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Post Harvest Anthracnose of Mango Caused by *Colletotrichum gloeosporioides*: A Review

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Authors' contributions

This work was carried out in collaboration among all authors. Authors SJ, AP, RL and KB conducted an extensive literature review, synthesized existing research findings, and critically analyzed relevant studies to provide a comprehensive overview of the topic. Additionally, the author contributed to the conceptualization, drafting, and revision of the manuscript, ensuring its accuracy and coherence. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Mango (*Mangifera indica* L.) is an edible stone fruit 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. Mango is the most cultivated and important fruit around the world especially in India. Since ages, the people from ancient India describe mango tree

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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. Mango is 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 the fungus anthracnose incited by *Colletotrichum gloeosporioides;* it causes the post-harvest losses of about 35 to 40 percentage, becaming 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 this disease, the factors influencing them and the recent management approaches to sustain the fruit quality and maintain the supply chain of mango.

Keywords: Tropical fruit; pathogen diversity; epidemiology; disease cycle; symptomatology; integrated disease management.

1. INTRODUCTION

Mango (*Mangifera indica* L.) is popularly known as "King of fruits". It is the most popular leading commercial horticultural fruit crop grown in India. Mango is a dicotyledonous plant belonging 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 reported that the chromosome of mango is $2n = 2x = 40$ 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, among them India, China, Thailand, Indonesia, Philippines, Pakistan and Mexico as the predominant mango producing countries [3]. The leading exporter of mango is Thailand, and the main importer is China; the biggest producer is India. The worldwide production in 2021 was 54.73 metric tons. Mango is rich in vitamin C, vitamin A, vitamin B6, fibers as well as known to be a gradient source ascorbic acid, ß-carotene, thiamine and niacin [4]. India is the largest producer of mango in the world. The country produces 20 million tons of mango annually, representing 40.48% of the total world mango production**.** However, mango is highly susceptible to diseases caused by plant pathogenic microbes favoured by the rich nutrients compound as well as water that provide an ideal source for the growth and development of pathogenic microbes. This fact led to the reducing the quality of mango, during the period of post-harvest, leading to a high cause of economic loss niacin [5]. Mango is highly susceptible to post-harvest attack of various plant pathogenic organisms, leading to heavy economic losses [6]. There are various pathogens attacking mango, among them anthracnose caused devastating problem in export industry [7]. In fruits and vegetables, during post-harvest period more than 50% of disease damages are due to *Colletotrichum* species [8] as *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. But it is a later devastating disease, leading to serious 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. In case of mature fruits shows black sunken lesions during the storage period. The genus *Colletotrichum* is a large genus consisting of a large number of major species that are among the most prevalent fungal pathogens causing disease in diverse tropical as well as sub-tropical crops. Anthracnose affects nearly all mango varieties 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 [8]. The *Colletotrichum* was first reported by Tode [9], initially known as 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, among them 15 species are more complex in causing diseases. In India, 20 different genera of fungi are known to be attacking mango fruits during post-harvest period, among them the *C. gloeosporioides* is most important disease-causing pathogen. The paper aims to explore various aspects of *Colletotrichum* spp., including morphology and pathogen diversity. It may investigate factors such as the conducive environmental conditions that promote the growth and spread of this pathogen. Understanding these conditions is crucial for developing strategies to manage and control the disease it causes. Furthermore, the paper seems to address the fact that understanding these post-harvest losses is important for developing effective storage practices and preventing economic losses in agriculture. The mention of integrated plant disease management indicates that the paper explores holistic approaches to control *Colletotrichum* spp. This could involve combining various strategies, such as biological control, chemical treatments, and cultural practices, to manage the pathogen effectively. This implies that the findings and recommendations from the review may be used to develop practical solutions or guidelines to minimize the impact of *Colletotrichum* spp. on stored crops.

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 [12,13]. Additionally, in certain instances, *C. acutatum* sensu lato has been documented as being associated with mango anthracnose [12] [14]. By utilizing restriction analysis and ITS region sequencing, revealed diverse subgroups within *C. gloeosporioides* associated with mango anthracnose in India [13]. 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 [15]. Notably, none of the *Colletotrichum* isolates from mango samples grouped with *C. gloeosporioides* sensu stricto, aligning with earlier findings [16]. 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 [17].

Phylogenetic analysis, primarily relying on internal transcribed spacer (ITS) sequences, reveals that *C. gloeosporioides* encompasses diverse groups or species sub-populations,

Table 1. Casual pathogenic organism among *Colletotrichum* attacking fruit crop

Fruit Crop	Reported casual organism	Country	References
Mango (*Mangifera indica*)	*C. gloeosporioides*	Panama	Rojas et al. [18]
	C. gloeosporioides	Srilanka	Krishnapillai and Wijeratnam [19]
	C. gloeosporioides	Colombia	Pardo-De la Hoz et al. [20]
	C. gloeosporioides	South china	Li et al. [21]
	Colletotrichum spp.	Brazil	Lima et al. [22]
	Colletotrichum spp.	Sri Lanka	Krishnapillai et al. [23]
	Colletotrichum spp.	Sanya City and other areas of China	Tarnowski et al. [24] and Nascimento et al. [25]
	Colletotrichum spp.	South Africa	Sharma et al. [26]
	Colletotrichum spp.	Malaysia	Latiffah et al [27]
	Colletotrichum spp.	Taiwan	Wu et al. [28]
	Colletotrichum spp.	Mexico	Tovar-Pedraza et al. [29]
	Colletotrichum spp.	Philippines	Alvarez et al. [30]
	Colletotrichum spp.	Indonesia	Benatar et al. [31]

suggesting the potential involvement of other *Colletotrichum* species in mango anthracnose [13,32]. Conversely, various studies indicate that *Colletotrichum* isolates obtained from mango may represent pathogenically and genetically distinct populations within *C. gloeosporioides* [33, 34]. The *C. gloeosporioides* population affecting mango exhibits a restricted host range and demonstrates high virulence exclusively towards mango. Upto 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 [35].

3. ANTHRACNOSE OF MANGO: A CHALLENGE FOR AGRICULTURE-FOOD SECTOR

Anthracnose of mango is one of the most devastating pathogen during the post-harvest period. In case of anthracnose infection, it is due to the latent or quiescence of the pathogen [36]. The infection initially occurs in the 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 yield losses in mature mango fruits. Anthracnose disease is seviour; in the case of climacteric fruits as mango, being the best example for climacteric fruit, since the fruit 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 to describe the detailed cause the anthracnose disease plays as an evident role in post-harvest period [37].

3.1 Epidemiology: The Post-harvest Condition Favors Anthracnose Attack of Mango

The disease development is not always dependent of 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 influence the disease epidemic [38]. Typically, fruits are free from diseases at the time of harvest as pathogens are usually quiescent or latent state. However, during storage and ripening, mature fruits may exhibit symptoms of anthracnose. 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 high relative humidity-RH [21]. The anthracnose pathogen is established at the following conducive factors, RH of 95% at least it favors for the spore germination and it produces appressorium at the temperature of 20-25ºC. Then the formation of penetration peg is highest at the temperature of 25ºC Celsius. The optimum environment conditions are: temperature for the production of conidia is between 25 to 30ºC and free available high moisture. The spores are released free from the acervuli under high moist condition. The severity of anthracnose on mango is highest at the temperature of 25ºC and RH of 100% whereas the fungi failed to establish the infection at the temperature of ≤ 10ºC and ≤ 30% RH [38].

3.2 Disease Cycle

In terms of dissemination of the *Colletotrichum,* the conidia were 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 where it causes the infection. The *Colletotrichum* development has two phases: a) The first phase of infection occurs in the young fruits or immature fruits. The germination of spore and cuticle epidermal penetration occurs in the young tissues; b) The second phase of infection, begins when the climacteric fruits begin to ripen after the invasion of the pathogen into the cuticle. It remains quiescent once the fruits begin to ripen and the pathogen development starts. Thereby it exhibits the symptoms on pre harvest and post-harvest phases. The Pre-harvest phase on immature fruits, 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, favor the reproduction of the pathogen. On the symptomatic region of the 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 [39]. (Fig.1).

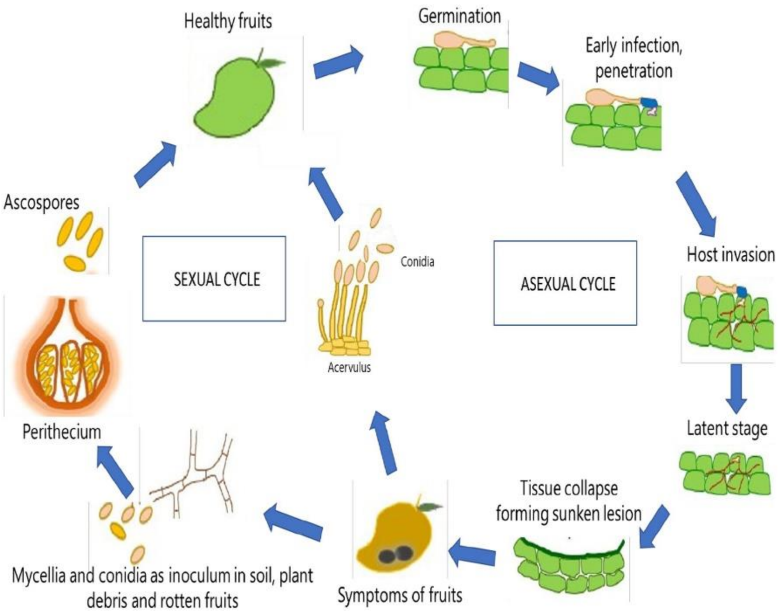

Fig. 1. Disease cycle of mango anthracnose. Picture courtesy [57]

3.3 Symptomatology

The name of *Colletotrichum gloeosporioides*, was first proposed in 1882 in Penzig, Poland [40] as Anthracnose fungus, genus *Colletotrichum gloeosporioides* (perfect stage: *Glomerella cingulata*) [41]. This fungus, (*C. gloeosporiodes*) is responsible for a major fruit infection disease of subtropical and many tropical fruits species, later referred to as anthracnose [42]. The first symptoms of anthracnose on mango are exhibits, initially 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 killing the whole inflorescence [40,43]. The infection of the fungus occurs in young fruits in the field and it remains in latent phase until ripening [37]. Beyond 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 be manifested 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 [12,41]. Initially, small, dark brown to black spots appeared on fruits; later, these markings underwent gradual enlargement during post-harvest ripening. Eventually, they transform into circular, water-soaked lesions, presenting as dark brown to black, soft, and sunken areas on the fruit, frequently surpassing 2 cm in diameter. Later, the 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 [41]. 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 [44]. (Fig.2).

3.4 Post-harvest Management 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 losses, negatively affecting market price. To reducing the anthracnose of mango, efficient integrated pre- and post-harvest management practices should be achieved on Johnson & Hofman (2009) [45]. After the harvest, the quality of fruits cannot be improved but it can be maintained wisely during storage [46].

3.4.1 Resistant cultivars

Nariayal and Chenna-Swarnarekha are varieties resistant to mango anthracnose, and K.B. Karel, Maharaja of Mysoor, Sona Kullu, Banarasi Betali, Neelum×YoraMalgoa are moderately resistant varieties [45].

Fig. 2. Post – Harvest symptoms of mango anthracnose

3.4.2 Cultural diseases control of mango

Implementing effective sanitation practices in both the field and storage facilities is crucial for minimizing disease incidence. High wetness and high temperature favors for the pathogen growth and development. If this condition prolongs, the disease begins its reproductive phase for the dispersal and survival [46]. A rainy season highly favors *C. gloeosporioides* development. So, development of mango orchards in dry areas prevail this disease during the flowering and fruit formation period. Maintaining proper spacing, pruning of trees and intercropping with other type of trees [47]. In case of post-harvest condition, store the harvested mangoes in the sanitized, dry aerated places and refrigerate keep at 10-12°C [45]. The fruit development occurs at the dry season, the anthracnose occurrence will be almost zero (0) [41].

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. Harvesting fruits at the optimal time ensures minimal disease incidence. Harvesting the mango fruits immediately after rain, which provokes the pathogen attack so avoid the harvest after rain [40].

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 [40]. The temperature above 55°C cause scalding of mango peel and below the temperature 52 ºC is not effective against the anthracnose pathogen [48]. Forced dry air and vapor heat: application of dry air heat for 3–6 hours at different temperatures, depending on the mango variety [48]. Cold 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 [49, 50]. Research utilizing cold plasma technology has been conducted on food and feed contaminated with spoilage and mycotoxigenic fungi, yielding promising outcomes [50].

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 [51]. The utilization of *Trichoderma asperellum* as an antagonistic organism has proven effective in combating mango anthracnose [52]. 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 [53,54]. Other applications like essential oils like., mustard oil, lemon oil, basel oil at 150 ppm are used to reduce the *C. gloeosporioides* on mango [55]. 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 [56,57].

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. 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 pre-harvest and postharvest practices, which provides a sensible manipulation of disease control strategies that increases the quality retention and reduce the disease incidence during the supply chain of mango.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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