is the most important climatic factor in anthracnose development on chilies (Ali *et al.*, 2016). Infections grow quickly on young pods during periods of excessive irrigation or rain (Hussain and Abid, 2011).

The anthracnose fungus is known to persist in and on seed as acervulus and micro-sclerotia. Scientists reported mycelia and stromata survival in colonized chilli seed. Mycelium can be found in the testa's outer and inner layers, as well as in the endosperm that emerges to the surface after the seed coat is disrupted. Chilli seeds stored at 5°C can keep anthracnose fungus alive for nearly eight years. The pathogen can live in soil, contaminated crop wastes, and weeds for long periods of time. Infected seeds produce weak seedlings, which serve as the field's principal source of inoculum. Conidia from acervuli are dispersed through wind, rain splash or irrigation water from infected to healthy plants throughout the warm and wet season (Singh *et al.*,2012). Perithecia can also serve as survival structures for pathogens, allowing them to overwinter when they are not in contact with a susceptible host (De Silva *et al.*, 2017).

The germination of conidia and the formation of specialized infection structures known as appressoria, which use small penetration pegs to pass through the host cuticle and epidermal cell walls, *Colletotrichum* spp. enter and colonies host tissues. Rarely, direct penetration via wounds or stomata happens without appressoria developing. The infection process of *C. acutatum* in Capsicum fruit resulted in the production of highly branched, thick-walled dendroid structures, which allowed penetration at the cuticle. Particularly important in the initial infection phase and perhaps acting as a fungal infection barrier is the host plant surface structure (thickness of the cuticle and epidermis, leaf hairs, stomata, and trichomes). In subcuticular, intramural necrotrophic infection, the fungus grows within the periclinal and anticlinal walls of epidermal cells beneath the cuticle, without penetrating the protoplasts. Ascospores are discharged when the environment is suitable for the development of perithecia, infecting neighboring plant tissues. Ascospores develop into acervuli that produce a large number of conidia on conidiophores after germinating and infecting plant cells. Conidia are spread by wind or rain splash on healthy foliage, young fruit, and blossoms. After infection, the pathogen generates conidia all season long, resulting in a polycyclic disease cycle. The senescence of the host tissue may trigger the development of the sexual stage to resume the life cycle (De Silva *et al.*, 2017).

5. Management tactics towards chilli anthracnose

Agriculturists and farmers have been deeply concerned about managing chilli anthracnose because there are now no available effective control methods. The need for a long-term strategy to prevent the disease's spread has grown as a result of the decrease in chilli production and the degradation in fruit quality. No single management strategy has managed to put the disease under control. Combining numerous approaches, including chemical management, biological control, physical control, and inherent resistance, has been suggested to overcome disease. There are five kinds of management strategies for preventing *Colletotrichum* spp. from spreading and causing a disease. Cultural practices, chemical management, resistant cultivars, plant activators and biological control are all utilized (Saxena *et al.*, 2016).

6. Cultural practices to overcome chilli anthracnose

Strategies to restrict the pathogen's spread in the field should concentrate on three key areas for disease-free crop production: appropriate drainage, crop rotation, and removal of any contaminated plant parts. This is because the pathogen is not only soil-borne but also seed-borne, wind-borne, and water-borne. From infected to uninfected plant parts, fungal conidia can spread swiftly via rain splashes. Relative humidity also promotes pathogen colonization. In addition, adequate spacing between plants should be maintained to minimize dense canopy, which allows moisture to develop (Amrita, 2015).

The region needs to be adequately drained and watered in order to prevent the disease from spreading. Another common approach is to use transplants grown from disease-free chilli seeds. Keep the transplants weed-free and apart from other solanaceous crops. After every 2-3 years, the crop should be cycled with crops that aren't *Colletotrichum* hosts. In the field, proper cleanliness should be maintained by removing weeds on a regular basis and allowing pepper plants to volunteer. Pathogens will be able to escape and so disease incidence will be reduced if cultivars with early fruit sets are used. To prevent the transmission of the disease to healthy plants, the field should be cleared of any infected plants or plant components. Damaged fruits should also be removed from the field to prevent pathogenic bacteria or fungus from colonizing them. To thoroughly hide the crop diseases, the area should also be deep ploughed after each crop. Rice husk and plastic mulches have also been described as effective disease control methods(Amrita, 2015).

7. Chemotheuroptic Management

One of the most prevalent methods for managing chilli anthracnose has traditionally been the use of synthetic chemicals. However, due to human health issues and the possibility for pathogen resistance to the fungicides. Post-harvest anthracnose can be considerably minimized by following suitable cultural techniques without applying synthetic fungicides. On the other hand, fungicide resistance can develop quickly if a particular chemical is used too frequently. Anthracnose is frequently controlled by planting pathogen-free seeds or pre-treating seeds with synthetic pesticides Baistin, Captan and Thiram (Choudhary *et al*., 2013). Carbendazim, difenoconazole, propiconazole and maneb are some of the most often used fungicides for pre-harvest chilli anthracnose treatment (Gopinath *et al*., 2006). The efficiency of pyraclostrobin, trifloxystrobin and azoxystrobin in managing chilli anthracnose has also been labelled, but there are only tentative reports on their efficacy against the disease in its severe form in field trials (Lewis and Miller, 2003). Even after successful aspects in pre-harvest studies using these synthetic chemicals to manage chilli anthracnose, some *Colletotrichum* spp., such as *C. Siamese, C. capsici and C. gloeosporioides,* have developed resistance to thiophanate-methyl, Strobilurin-fungicides (kresoxim-methyl, carbendazim and azoxystrobin (Hu *et al.,* 2015).

The most frequently recommended chemical fungicides for controlling the anthracnose disease include triazole compounds, dithiocarbamates, benzimidazole, and copper compounds. It has also been treated with more recent substances like fungicides based on strobilurins like pyraclostrobin and azoxystrobin. Few reports exist of this type of fungicide controlling chilli anthracnose in broad field trials. Fungicides should always be applied at the right rate and interval to prevent the pathogen from successfully colonizing plant tissue. Fungicides should be sprayed on young growing tissues including fruits, leaves and flowers to prevent disease from penetrating the plant system. It is impossible to ignore the numerous studies demonstrating the harmful impacts of fungicide use on farmers' health, financial situation, and toxic impact of the environment, particularly in developing countries. Different fungicide classes have different mechanisms of action and durations of effect on disease control. As a consequence, farmers in a specified area should make effective choices about which fungicides to use based on the current environmental conditions. It is highly suggested that two or more different classes of fungicides be rotated in the fields to maximize the probability of greater disease protection(Amrita, 2015).

Containers, seed trays, and propagators should all be well disinfected. Dettol substitutes that are acceptable for use on plants include tea tree oil and camomile tea. It is also useful to soak the soil with a 1% Bordeaux mixture or 3g of copper oxychloride, such as blue copper, per litre of water at 12 and 20 days after sowing. It is greatly beneficial to treat seeds with 4 g of the *Trichoderma viride* formulation and 6 g of Metalaxyl (Hussain and Abid, 2011).

Soaking chilli seeds in % thiram for 12 hours is the most effective method for eradicating Colletotrichum species. Recently suggested strobilurin fungicides for the management of chilli anthracnose include trifloxystrobin, azoxytrobin, and pyraclostrobin. Additionally, effective seed dressings like benlate and Delsene M as well as fungicides like 0.5 % or 1% Bordeaux mixture, % Bavistin, % ziram, and % mancozeb have been demonstrated to be effective (CPC, 2007).

8. Eco-friendly Strategy to overcome chilli anthracnose

As a long-term method of restoring environmental balance, biocontrol as a disease management strategy has gained popularity. The BCAs that have been used to investigate the antagonistic potential against *Colletotrichum* spp., which have so far damaged the chilli crop, include *Trichoderma* spp., *Candida oleophila, Bacillus subtilis, Psuedomonas fluorescens,* and *Pichia guilliermondii*. The Ascomycete class includes the well-known genus Trichoderma. Its ability to colonies wood, bark, agricultural waste, and other surfaces, in addition to its predominance in a variety of soil types, demonstrate its amazing aptitude for adaptation. *Alternaria, Colletotrichum, Phytophthora, Pythium, Rhizoctonia, Sclerotinia, Verticillium,* and other phytopathogens have all been successfully controlled by Trichoderma (Saxena *et al.,* 2016). Antibiosis, mycoparasitis, nutrition and space competition, and the possibility for plants to develop systemic resistance against pathogens have all been suggested as mechanisms. *Trichoderma* species application has also been acknowledged with efficiently stimulating plant growth and a significant increase in output. Its potential has been

Table.1. **Chemicals along with active ingredients and mode of action evaluated by various researchers towards *Colletotrichum capsici* causing chilli anthracnose**

Trade Name	Active Chemical	Mode of action	Reference
Score	Difenoconazole	This fungicide stops the development of pathogenic fungi by interfering with the biosynthesis of sterols in the cell membrane of fungi.	Gopinath *et al.*, 2006
Ridomil Gold	Mancozeb	The germination of pathogenic fungus spores is inhibited by this fungicide.	CPC. 2007
Bavistin 50DF	Bavistin	By interacting with the cell membrane, this fungicide (Bavistin) can inhibit the germination of pathogenic fungal spores and disturb the metabolism of fungi.	Choudhary *et al.*, 2013
Blue Shield DF	Copper oxychloride	This fungicide (Copper oxychloride) inhibits the germination of pathogenic fungal spores.	Hussain and Abid, 2011
Amistar Top	Azoxystrobin	This fungicide prevents respiration of fungi because of disruption of ETC (Electron Transport Chain).	Hu *et al.*, 2015
Tilet 250 EC	Propiconazole	It stops the development of fungus and interferes in the biosynthesis of sterols in cell membranes.	Gopinath *et al.*, 2006
Nativo®WG 75	Trifloxystrobin+Tebuconazole	It acts as a respiration inhibitor. It blocks the electron transfer at the mitochondrial membrane of the fungus.	Lewis and Miller, 2007
Thiram	Dimethyl dithiocarbamate	It suppresses the sulfhydryl enzyme and metal-dependent systems in fungus.	Choudhary *et al.*, 2013

demonstrated by its quick colonization ability and mycoparasitic nature, which promote coiling and parallel growth of the pathogen in the *colletotrichum* plant pathosystem. The release of extracellular enzymes like glucanases and chitinases, which kill pathogenic mycelia, has also been connected to this characteristic. Consequently, it has a restricted capacity to grow and colonize the host tissue (Saxena *et al.*, 2016).

Fungal growth and spore germination were completely suppressed using a 3 % dose of garlic bulb extract. The ability of extract from various Sweet Flag parts, Palmorosa oil, and Neem oil to inhibit the growth of anthracnose fungi has been demonstrated. Neem (*Azadirachta indica*), mahogany (*Swietenia mahagoni*), and garlic plant extracts applied together are an effective method for treating chilli anthracnose in an environmentally friendly manner (*Allium sativum*). Both the yield of chilli and the control of disease are significantly influenced by the combination of these plant extracts (Banya *et al.*, 2020).

9. Physical control of chilli anthracnose

When used alone or in combination with other treatments, physical control techniques including blanching, brushing, hot air, steam, or hot water rinsing, and boiling can prevent post-harvest degradation in bell and chilli peppers. Treatments with hot water at 53 °C for 4 minutes or 45 °C for 15 minutes reduced chilling damage and stopped degradation in bell peppers (*C. annuum*) after 14 and 28 days of storage at 8 °C. The researchers found that after 28 days of storage at 8 °C, hot water treatments (4 minute dip at 53 °C) combined with low density polyethylene film wrapping significantly decreased the rate of respiration, decreased decay, maintained turgor pressure, and preserved green coloration, resulting in excellent overall quality (Ali *et al.*, 2016).

A rapid method for simultaneously cleaning and disinfecting sweet pepper (*C. annuum*) using hot water and brushes at 55 1 °C was developed after storage at 7 °C for 15 days and further 4 days at 16-18 °C. By removing debris, dust, and even fungal spores from the fruit calyx and skin, as well as by sealing minute fissures in the fruit's epidermis, physical treatments like hot water rinsing and brushing aid in the disinfection process and improve maintaining quality. On the other hand, quick hot water treatments might not be able to control latent *Colletotrichum* spp. infections, and their use alone will not be able to provide or maintain pepper's post-harvest qualities (Ali *et al*., 2016).

10. Management through plant activators

The lignification and fortification of cell walls, the biosynthesis of pathogenesis-related (PR) proteins, the production of phytoalexins, and the stimulation of stress-related genes all serve as defense mechanisms for plants against invading pathogens. Additionally, a number of transcription factors (TFs) work with DNA to bind to cis-acting regions of genes that are regulated by defense, controlling the expression of those genes. By coordinating signaling pathways and downstream effectors, the activation of these defense-related genes reduces the effects of biotic stressors. Hormones made by plants, such as jasmonic acid, salicylic acid, ethylene, gibberellins, auxins, and brassinosteroids, have a synergistic or antagonistic effect on the expression of numerous stress-sensitive genes implicated in plant immune response pathways (Mishra *et al.*, 2017).

Host defense responses against insects and diseases are defined by global changes in gene expression regulated by numerous signaling pathways. These defensive pathways mostly involve small chemical modules like ethylene, salicylic acid, and jasmonic acid. These signaling molecules activate a slew of defense-related genes after pathogen infection, triggering a complex innate immune response. Under incompatible pathogen-plant host interactions, a considerable number of defense response (DR) proteins accumulate. During a defense reaction, resource balancing is frequently a goal in order to limit plant damage while simultaneously optimizing reproductive and vegetative growth. As a result, the defensive response is not constitutive, and the infected plant's increased transcript accumulation of defense genes is required to combat the invading pathogens' threat (Mishra *et al.*, 2017)

11. Resistant source towards chilli anthracnose

The most important and long-term strategy for controlling the disease is to develop resistance against the parasite in the host. This technique not only reduces disease losses, but also removes the chemical and mechanical costs of disease management. The goal is using resistant varieties is to activate the host's defensive response, which then inhibits or slows the pathogen's growth. A host resistance gene and a pathogen avirulence gene are combined to achieve this. Several effective resistant chilli varieties against *C. capsici* have been reported from around the world. There are a number of resistant chilli varieties that are effective against *C. capsici*. Knowledge of the resistant Capsicum cultivars that abound in the region, as well as the various pathotypes of the disease prevalent there, are two essential criteria before moving on with cultivar development. The difficult task of breeding resistance strains in the *Colletotrichum* chilli patho system is particularly challenging due to the interaction of multiple pathogen species with the disease and the variable ability of the pathogen pathogenicity (Banya *et al.*, 2020).

12. Nanotechnology: An emerging tool towards chilli anthracnose

Commonly, chemotherapeutic management strategy is given preference to fight against phytopathogens and toxic chemicals are potentially harmful to environment and the humans. In the field of agriculture, nanotechnology is a new tool that offers a wide range of potential especially it is being preferred in plant disease management. It can offer advantages to pesticides such as increasing the solubility of poorly water-soluble pesticides, reducing toxicity and improving the shelf-life, all of which could have positive impacts on environment. Of the several NPs that exist, only AgNPs, CuNPs and ZnNPs have received much attention due to their antimicrobial activity. The first NPs to be studied in plant disease management were silver nanoparticles. Silver (Ag) exhibits significant antimicrobial activity and research efforts on it as a substitute for chlorine and other toxic nanomaterials has been progressing (Park *et al.*, 2016). In numerous studies, the efficacy of silver nanoparticles against fungi has been evaluated (Mallaiah, 2015). Due to its incredible utilization in numerous fields, silver nanoparticles are currently being applied. It has been investigated that some pathogens have developed resistance to various antimicrobial agents, including chemicals, but not to AgNPs (Bratovcic, 2020). Antifungal potential of AgNPs against chilli anthracnose has been studied under field conditions. In vitro, the application of silver nanoparticles at a concentration of 100 ppm resulted maximum inhibition of conidial germination of pathogenic fungi compared to the control. In a field experiment, fungal growth was considerably reduced when silver nanoparticles were applied before the development of plant disease. Silver nanoparticles had a negative impact on the mycelial development of *Colletotrichum* species, according to results from scanning electron microscopy (Lamsal *et al.*, 2011). *Colletotrichum* spp. has been exposed to concentrations of 730 ppm, 980 ppm, and 1200 ppm of zinc oxide nanoparticles (ZnNPs) and compared with the effect of ciproconazole (+ve control) as well as with normally grown fungus (-ve control). At a concentration of 15 mmolL-1, the zinc oxide nanoparticles demonstrated an excellent result by suppressing fungal growth up to 96 % (Mosquera-Sanchez *et al.*, 2020).At a concentration of 15 mmolL-1, the zinc oxide nanoparticles demonstrated an excellent result by suppressing fungal growth up to 96 % (Mosquera-Sanchez *et al.*, 2020). ZnO-NPs and MgO-NPs have been evaluated against *Colletotrichum* strains obtained from tropical fruits. The ZnO-NPs including MgO-NPs proved fruitful by inhibiting 88% fungal growth. The ZnO-NPs are effective and viable antifungal alternative to be used in crop protection systems (Rosa-Garcia *et al.*, 2018). Antifungal potential of Silica- Silver NPs has been studied against fungal pathogens such as *Colletotrichum* (Park *et al.*, 2016).

13. Conclusion

Chilli anthracnose is a ravaging biotic stress to chilli crop cultivation across the globe. IDM (Integrated disease management) strategy is a fruitful option to contest the disease, rather than relying upon a single method. An understanding of the etiological agent of the disease is a pre-requisite for management. To date, there is no effective strategy for disease management because of withdrawal of various varieties in chilli cultivation around the world. To develop resistant varieties, breeders need to know races and there is still dearth of information on early detection of pathogenic fungus and strategies for its management.

14. Future Direction

It is the most pressing need to direct research efforts on cutting-edge research areas especially in Pakistan. Introduction of new pathogen strains has been blamed for the withdrawal of varietal resistance to chilli anthracnose disease. There are pathogenicity variations in C. capsici that's why enhancing the resistance of chilli to the pathogenic fungus is very significant to be the foremost economical and effective approach for controlling this disease. Work on pathotyping should be done because of the complex and diverse nature of the pathogen. A comprehensive study regarding the impact of epidemiological factors and the development of disease forecasting models should be done. Disease forecasting models should be introduced at region-level by keeping in view ecological conditions. Researchers are using the CRISPR/Cas9 technique in several agricultural plant spp. through targeting several genes of interest for improved nutrition, improved tolerance against drought and enhanced disease resistance. The CRISPR/Cas9 technique has been successfully applied in many plants spp. as wheat, potato, rice, maize, soybean, banana, sorghum, poplar, tomato, tobacco and apple. The research efforts should be done to engineer resistance in chilli to fight against anthracnose disease. For eco-friendly management, it is vital to explore the potential of endophytes towards C. capsici. Various BCAs do not have the potential to thrive in newly introduced habitats that's why, it is also vital to introduce new biocontrol agents to contest this ravaging pathogen. Very limited work has been done on the nanotechnological approach for disease management. Nanotechnology is a rapidly evolving discipline for plant disease management and this nanotechnological approach may prove a fruitful tool to combat this phytopathological challenge.

15. REFERENCES

Ali, A., P.K. Bordoh, A. Singh, Y. Siddiqui, and S. Droby. 2016. Post-harvest development of anthracnose in pepper (Capsicum spp): Etiology and management strategies. Crop Prot. 90 (2016): 132-141.

Ali, M. 2020. Cluster-development based agriculture transformation plan. Cluster development-based agriculture transformation plan vision-2025. Project. 131: 434.

Amrita, S. 2015. Epidemiology and management of Anthracnose of chilli. Banaras Hindu University, India.

Anggrahini, D.S., A. Wibowo, and S. Subandiyah. 2020. Morphological and Molecular Identification of Colletotrichum spp. Associated with Chili Anthracnose Disease in Yogyakarta Region. J. Perlind. Tanam. Indones. 24:161-174.

Arin, S. 2019. Scenario of chilli production and hindrances faced by the growers of Sindh province of Pakistan. Mod. concepts dev. agron. 4(3): 436-442.

Banya, M., S. Garg, and N.L. Meena. 2020. A review: Chilli anthracnose, its spread and management. J. Pharma. Phytochem. 9:1432-1438.

Bratovcic, A. 2020. Nanocomposite hydrogels reinforced by carbon nanotubes. Int. J. Eng. Res. 10(5): 30–41.

Choudhary, C.S., C. Jain, R. Kumar, and J.S. Choudhary. 2013. Efficacy of different fungicides, biocides and botanical extract seed treatment for controlling seedborne Colletotrichum spp. in chilli (Capsicum annuum L. Bioscan. 8:123-12.

CPC. 2007. Crop Protection Compendium. CAB International.

De Silva, D.D., J.Z. Groenewald, P.W. Crous, P.K. Ades, A. Nasruddin, O. Mongkolporn, and P.W. Taylor. 2019. Identification, prevalence and pathogenicity of Colletotrichum species causing anthracnose of Capsicum annuum in Asia. IMA fungus. 10:1-32.

De Silva, D.D., P.W. Crous, P.K. Ades, K.D. Hyde, and P.W. Taylor. 2017. Life styles of Colletotrichum species and implications for plant biosecurity. Fungal Biol. Rev. 31:155-168.

Deshpande, S., D. Mohapatra, M. Tripathi, and R. Sadvatha. 2015. Kodo millet nutritional value and utilization in Indian foods. J. Grain Proc. Stor. 2:16-23.

Ganguly, S., K. Praveen, P.A. Para, and V. Sharma. 2017. Medicinal properties of chilli pepper in human diet. ARC J. Public Health Community Med. 2:6-7.

Gopinath, K., N.V. Radhakrishnan, and J. Jayaraj. 2006. Effect of propiconazole and difenoconazole on the control of anthracnose of chilli fruits caused by Colletotrichum capsici. J. Crop Prot. 25(9): 1024 -1031.

Hasan, R., A. Huque, M.K. Hossain, and N. Alam. 2015. Assessment of genetic divergence in Chilli (Capsicum annuum L.) genotypes. Pl. Gene Trait. 6:1-5.

Hu, M.J., A. Grabke, M.E. Dowling, H.J. Holstein, and G. Schnabel. 2015. Resistance in Colletotrichum Siamese from peach and strawberry to thiophanate-methyl and azoxystrobin. Pl. Dis. 99: 806-814.

Hussain, F. and M. Abid. 2011. Pest and diseases of chilli crop in Pakistan: A review. Int. J. Biol. Biotech. 8:325-332.

Lamsal, K., S.W. Kim, J.H. Jung, Y.S. Kim, K.S. Kim, and Y.S. Lee. 2011. Application of silver nanoparticles for the control of Colletotrichum species in vitro and pepper anthracnose disease in field. Mycobiol. 39(3): 194-199.

Lewis, I.M.L. and S.A. Miller, S.A. 2003. Evaluation of fungicides and biocontrol agents for the Control of anthracnose on green pepper Fruit. 2002. Nematicide Test Report. New Fungicide Nematic. Data Comm. Am. Phytopathol. Soc. 58: 62.

Mallaiah, B. 2015. Integrate approaches for the management of Crossandra (Crossandra infundibuliformis L. nees) wilt caused by Fusarium incarnatum (Desm.) Sacc. PhD Thesis.

Mishra, R., S. Nanda, E. Rout, S.K. Chand, J.N. Mohanty, and R.K. Joshi. 2017. Differential expression of defense-related genes in chilli pepper infected with anthracnose pathogen Colletotrichum truncatum. Physiol. Mol. Pl. Pathol. 97:1-10.

Mongkolporn, O. and, P. Taylor. 2018. Chili anthracnose: Colletotrichum taxonomy and pathogenicity. Pl. Pathol. 67:1255-1263.

Mosquera-Sánchez L.P., P.A. Arciniegas-Grijalba, M.C. Patiño-Portela, B.E. Guerra–Sierra, J.E. Munoz-Florez, and J.E. Rodríguez-Páez. 2020. Antifungal effect of zinc oxide nanoparticles (ZnO-NPs) on Colletotrichum sp., causal agent of anthracnose in coffee crops. Biocatal. Agric. Biotechnol. 25(2020): 101579.

Park H.J., S.H. Kim, H.J. Kim, and S.H. Choi. 2016. A new composition ofnanosized silica-silver for control of various plant diseases. Pl. Pathol J. 22: 295–302.

Perry, L., and K.V. Flannery. 2007. Precolumbian use of chili peppers in the Valley of Oaxaca, Mexico. Proc. Natl. Acad. Sci. 104:11905-11909.

Prathibha, V., A.M. Rao, R. Ramesh, and C. Nanda. 2013. Estimation of fruit quality parameters in anthracnose infected chilli fruits. Int. J. Agric. Food. Sci. Tech. 4:57-60.

Rosa-García S.C., P. Martínez-Torres, S. Gomez-Cornelio, M.A. Corral-Aguado, P. Quintana, and N.M. Gomez-Ortíz. 2018. Antifungal activity of ZnO and MgO nanomaterials and their mixtures against Colletotrichum gloeosporioides strains from tropical fruit. J. Nanomater. 2018: 3498527.

Saxena, A., R. Raghuwanshi, and H. Singh. 2014. Molecular, phenotypic and pathogenic variability in Colletotrichum isolates of subtropical region in north-eastern India, causing fruit rot of chillies. J. Appl. Microbiol. 117:1422-1434.

Saxena, A., R. Raghuwanshi, V.K. Gupta, and H.B. Singh. 2016. Chilli anthracnose: the epidemiology and management. Front. Microbiol. 7:1527.

Singh, B., S. Malik, and P. Agarwal. 2012. Survival of Colletotrichum capsici in decade-long cryopreserved Chilli (Capsicum annuum) seeds. Seed Res. 40(1): 92-94.

Sonawane, V. and H. Shinde. 2021. Anthracnose disease of Capsicum annuum L. and its biocontrol management: A Review. Appl. Ecol. Environ. Sci. 9:172-176.

Thakur, H., S.K. Jindal, A. Sharma, and M.S. Dhaliwal. 2019. A monogenic dominant resistance for leaf curl virus disease in chilli pepper (Capsicum annuum L.). J. Crop Prot. 116: 115-120.