Review Article

POST-HARVEST ANTHRACNOSE OF MANGO CAUSED BY *COLLETOTRICHUM GLOEOSPORIOIDES*: A REVIEW

Abstract

Mango (*Mangifera indica* L.) is an edible stone fruit is most widely grown in tropical and sub-tropical regions. It is been cultivated in south Asia around 4000 years. The genus *Mangifera* consists totally 49 species, but only 41 species are considerable one. Mango is the most cultivable and important fruit around the world especially in India. Since ages, the people from ancient India describe mango tree as 'Kalpavriksha' which means wish granting tree. Mango is the eight most important fruit crop grown throughout the world which it contains the nutritive values, minerals, vitamins and dietary fibers in it. Mango is a highly perishable due to climacteric nature of the fruit, it produces high amount of ethylene which is known as 'Ripening hormone'. However, the fruit quality and commercialization were drastically reduced by anthracnose of mango incited by *Colletotrichum gloeosporioides;* it causes the post-harvest losses about 35 to 40 percentage so it is a major post-harvest disease of mango. Many pre-harvest and post-harvest management practices have been practiced to control mango anthracnose including chemical methods. This review summarizes an overview on exhibiting of disease, the factors influencing them and the recent management approaches to sustain the fruit quality and maintain the supply chain of mango.

Keywords: Mango, Anthracnose, Post-harvest, *Colletotrichum gloeosporioides,* Integrated Disease Management.

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1. Introduction

Mango (*Mangifera indica* L.) is popularly called as "King of fruits". It is a most popular leading commercial horticultural fruit crop grown in India. Mango is a dicotyledonous plant belongs to the order Sapindales and in the family Anacardiaceae. It is a climacteric horticultural fruit crop which is widely grown in the regions of tropics as well as in sub tropics [1]. Mango was originated from south east Asia mainly in Indo Burmese region. It is been reported the chromosome of mango to be $2n = 2x = 40$ and $n = 20$ as well the mango is believed to be an

allopolyploid [2]. Mango is known to be the most important tropical fruit crop of Asia widely cultivated in more than 87 countries. India, China, Thailand, Indonesia, Philippines, Pakistan and Mexico are predominant mango producing countries [3]. The leading exporter of mango is Thailand, importer is China, producer is India and the worldwide production was 54.73 mt tons as of 2021. Most is highly consisting of vitamin C, vitamin A, vitamin B6, fibers as well as Mango is known to be a gradient source ascorbic acid, ß-carotene, thiamine and niacin [4]. India is the largest producer of mango in the world. India producing 20 million tons of mango annually and it produces 40.48% of the total world mango production**.** Mango is highly susceptible to diseases caused by plant pathogenic microbes because of rich in nutrients as well water that provide an ideal source for the growth and development of pathogenic microbes. This led to the reducing in the quality of mango, during the period of post-harvest it's leading to high cause of economic loss niacin [5]. Mango is highly susceptible to post-harvest attack of various plant pathogenic organisms leads to heavy economic loss [6]. The various pathogens viz., anthracnose, stem end rot, aspergillus rot and rhizopus rot [7]. In fruits and vegetables, during post-harvest period more than 50 % of damages are due to *Colletotrichum* species [8]. *Colletotrichum gloeosporioides* penz & sacc. The Anthracnose is one of the major latent infection in horticultural crops especially in mango the prominence of anthracnose is delayed onset of disease symptoms caused by the fungus in a crop is later devastating and leads to the post-harvest loss. This pathogen attack leaves and immature fruits as a latent infection later during the storage the lesion progressively appear. The Anthracnose attacks young fruits, flowers and twigs incase of mature fruits shows black sunken lesions during the storage period. The genus *Colletotrichum* is a large genus consisting a large number of major species that are among the most prevalent fungal pathogens cause disease in diverse tropical as well sub-tropical crops. Anthracnose affects nearly all mango cultivars cultivated in many tropical countries, primarily due to the prevalent high temperatures and humidity typical of tropical regions. The incidence of anthracnose in mango fruit reaches almost 100% during wet conditions [33]. The *Colletotrichum* was first reported by Tode [9] but it was there on the genus *Vermularia*. Corda [10] introduced the genus *Colletotrichum* and it was comprised "Coelomycetes" with a telomorphic stage of *Glomerella* [11]. The *Colletotrichum* genus consists of 200 fungal species, 15 species are more complex in causing diseases. In India, 20 different genera of fungi are known to be attack mango fruits during post-harvest period, among them *C. gloeosporioides* is most important disease-

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causing pathogen. Considering the above, this review paper which concentrates on the detailed studies and analyzes the recent advances and trends on *Colletotrichum* spp. in devastating pathogen to cause the disease by the conducive environmental conditions, pathogen morphology, post-harvest losses and integrated plant disease management to control as well reducing the post-harvest losses during storage period.

2. Pathogen diversity of mango anthracnose – *Colletotrichum spp.*

Several reports from India, the world's largest mango producer, highlight *C. gloeosporioides* as the primary causative agent of mango anthracnose. However, this may not always be accurate. *Colletotrichum gloeosporioides* sensu lato plays a pivotal role as a significant pathogen responsible for mango anthracnose on a global scale [34,35,36]. Additionally, in certain instances, *C. acutatum* sensu lato has been documented as being associated with mango anthracnose [34, 37]. By utilizing restriction analysis and ITS region sequencing, revealed diverse subgroups within *C. gloeosporioides* associated with mango anthracnose in India [36]. Pathogenicity tests demonstrated varying degrees of virulence among *C. gloeosporioides* isolates, suggesting the potential presence of multiple species causing the disease. Subsequent multigene phylogenetic analysis identified four phylogenetic species (*C. fragariae* sensu stricto, *C. fructicola*, *C. jasmine-sambac*, and *C. melanocaulon*) and five *Colletotrichum* lineages without designated species names associated with mango anthracnose in India [38]. Notably, none of the *Colletotrichum* isolates from mango samples grouped with *C. gloeosporioides* sensu stricto, aligning with earlier findings [39]. The study identifies 13 species associated with mango anthracnose, including *C. asianum, C. cliviicola, C. cordylinicola, C. endophytica, C. fructicola, C. gigasporum, C. gloeosporioides, C.karstii, C. liaoningense, C. musae, C. scovillei, C. siamense,* and *C. tropicale*. Among these, *C. asianum* and *C. siamense* emerge as the most prevalent, each constituting 30% of the total species. *Colletotrichum cordylinicola, C. endophytica, C. diaspora, C. liaoningense,* and *C. musae* were the initial *Colletotrichum* spp. reported in association with mango anthracnose [40].

List 1 : **casual organism for fruit crop**

Fruit Crop	**Reported casual organism**	**Country**	**References**

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Mango (*Mangifera indica*)	*C. gloeosporioides*	Panama	Rojas et al [12]
	C. gloeosporioides	Srilanka	Krishnapillai and Wijeratnam [13]
	C. gloeosporioides	Colombia	Pardo-De la Hoz et al [14]
	C. gloeosporioides	South china	Li et al [15]
	Colletotrichum spp.	Brazil	Lima et al [41]
	Colletotrichum spp.	Sri Lanka	Krishnapillai et al. [42]
	Colletotrichum spp.	Sanya City and other areas of China	Tarnowski et al [43] and Nascimento et al [44]
	Colletotrichum spp.	South Africa	Sharma et al [45]
	Colletotrichum spp.	Malaysia	Latiffah et al [46]
	Colletotrichum spp.	Taiwan	Wu et al [47]
	Colletotrichum spp.	Mexico	Tovar-Pedraza et al [48]
	Colletotrichum spp.	Philippines	Alvarez et al [49]
	Colletotrichum spp.	Indonesia	Benatar et al [50]

Phylogenetic analysis, primarily relying on internal transcribed spacer (ITS) sequences, reveals that *C. gloeosporioides* encompasses diverse groups or species sub-populations, suggesting the potential involvement of other *Colletotrichum* species in mango anthracnose [36][51]. Conversely, various studies indicate that *Colletotrichum* isolates obtained from mango may represent pathogenically and genetically distinct populations within *C. gloeosporioides* [52][53]. The *C. gloeosporioides* population affecting mango exhibits a restricted host range and demonstrates high virulence exclusively towards mango. As of now, mango anthracnose is linked to 17 *Colletotrichum* species globally. The application of multiple markers in phylogenetic analysis suggests the possibility of discovering additional species in mango-producing regions around the world [54].

3. Anthracnose of mango: A challenge for agriculture-food sector

Anthracnose of mango is one of the devastating pathogen during the post-harvest period. In case of anthracnose infection, it is due to the latent or quiescence of the pathogen [16], the infection initially occurs in field *viz*., inflorescence, twigs, young fruits but the highest impact is during the post-harvest period of mango, it causes up to 40-50 % of loss of yield loss in mature mango

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fruits. Anthracnose is seviour, in case of climacteric fruits as of mango is a best example for climacteric fruit, since the ripening induces the biochemical and physical changes which provides the suitable conducive conditions for the growth and development of a pathogen. In India, more than 25% of mangoes are spoiled due to the lack of proper post-harvest management techniques. So thus, the main motive of this study is detailed cause of anthracnose disease plays an evident role in post-harvest period [17].

3.1 Epidemiology: A post-harvest condition favors anthracnose of mango

The disease development is not always depending on the presence of the pathogen on the source but it also depends on the conducive environmental factors and proper storage management practices such as rainfall, humidity and temperature which also influencing the disease epidemic [18]. Fruits usually appear fresh and diseased free at the time of harvest the pathogen usually quiescent or latent but during the post-harvest while it's ripening it shows the anthracnose symptoms on mature fruits. Initially the pathogen infects non wounded, green immature fruits in the field condition. Later at the time of post-harvest, the conducive environmental conditions are the high temperature as well as the relative humidity [15]. The anthracnose pathogen is established at the following conducive factors, RH as low of 95% it favors for the spore germination and it produces appressorium at the temperature of 20- 25 degree Celsius then formation of penetration peg highest at the temp of 25 degree Celsius. Then optimum temperature for the production of conidia is between 25 to 30 degrees Celsius as well with the free available high moisture. The spores are released free from the acervuli when there is the high moist condition occurs. The severity of anthracnose of mango is high at the temperature of 25 degree Celsius and RH of 100% whereas the fungi failed to establish the infection at the temperature and RH of 10 degree Celsius and 30% RH [18].

3.2 Disease cycle

Dissemination of the *Colletotrichum* conidia was passively dispersed through rain splash or irrigation water. At the time of Inoculation, Conidia or spores are landed on the infection court such as leaves, panicles, branch terminals which it causes the Infection. In case of this it having two phases, on the first phase of infection is occurs in the young fruits or immature fruits. The germination of spore and cuticle epidermal penetration occurs in the young tissues. The second phase of infection, it begins when the climacteric fruits begin to ripening after the invasion of pathogen into the cuticle it remains quiescent once the fruits begin to ripen the pathogen

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development starts. Thereby it exhibits the symptoms on pre harvest and post-harvest phases. The Pre-harvest phase on immature fruits, it produces tear strain appearance and alligator skin development on the unripe mango fruits and at the time of post-harvest, in the storage period black sunken round to irregular lesions appear on the mature or ripening fruits. During storage, the environmental conditions like continuous rain as well the humid or moist condition favors the reproduction of a pathogen. On the symptomatic region of a tissue, it produces acervuli from that the dissemination of conidia happens. The pathogen survives as an inoculum in defoliated branch terminals and mummified flowers. It is spread through air borne conidia [19].

Fig.1

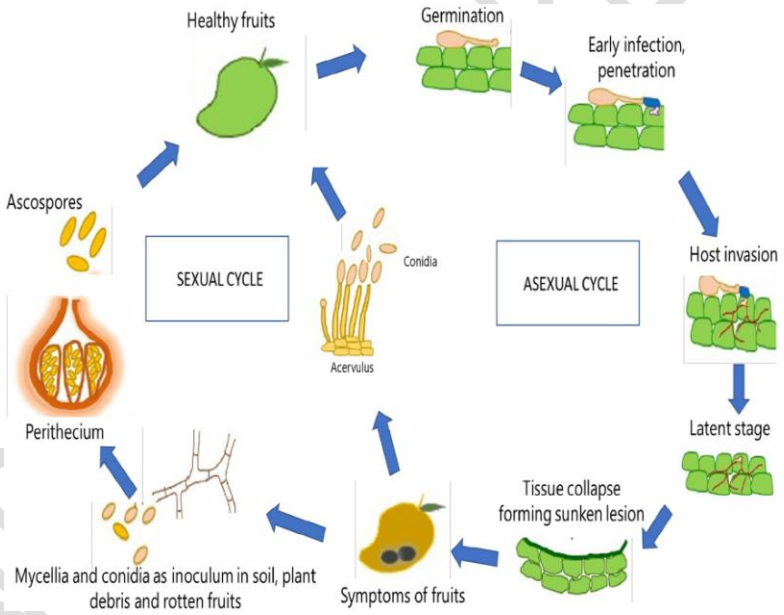

Fig. 1 Disease cycle of mango anthracnose. Picture courtesy [59]

3.3 Symptomatology

The *Colletotrichum gloeosporioides*, the name was first proposed in the year 1882 in Penzig, Poland. Anthracnose fungus, *Colletotrichum gloeosporioides* (perfect stage: *Glomerella cingulata*) [20]. *C. gloeosporiodes* is responsible for major fruit infection disease of subtropical and many tropical fruits later it was referred as anthracnose [21]. Anthracnose of mango, Initially

the first symptoms are exhibits in the field as a reddish brown to deep brown spots with various sizes spread all over the leaf later the spots enlarge which forms ‘shot hole’ appearance and it killed the whole inflorescence [22][23]. The young fruits are already infected in the field and it remains latent phase until ripening [17]. Beyond just the fruits, leaves, twigs, and flowers also fall victim to mango anthracnose. Observable leaf symptoms manifest as black necrotic spots with irregular shapes on both leaf surfaces. Similar symptoms can manifest on twigs and flowers, with these black necrotic spots potentially merging to create larger infected areas. Ultimately, the infected tissues dry up, leading to the eventual death of the affected parts of the plant [34][20]. During the post-harvest, whole ripening, minute dark brown to black spots on the fruits becomes enlarges to form dark brown to black circular water-soaked soft sunken lesions on fruits exceeds to 2 cm. Later Lesions with various sizes can coalesce together and cover considerable areas of the fruit, typically developing tear skin from the base towards the end of the fruit [20]. But in severe cases, apart from the peel which was restricted it even penetrate in the pulp of the fruit as well as it produces acervuli, with orangish to salmon pinkish mass of conidia arise on the lesions [24]. Fig.2

Fig. 2 Post – harvest symptoms of mango anthracnose

3.4 Post-harvestmanagement approaches

The post-harvest disease on fruits is radiantly controlled by adopting effective pre- and post-harvest management practices. In mango diseases, especially the anthracnose of mango causes the major storage loss and losing in market price. By reducing the anthracnose of mango,

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efficient integrated pre-and post-harvest management practices are achieved [25]. After the harvest, the quality of fruits cannot be improved but it can be maintained wisely during storage [26].

3.4.1 Resistant cultivars

Use resistant varieties for anthracnose of mango like Nariayal and Chenna-Swarnarekha and moderately resistant varieties are K.B. Karel, Maharaja of Mysoor, Sona Kullu, Banarasi Betali, Neelum×YoraMalgoa [25].

3.4.2 Cultural control

First to practice a proper sanitation of field and storage go downs to reduce the disease incidence. High wetness and relative humidity favors for the pathogen growth, development. If this condition prolongs it begins its reproductive phase for the dispersal and survival [27]. The rainy season highly favors for C. *gloeosporioides* development so, develop a mango orchard in the dry area prevailing during the flowering and fruit formation period. Maintain proper spacing, pruning of trees and intercropping with other type of trees [16]. In case of post-harvest condition, store the harvested mangoes in the sanitized, dry aerated places and refrigerate keep at 10-12°C [1]. The fruit development occurs at the dry season, the anthracnose occurrence will be almost zero (0) [20].

3.4.3 Time of harvesting

The harvested immature and over matured mangoes are highly susceptible for various pathogen attacks. The harvesting time plays an important role in pathogen incidence, the mature fruits are harvest at which attains some criteria's viz., fruit size, proximal shoulder development, skin color, sugar content. If the fruits are harvested at the proper time which guarantee the minimal disease incidence. Harvesting the mango fruits immediately after rain which provokes the pathogen attack so avoid the harvest after rain [23].

3.4.4 Physical methods

Hot water treatment: HWT is a non-chemical effective treatment to control mango anthracnose. Hot water dip of fruits for 15- 20 minutes at 53–55°C, application of hot water dip without the waxing of fruits causes the shriveling of fruits due to the destruction of natural wax [23]. The temperature above 55°C cause scalding of mango peel and below the temperature 52 ºC is not effective against the anthracnose pathogen [28]. Forced dry air and vapor heat: application of dry air heat for 3–6 hours at different temperatures, depending on the mango variety [16]. Cold

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plasma technology represents an alternative method for inhibiting anthracnose pathogens in tropical fruit. Cold plasma refers to a partially ionized gas, wherein a small subset of atoms and molecules undergo ionization through electrical discharges at atmospheric or sub-atmospheric pressure [55][56]. Research utilizing cold plasma technology has been conducted on food and feed contaminated with spoilage and mycotoxigenic fungi, yielding promising outcomes [56].

3.4.5 Biological methods

Globally fungicide treatments are not welcoming instead of people are looking forward to eco-friendly and non-residual management practice is biological control. *Bacillus licheniformis* and *Candida oliophila* are used as a fruit protectant against anthracnose of mango [29]. *Trichoderma asperellum* used as an antagonistic against the mango anthracnose [30]. Yeasts, which are unicellular fungi, possess various traits that render them attractive as biocontrol agents. They exhibit rapid growth on a diverse range of substrates, boast a high reproductive rate, and have straightforward nutritional requirements. Additionally, yeasts are non-mycotoxigenic and can thrive in high-sugar environments [57][58]. Other applications like essential oils like., mustard oil, lemon oil, basel oil at 150 ppm are used to reduce the *C. gloeosporioides* on mango [31]. The rising demand for anthracnose control methods that are chemical-free or involve reduced chemical usage has prompted the exploration of alternative, consumer-safe approaches. Examples include the development of safer methods such as edible coatings made from chitosan and essential oils. Additionally, Generally Recognized as Safe (GRAS) salt treatments, nanomaterials, and cold plasma technology have been subjects of investigation. Frequently, these alternative strategies are employed in combination to achieve more effective inhibition of anthracnose pathogen growth and a reduction in disease severity.

3.4.6 Chemical methods

The another alternative and most efficient method is chemical based control the fungicide thiabendazole (TBZ) benzimidazole group of fungicide is add to wash water at a conc. of 400 ppm to prevent mango anthracnose. The other some post-harvest dip fungicides such as propineb, difenoconazole, prochloraz, Carbendazim are recommended to control mango anthracnose [32].

4. Conclusion

This literature has reviewed the overview on pathogen morphology, pathogen growth and development, symptom production, post-harvest management practices of anthracnose of mango.

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This chapter provides aninteresting finding on the environmental factors and management practices which can reduces the disease incidence. Recent approaches in postharvest disease, that consists of regulatory, biological, physical, chemical management methods. Nowadays, IDM (Integrated disease management) practices is the highly suggested strategy to reduce the residual effect and protecting the consumer health by gradually increasing the eco- friendly practices rather than using chemical methods, even though the chemical practices give a drastic protection but it leaves anaberrant residual effect in fruits. The predominant preharvest and postharvest practices which provides a sensible manipulation that increases the quality retention and reduce the disease incidence during the supply chain.

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