Review Article

Mango Anthracnose: Global Status and the Way Forward for Disease Management

Shahid Iqbal, Muhammad Aslam Khan, Muhammad Atiq*, Nasir Ahmed Rajput, Muhammad Usman, Ahmad Nawaz, Ghalib Ayaz Kachelo, Azeem Akram and Hadeed Ahmad

Department of Plant Pathology, University of Agriculture, Faisalabad, Pakistan.

Abstract | Mango anthracnose is the most ravaging biotic stress to the successful production of mango fruit across the globe. *Colletotrichum gloeosporioides* is an etiological agent of this disease that adversely affects the quality as well as quantity of produce. The occurrence of disease at pre- and postharvest conditions is a common phenomenon which is responsible for potential economic losses. It has been studied that the hot and humid climatic conditions are conducive for the outbreak of disease. Therefore, integrated management of mango anthracnose is essential. It has been estimated that approximately 25 to 30% loses in mango production are due to anthracnose and stem end rot. Previous investigations revealed that the disease incidence may reach up to 100% on fruits under humid conditions. Many management strategies such as chemical control, biocontrol, use of Phyto-extracts and nanotechnological approaches have been introduced to combat this disease. The synthetic fungicides are used to curb the disease incidence. Pathogen have developed resistance against various chemicals that are generally utilized to overcome this disease. Because of its antifungal potential against mango anthracnose, among these strategies, nanotechnology is a rapidly evolving discipline that is gaining the attention of researchers.

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***Correspondence** | Muhammad Atiq, Department of Plant Pathology, University of Agriculture, Faisalabad, Pakistan; **Email:** dratiqpp@gmail.com, Muhammad.atiq@uaf.edu.pk
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1. Introduction

Mango (*Mangifera indica* L.) is an agro-industrial fruit crop that belongs to the family Anacardiaceae and it is believed to be the king of all fruits ranking 8th position in terms of productivity globally. The mango is considered as most delicious fruit grown around the tropical and sub-tropical regions of the world. It is a main component of the diet in most of the countries of the world (Mukherjee and Litz, 2009), and is considered an important fruit crop because of its high nutritional and medicinal value, it is a good source of vitamins such as carotene, thiamine, riboflavin and niacin (Archibald *et al*., 2003). It has been estimated that mango ranked 2nd after citrus in terms of area under cultivation and production in Pakistan. According to a statistical report, Pakistan produces approximately

85 thousand tons of mango per annum and occupies 9th position in the world's mango exporting countries. In Pakistan, it is cultivated on an area of 158.6 thousand hectares with an annual production of 1.8 million tons (MNSFR, 2020). It plays a vital role to enrich the economy of Pakistan with a contribution in the export of up to $ 36.66 million annually. The pathogen causing mango anthracnose is pathogenic to more than 470 different plants (Pavitra *et al*., 2017). Among these, mango anthracnose is gaining more attention because of its commercial prospects. The disease is caused by 2 spp where *C. gloeosporioides* is mainly responsible and C. acutatum is thoughtless destructive in a few locations (Tarnowski and Ploetz, 2008). High humidity is a primary factor that promotes disease spread and development. The *C. gloeosporioidies* Penz is one of the most devastating pathogenic fungi that are responsible to cause pre-harvest as well as postharvest losses in mango fruit (Chowdhury and Rahim, 2009). Pathogen attacks young fruits, leaves, flowers and twigs even this disease can also occur in the storage of mature fruits (Chowdhury and Rahim, 2009). It has been detected that the postharvest phase of this disease is economically significant because of its serious threat to fruit worldwide. However, proper knowledge of this disease is a basic need for the management of disease to ensure a fruitful mango yield. Keeping in view the seriousness of this phytopathological problem, the main aim of the present manuscript is to throw light on the pathogen profile, historical perspective of the disease, symptomology, geographical distribution of the disease and fruitful strategies to overcome pathogen causing anthracnose disease.

1.1 Taxonomic status

The *Colletotrichum gloeosporioides* (Penz.) is an ascomycetes fungus that belongs to the family Phyllachoraceae and is a facultative parasite. However, the latest published data have raised a question on the accurate identification of C*olletotrichum gleosporioides* which is based on morphological and microscopic parameters, Hyde *et al*. (2009) described that it is difficult to identify the Colletotrichum species based on limited morphological parameters i-e. size and shape. Phoulivong *et al*. (2010) conducted a research trial on tropical fruits to check the cross pathogenicity of *Colletotrichum gloeosporioides*. Similarly, several researchers and scientists reviewed the taxonomic confusion of *Colletotrichum gloeosporioides* (Cano *et al*., 2004; Cai *et al*., 2009; Cannon *et al*., 2012). All studies discussed the use of molecular approaches by applying sequencing of gene loci including ITS, ACT, CAL TUB2, LSU GS, GAPDH, TUB2, EF1α, APN2, RPB1 and MAT1- 2 (Moriwaki *et al*., 2002; Than *et al*., 2008) to assign the strains to *Colletotrichum gloeosporioides* in its currently defined sense. Variability among the isolates of *Colletotrichum gloeosporioides* was also assessed through molecular approaches and sequences (Prashanth and Sataraddi, 2011), studies on the description of the taxonomic status of fungi based on morphological and molecular approaches were also conducted in India while a detailed description of its taxonomy was presented by Shigh and Prasad (1967) during an epidemiological study of anthracnose disease of *Dioscorea alata*.

1.2 Biology of pathogen

The *C. gloeosporioides* is the asexual or imperfect stage of fungi while the *Glomerella cingulate* is its sexual or perfect stage. *Glomerella cingulata* attack on a variety of host species and produce acervuli within a host part during the asexual stage (mitotic phase) of their life cycle. The teleomorph stage of fungus is known because of its ability to incite a severe infection that leads to disease development (Cannon *et al*., 2012) and it requires warm -humid conditions for the dispersal of disease more effectively and uniformly (Farr *et al*., 2006). The fungus primarily entered through injured or weakened parts and produces specialized structures i.e., conidia, setae, acervuli and appressoria during host-pathogen interaction. *Colletotrichum gleosporioides* colonizes the injured plant parts (tissue) and produce a number of conidia as well as acervuli which are dispersed to short distances through rain splashes or overhead irrigation that cause infection to healthy plant tissue. The penetration of fungus depends on the formation of specialized structures known as "appressoria" and these appressoria facilitate the fungus for penetration into the host epidermal cell directly through narrowing the penetration peg that emerges at the base of appressoria while acervuli are asexual bodies that are produced during infection cycle as a small, flask-shaped structure of which short conidiophore is produced and can be found on the surface infected plants, setae are long brownish structure developed from acervuli (Purkayastha and Gupta, 1973; Perfect *et al*., 1999). The whole infection cycle includes the formation of acervuli, conidia, setae and appressoria and infection results in the necrosis of tissue. The water-soaked spots appeared on diseased plant parts. But variation in symptoms is recorded from host to host and these symptoms may be water-soaked, round to oval, irregular brownish to black spots. Similarly, the characteristics of fungi on culture media also differentiate among the host. Generally, *Colletotrichum gleosporioides* produces circular, cottony colonies on cultured medium with characteristic colors such as greyish white or pale brown (Hiremath *et al.*, 1993; Vidyalakshmi and Divya, 2013) and on the growing culture, it produces hyaline, branched and septate mycelium. The *Colletotrichum gleosporioides* show maximum growth at a temperature of 25-30°C and in the pH range of 6-7 whereas it requires 12hrs of light duration for maximum growth of mycelia (Nelson *et al.*, 2015).

Figure 1: Distribution map of the world for mango anthracnose.

1.3 Distribution map

1.3.1 Disease cycle

Spore (conidia) dispersion occur through rain splashes and irrigation water from infected plants to healthy one. Spores (conidia) arrives at infection sites i-e. leaves, panicles and branch terminals Spores (conidia) penetration on immature fruits and young tissues takes place through cuticle as well as through epidermis. Black sunken rapidly spreading lesions established on affected parts of plant. Sticky masses of spores (conidia) are developed in acervuli (fruiting body) on infected tissues especially under moist conditions. Many disease cycles may occur as pathogen continues to reproduce during the whole season. The Pathogen (fungus) survives b/w the season on infected leaves and on the defoliated branch terminals.

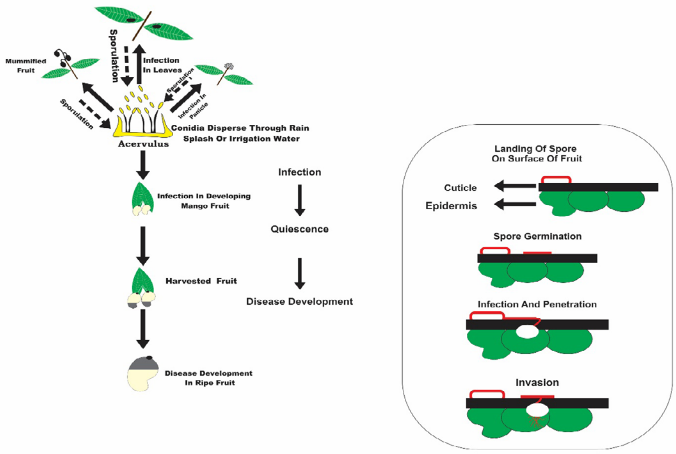

Figure 2: Disease cycle of mango anthracnose caused by *Colletotrichum gleosporioides*.

1.4 Chemotherapeutic management of mango anthracnose

A variety of synthetic fungicides have been recommended to control mango anthracnose disease (Shukla and Adak, 2017). Application of fungicides in the mango field are most suitable strategy in order to achieve effective anthracnose control as well as safeguard production in the areas with high humidity (Arauz, 2000). The latest technology with fungicides spray at the time of flowering as well as 50% fruit maturity give best result to minimize the incidence of disease and severity which may be equal or less to the traditional (Paez, 2000). Azoxystrobin reduced hundred percent mycelial growth of *C. gloeosporioides*. The successful anthracnose control may be achieved by the utilization of pre harvest as well as postharvest fungicides. By the application of Dithio-Carbamates which are organic sulphure fungicide and heterocyclic nitrogenous compounds like mancozeb, zineb as well as captan, respectively sufficient over anthracnose of mango may be achieved (Cole *et al.*, 2005).The benzimidazoles especially benomyl and carbendazim proved to be most effective in controlling anthracnose diseases under in *vivo* conditions (Akem, 2006) The control of anthracnose disease in the field can be done mostly by the application of chemical fungicides like benomyl, chlorothalonil, maneb and mancozeb. Chemical control of anthracnose needs biweekly as well as monthly fungicide application which proved to be harmful to environment, and regular application of fungicides may lead to the evaluation of chemical resistant strains (Onyeka *et al.*, 2006). The hot benomyl dip control the anthracnose disease found on fruits of mango which are infected after harvest (Kim *et al.*, 2007).

Table 1: Previous investigation regarding use of fungicides against anthracnose diseases caused by Colletotrichum gleosporiodes.

Active chemicals	Trade name	Mode of action	References
Thiophanate methyl	Topsin M	Curative action	Arauz (2000)
Azoxystrobin	Amistar Top	Distrub ATP synthesis	
Mancozeb	Dithan M-45	Distrub biochemical processes in fungi	Diedhiou *et al.* (2014)
Copper hydroxide	Kocide	Curative and systemic action	Nelson (2008)
Carbendazim	Bavistin	Interfere with DNA synthesis	Thomas *et al.* (2008)
Tebuconazole	Elite	Affects fungal cell wall	
Benomyl	Benlate	Distrub tubulin polymerization	
Thiabendazole	Mintezol	Inhibit mitochondrial enzymes	Muñoz (2002)
Azoxystrobin	Amitar Top	Distrub ATP synthesis	Ishii *et al.* (2022)
Propiconazole	Tilt	Inhibit fungal cell membrane	Atri *et al.* (2022)
Carbendazim	Bavistin	Inhibit DNA synthesis	

Table 2: Previous investigation regarding use of Phyto-extracts against anthracnose diseases caused by Colletotrichum spp. on different hosts.

Phyto-extracts	Mode of action	Host plant	References
Eucalyptus oil	Inhibit fungal growth	Mango	Chauhan *et al.* (1990)
castor oil	Reduce the absorption of electrolyte	Mango	
Lantana leaves	Inhibit fungal growth	Mango	
Garlic cloves	Inhibit fungal growth	Mango	Gahlot *et al.* (2021)
Azadirachta indica	Therapeutic action	Tomato	Ehsan *et al.* (2020)
Allium sativum	Inhibitory action	Tomato	
Garlic extracts	Inhibit spore formation	Mango	Chowdhury *et al.* (2007)
Azadirachta indica	Therapeutic action	Mango	Ahmed *et al.* (2018)
Prosopis juliflora	Inhibit mycelial growth	Mango	Deressa *et al.* (2015)
Oregano extract	Membrane breakage	Bean	Pinto *et al.* (2010)
Custard apple extract	Cell death	Pappya	Bautista-Baños *et al.* (2003)
Ginger	Cell death	Bell pepper	Alves *et al.* (2015)
Turkey Berry	Cell death	Banana	Thangavelu *et al.* (2004)
sGinger	Spore inhibitionand cell death	Banana	Bhutia *et al.* (2016)
Eucalptus	Inhibitory action	Mango	Hur *et al.* (2000)
Yarrow	Inhibit spore germination	Tropical fruits	Fiori *et al.* (2000)

The systematic as well as non-systematic fungicide were used with various doses in lab due to their efficacy against *C. gloeosporioides* and in systematic fungicides the carbendazim proved to be the most effective against mango anthracnose and inhibit the 89.66% fungus growth at 0.1% concentration and among non-systematic fungicides mancozeb inhibited the 89.38% fungus growth at 0.25% concentration followed by propineb (at 0.3% conc.) and thiophanate (at 0.1% conc.) which showed 58.57% and %7.35% inhibition respectively (Sudhakar, 2000) The systemic fungicide such as carbendazim had fully inhibited the mycelial growth of *C. gloeosporioides* at all concentration in laboratory conditions (Prabakar *et al*., 2008). Studies showed that the effect of 8 fungicides such as Carbendazim (at 0.1% concentration), cholorothalonil (at 0.2% concentration), copper oxychloride (at 0.25% concentration), difenoconazole (a 0.1%concentration), hexaconazole (a0.2% concentration),mancozeb (at 0.2% concentration), thiophanate-methyl (at 0.1% concentration) and ziram (a 0.3% concentration) and among the eight fungicides which were tested against *C. gloeosporioides* pathogen the carbendazim reduced 88.76% and thiophanate-methyl 85.39% reduced the growth of mycelia of *Colletotrichum* pathogen (Sharma and Verma, 2007). List of fungicides are given in Table 1 which have been used against mango anthracnose in different studies.

Table 3: Previous investigation regarding use of nanoparticles against anthracnose diseases caused by *Colletotrichum* spp. on different hosts.

Nanoparticles	Mode of action	Host Plant	References
Nano-silver	Cell membrane lysis	Chilly pepper	Lamsal *et al.* (2011a)
Thiamine di-launrate sulphate (TDS)	Inhibition of mycelial growth	Chilly pepper	Seo *et al.* (2011)
Chitosan	Disrupt DNA synthesis	Chilly pepper	Chookhongkha *et al.* (2012)
Chitosan AgNP composite	Disrupt plasma membrane and DNA	Mango	Chowdappa *et al.* (2014)
Cz-AgNPs	Denaturation of proteinand cell wall damage	Mango	Shivamogga *et al.* (2020)
CuNPs	Cellular leakage	Several tropical fruits	Nguyen *et al.* (2020)
ZnO NPs	Membrane leakage and reduces cell viability	Dendrobium orchards	Ruangtong *et al.* (2021)
EC-NPs	Inhibit spore germination	Postharvest fruits	Xue *et al.* (2019)
Ag-Neem Nps	Cell wall breakdown	Banana	Jagana *et al.* (2017)
Ajwain-Ni NPs	Therapeutic action	Banana	
CuNPs	Cellular leakage	Olive	Ntasiou *et al.* (2021)
Cur-ChNP	Cell death	Papaya	Suryadi *et al.* (2020)
CuNPs	Cellular damage	Chilli	Divte *et al.* (2019)
ZnO NPs	Distrupt fungal hyphae	Coffee	Mosquera *et al.* (2020)
Chitosan-silver NPs composite	Disrupt fungal cells	Mango	Ruffo *et al.* (2019)
Copper oxychloride-conjugated AgNPs	Inhibit spore formation	Mango	Ruffo *et al.* (2019)
Aloe vera gel, glycerol and ZnO NPs	Membrane leakageand cell viability	Mango	
Chitosan NPs	Damage fungal cells	Postharvest fruitsand vegetables	Bautista-Baños *et al.* (2017)
Mc-AgNPs	Damage fungal cell cytoplasm	Mango	Raghavendra *et al.* (2020)

The non-systematic fungicide such as mancozeb inhibited the mycelial growth (64.0%) of *C. gloeosporioides* at 0.1% concentration whereas systematic fungicides such as difenoconazole and propiconazole inhibited mycelial growth more than 90.7% at 0.1% concentration (Prashanth *et al.*, 2008). The fungicides such as Score(difenoconazole), Contaf (hexaconazole) and Bavistan (carbendazim) had fully inhibited the pathogen growth at 100ug per milliliter concentrations tested in the laboratory, whereas copper oxychloride was less effective because it did not cause considerable reduction in the growth of pathogen (Sing *et al.*, 2008). The excessive use of such chemicals disturb the ecological balance of nature by finishing the beneficial and antagonistic microbes present in the soil. Jabbar *et al.* (2011) described that carbendazim which is a systemic fungicide completely reduced the mycelial growth of *C. gloeosporioides* pathogen at each concentration under lab conditions (Sharma and Verma, 2007). Anthracnose disease can be victoriously controlled by the application of pre-harvest and postharvest fungicides treatment, heat treatment or by the combination of both fungicides and heat treatment (Jabbar *et al.*, 2011). The efficacy of various fungicides against *C. gloeosporioides* by following the poisoned food technique at different concentrations, and find out that the collaboration of mancozeb and carbendazim a (0.2% concentration) proved to be superior over all the treatment with 96.25% hindrance of the fungus followed by the carbendazim (a 0.1% concentration) 68.34%, mancozeb (at 0.25% concentration) 67.51% and copper oxychloride (at 0.3% concentration) 64.88% inhibition. The minimum inhibition (63.62%) was recorded in the treatment of tridemorph at 0.1% concentration (Patil *et al.*, 2009). The tricyclazole at 0.1% concentration and procbloraz at 0.125% concentration were proved to be most optimistic fungicides which showed 50.38% and 48.78% anthracnose disease control (Bhagwat *et al.*, 2010).

Various species of *Colletotrichum* as well as its various isolates has shown differential response against a range of fungicides. Sharma *et al.* (2009) described that the application of Saaf (mancozeb 63% and carbendazim 12%) at 0.2 percent concentration was most optimistic fungicide in field conditions and may be recommended to manage the anthracnose disease of mango (Nithyameenakshi *et al*., 2010). Carbendazim which is systematic fungicide was proved to be best effective while mancozeb a non-systematic fungicide found to be best inhibition of the pathogen *C. gloeosporioides* which is responsible to cause mango anthracnose disease (Kolase *et al*., 2014). The efficacy of 5 fungicides such as carbendazim, copper oxychloride, captan, propiconazole and mancozeb against the growth of fungal pathogen *C. gloeosporioides* under lab conditions followed by poisoned food technique and find out that the carbendazim fully reduced the mycelial growth of *Colletotrichumu* up to 100% at 100ppm dose whereas propiconazole at 500ppm dose fully reduced the mycelia growth up to 100%. Mancozeb completely inhibited the mycelial growth up to 100% at 1000ppm dose than 24.6% inhibition at a dose of 100ppm. Captan at 1000ppm inhibited the mycelia growth up to 80.00% whereas at 100ppm the growth inhibition was 52.2%. Copper oxychloride proved to be least effective against the growth of *Colletotrichum* among all the used fungicides because it inhibited 55.0% the fungal growth even at a 1000ppm dose (Pavitra *et al*., 2017).

1.5 Eco friendly approach for management

1.5.1 Antifungal potential of Bio-control agents and phytoextracts

The inhibitory action of *E. unigera* oil evaluated on the mycelial growth of various phytopathogenic fungi under field conditions (Hur *et al*., 2000) The fungitoxicity of essential oils and crude extracts of *Cymbopogon citrates, A. millefolium, E. maydis* were proved to be inhibitory against the germination of spore of *H. maydis* ranged from 50-100% under laboratory conditions (Fiori *et al*., 2000). These phyto-extracts act as bio-pesticides in controlling the *C. gloeosporioides*. Antagonistic microorganism were isolated and were evaluated against five to seven days old purified cultures of *A. flavus, C. gloeosporioides, A. niger, R. stolonifera and Pestalotia* grown on potato dextrose medium. *In vitro* evaluation of *T. viride* against post-harvest pathogens of mango showed that growth of *A. flavus, C. gloeosporioides, A. niger* and *Pestalotia* was hampered by 56.83, 52.76, 70.73 and 72.88%, respectively. Mango fruit inoculated with *T. viride* was found to be free from *Pestalotia, A. flavus, A. niger as* well as from *C. gloeosporioides* (Bhuvaneswari and Rao, 2001). *T. viride effective against pathogen* by reducing the target pathogen through antibiosis by the production of lytic enzyme (Janisiewicz and Korsten, 2002). The bioactive plants which have less residual effects in environment do not harm the mammals as well as other non-target animals or plants are used for the management of diseases at postharvest level (Meepagala *et al*., 2002). *Jatropha curcas* and leaf extract of various plants have antifungal properties against fungal pathogen *C. gloeosporioides* (Banos *et al*., 2003; Rahman *et al*., 2011). Phyto-extracts of *Jatropha curcas* increased the inhibitory effect of citralon at high concentrations on the spore germination of *C. gloeosporioides* under lab as well as field conditions (Palhano *et al*., 2004). The *Zanthoxyluma mericanum* as well as *Piper regnelli* are well known due to their antifungal activity and are used to control fungal diseases under field conditions (Pessini *et al*., 2005). The plant extracts are best alternate to currently applied synthetic fungicides in order to control the phytopathogenic fungi because these are a rich in bio-active chemicals like flavor compound, oils, terpenoids, chitosan as well as glucosinolate. These compounds help to prevent resistance in pathogen (Tripathi and Dubey, 2004; Song *et al*., 2011). The antifungal property of widdrol as well as its biotransformation against *C. gloeosporioides* Penz. (Nunez *et al*., 2006). Plant extracts are ecofriendly bio-pesticides against fungal pathogens. The lemon grass, palmarosa as well as thymus oil are proved to be most effective against fungal diseases at post-harvest level (Evueh and Ogbebor, 2008). The efficacy of eucalyptus leaves, garlic bulb as well as leaf extract of ocimum against *C. glosporioides* under field as well as lab conditions and found them effective (Prashanth, 2007). *Trichophyton* spp. as well as *Trichocladium* species showed the maximum antagonistic effect against *C. gloeosporioides* (Evueh and Ogbebor, 2008). The antagonists found to be most effective mainly in controlling the postharvest diseases when fruits were subjected to cold storage in order to stimulate the export conditions showed that many postharvest diseases can be controlled by the application of bio-control strategy like microbial antagonistic (Sharma *et al*., 2009). Nutrient competition and place is the main accepted way of their action. Moreover, formation of antibiotics and conceivably induced resistance in harvested products are other ways of their influence through which they inhibit the action of postharvest pathogen in fruits as well as in vegetables (Govender and Korsten, 2006). Various phytoextracts have been used in various studies which are discussed in Table 2.

Use of bio-control agents under field conditions is an important substitute of chemical control of plant pathogens because in chemical control the quality of fruit decreases due to the residual effects of toxic compounds which may persist for a long time in fruit (Haggag *et al*., 2011). Maximum growth inhibition among all isolates of *C. gloeosporioides* was observed by the field application of leaf extracts of *Moras alba* as well as *A. indica* (Pandey *et al*., 2009).The bio-control involve the utilization of microorganism (commonly from similar habitat as pathogen) which prevent the growth of pathogenic organism because of their specificity as well as environmental protection in the field conditions (Tongsri and Saghchote, 2009). The complete inhibition of mycelial growth as well as spore germination of *Colletotrichum* from papaya on chitosan solution confirm the possibility of effective bio-control of *C. gloeosporioides* (Govender and Korsten, 2006).Various plant species such as *Z. officinale, A.sativumbulb, C. ga*leaves, *C. sativus*, *A. indica*, and *A. squamosa* were found effective against *C. gloeosporioides* (Yenjit *et al*., 2004) The application of bacterial filtrate such as *S. aureofaciens* in the form of spray on mango plants proved to be most effective to control mango anthracnose due to their property of producing antifungal enzyme which protect the fruit against this pathogen (Haggag *et al*., 2011). Under field conditions the maximum growth inhibition of *C. gloeosporioides* was observed by the utilization of garlic extracts @ 70% dose (Mukherjee *et al*., 2011). Neem, Eucalyptus, Garlic and Akk extracts were used to manage the *C. gloeosporioides* under lab as well as field conditions. Eucalyptus proved to be most effective against the mycelial growth of pathogen at all doses among all the plant extracts which were used (Kumari *et al*., 2016). Neem extract proved to be most effective in the inhibition of mycelial growth of *Colletotrichum* at 5% concentration under field application (Kolase *et al*., 2014).

Among various plant extracts to control *C. gloeosporioides*, eucalyptus proved to be the most effective in inhibiting the mycelial growth at each concentration. The efficacy of 3 plant extracts *in vitro* such as leaf extract of eucalyptus, neem leaf extracts as well as extract of neem seed was evaluated and leaf extract of eucalyptus proved to be most effective against growth of *C. gloeosporioides* and inhibited its growth up-to 58.5% and 70.3% at 5 and 10% dose respectively. Leaf extract of neem inhibited the fungal growth up to 57% as well as 45.9% at 10 and 5% dose respectively while extract of neem kernel seed found to be least effective as compared to other extracts which were tested and inhibited 53.3% fungal growth at a dose of 10% (Pavitra *et al*., 2017).

1.6 Nanotechnological approaches for disease management

The demand for fungicides has grown because of their low cost and ease of application culminating in the overuse of chemicals (Youssef *et al*., 2019). This increased usage has tended to develop resistance in pathogens against fungicides. However, the introduction of ecologically acceptable novel techniques can prove feasible to combat diseases caused by fungi (Hussien *et al*.,2018). Nanotechnology approaches have provided new avenues to enhance agricultural productivity sustainably. Nanotechnology is a rapidly evolving discipline that encompasses synthesis including the development of nanoparticles that are 1-100 nm in size containing only a few hundred atoms. Antifungal activity of chitosan-AgNPs composite against *C. gloeosporioides* has been evaluated (Chowdappa *et al*., 2014). The potential of zinc and magnesium oxide nanomaterials to fight against pathogen associated with anthracnose disease has been studied (la Rosa-García *et al*., 2018). SNPs a promising solution to manage postharvest anthracnose disease of mango (Basu *et al*., 2019). The biosynthesized CuNPs, AgNPs, NiNPs and MgNPs have been utilized to evaluate their efficacy to inhibit the growth of Colletotrichum spp (Jagana *et al*., 2017). Previous research indicates that the Carbendazim-conjugated AgNPs could be effectively used to control anthracnose disease in mango against etiological agent of anthracnose disease (Nagaraju *et al*., 2020). Nanoparticles as an emerging field of study was used against different diseases which are discussed in Table 3.

Conclusions and Recommendations

It is the need of the hour to pay attention to cutting-edge research areas such as disease forecasting models and pathotyping because of the diverse and complex nature of this pathogenic fungus. Several biocontrol agents don't have the potential to thrive in newly introduced habitats that's why an extensive field evaluation of the biocontrol strategy is needed. Keeping in view a dearth of information available regarding the green nanotechnological approach, it is very vital to direct focus on this greener method to combat this phyto-pathological challenge.

Future direction

It is critical to focus attention on cutting-edge research areas, particularly in Pakistan. It is crucial to undertake a comprehensive study regarding the impact of epidemiological factors and the development of disease forecasting models. Disease forecasting models should be introduced at region level by keeping in view ecological conditions. It has been detected that introduction of new pathogenic starins has been blamed for the withdrawal of varietal resistance to *Colletotrichum gleosporioides*. Work on pathotyping should be done because of complex and diverse nature of pathogen. There are pathogenicity variations in pathogen that's why my hypothesis is that enhancing the resistance of mango to the *Colletotrichum gleosporioides* is very important to be the foremost economical and effective approach for controlling this disease. 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. Briefly, an intense genome project on this pathogen is urgently needed.

Novelty Statement

The data of current manuscript have not been copied from anywhere as it contains management tactics regarding mango anthracnose.

Author's Contribution

All authors have equally contributed in the preparation of manuscript.

Conflict of interest

The authors have declared no conflict of interest.

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