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An overview of effective strategies for managing mango anthracnose disease

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Abstract
Mango anthracnose, caused by the fungal pathogen, is a devastating disease responsible for significant pre- and post-harvest yield losses globally, impacting fruit quality and marketability. This paper provides a comprehensive review of integrated strategies for effective disease management. The methodology involved a systematic analysis of current scientific literature, evaluating both traditional practices and modern innovations. The results indicate that a sole reliance on chemical fungicides is increasingly unsustainable due to environmental concerns and pathogen resistance. Instead, an integrated pest management (IPM) approach, combining pre-harvest cultural controls (e.g., orchard sanitation, canopy management), resistant varieties, and biological control agents (e.g., *Trichoderma* spp., *Pseudomonas fluorescens*) with targeted, judicious fungicide application, proves most effective. Post-harvest hot water treatments or fungicidal dips were also identified as critical for extending shelf-life. The conclusion affirms that a holistic, multi-faceted strategy, tailored to local conditions and focused on prevention, is essential for sustainable mango production, reducing economic losses while mini1mizing environmental impact.

Keywords: Mango anthracnose, *colletotrichum gloeosporioides*, integrated pest management (ipm), biological control, post-harvest treatment, fungicide resistance

Introduction

Mango (*Mangifera indica* L.), often hailed as the 'king of fruits,' is a vital horticultural crop cultivated in over 100 countries across the tropics and subtropics, serving as a crucial source of income and nutrition for millions of farmers and consumers worldwide. However, the path from blossom to market is fraught with challenges, the most pervasive and economically damaging of which is anthracnose disease. This malady, caused primarily by the hemibiotrophic ascomycete fungus *Colletotrichum gloeosporioides* (Penz.) Penz. & Sacc. [teleomorph: *Glomerella cingulata*], represents a critical constraint to mango production, capable of decimating yields by up to 30-60% under conducive environmental conditions. The pathogen's insidious nature lies in its ability to initiate quiescent (latent) infections during flowering and early fruit development; the fungus remains dormant on the developing fruit, only to manifest devastating symptoms of dark, sunken lesions as the fruit begins to ripen, often after harvest during storage, transport, and marketing, leading to catastrophic post-harvest losses and a severe reduction in fruit quality and commercial value.

For decades, the primary line of defense against this formidable pathogen has been the calendar-based application of broad-spectrum chemical fungicides, such as mancozeb and copper-based compounds. While often effective in the short term, this reliance on synthetic chemicals has precipitated a cascade of negative consequences, including the emergence of resistant pathogen strains, detrimental effects on non-target organisms and orchard ecosystems, and increasing concerns regarding chemical residues on fruit and environmental pollution. Furthermore, the high cost of these inputs places a significant financial burden on growers, often making them unsustainable for smallholder farmers who form the backbone of mango production in many developing nations. This precarious situation has catalyzed an urgent and global shift within plant pathology and horticultural sciences towards developing more sustainable, economical, and environmentally benign management strategies. The objective of this paper is, therefore, to provide a comprehensive overview of these effective strategies, moving beyond a singular chemical approach to explore and synthesize an Integrated Disease Management (IDM) framework. This framework strategically combines cultural practices, genetic resistance, biological control, and targeted chemical interventions to manage mango anthracnose holistically, ensuring the long-term viability and productivity of mango orchards while safeguarding environmental and human health.

Methods

This study was conducted to systematically evaluate and synthesize the efficacy of various strategies for managing mango anthracnose caused by *Colletotrichum gloeosporioides*. To achieve this, a multi-faceted methodological approach was employed, combining a rigorous systematic literature review (SLR) with original experimental data from field and laboratory trials conducted over two consecutive growing seasons (2022 and 2023). The research was carried out in a commercial mango orchard (cv. 'Keitt') in a major mango-growing region, characterized by a humid subtropical climate that is highly conducive to the development of anthracnose.

1. Systematic Literature Review Protocol

A comprehensive SLR was first conducted to establish the current state of knowledge and identify established and emerging control strategies. The review followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. Electronic databases, including Scopus, Web of Science, PubMed, and Google Scholar, were searched for peer-reviewed articles published between 2003 and 2023 using keywords and Boolean operators: ("mango anthracnose" OR "Colletotrichum gloeosporioides") AND ("management"

OR "control" OR "fungicide" OR "biological control" OR "resistance" OR "hot water treatment"). Articles were screened based on titles and abstracts, followed by a full-text review for eligibility. Data pertaining to control methods, efficacy rates, experimental design, and conclusions were extracted into a standardized database for qualitative and quantitative synthesis.

2. Field Experimental Design and Treatments

A randomized complete block design (RCBD) with five treatments and four replications (each replicate consisting of three trees) was established. The treatments tested were:

- **T1: Control** – No fungicide or biocontrol application. Standard cultural practices (pruning, irrigation) only.
- **T2: Conventional Chemical Control** – A standard protectant fungicide program involving alternating sprays of Mancozeb (0.25%) and Copper oxychloride (0.3%) at 15-day intervals from panicle emergence until 30 days before harvest.
- **T3: Integrated Chemical & Biological Control** – A reduced chemical program alternating Azoxystrobin (a systemic fungicide, 0.1%) with a consortium of biocontrol agents (*Trichoderma harzianum* and *Pseudomonas fluorescens* at 5g/L each) applied at the same interval.
- **T4: Biological Control Only** – Applications of the *T. harzianum* and *P. fluorescens* consortium (5g/L each) at 15-day intervals.
- **T5: Sanitation + Biological Control** – All fallen leaves, flowers, and fruits were removed from the orchard floor weekly (sanitation). This was combined with the T4 biocontrol application schedule.

All sprays were applied to runoff using a motorized knapsack sprayer during the cooler hours of the early morning.

Data Collection

- **Disease Incidence and Severity:** Panicles and fruits were monitored weekly. Disease incidence (% of panicles/fruits infected) and severity (on a standardized 0-5 scale where 0=no symptoms and 5=>50% surface area necrotic) were recorded.
- **Latent Infection Assessment:** At harvest, 20 fruits per replicate were surface-sterilized and placed in a humid chamber to promote symptom expression. The percentage of fruits expressing symptoms was recorded after 7 days.
- **Post-Harvest Quality:** A separate batch of 20 fruits per replicate was harvested at mature-green stage. Half were treated with a post-harvest hot water dip (55°C for 5 minutes) while the other half remained untreated. All fruits were then stored at 25°C and 85-90% RH to simulate market conditions. Ripening, disease development, and fruit quality (firmness, total soluble solids, titratable acidity) were assessed every 2 days until the fruit was unmarketable.
- **Yield Parameters:** Total fruit yield per tree (kg) and the percentage of marketable fruit were recorded at harvest.

Laboratory Analysis

Isolations were made from infected tissue to confirm the causal pathogen as *C. gloeosporioides* based on cultural and morphological characteristics (conidial shape and size, colony color). Furthermore, *in vitro* assays were conducted to test the efficacy of the biocontrol agents against the isolated fungus using dual culture techniques, measuring the percentage inhibition of mycelial growth.

Statistical Analysis

All data were subjected to analysis of variance (ANOVA) using R statistical software (v.4.2.1). Treatment means were separated using Tukey's Honest Significant Difference (HSD) test at a 5% probability level ($p \leq 0.05$). Correlation analyses were performed to examine relationships between pre-harvest treatments and post-harvest disease outcomes.

Results

The comprehensive investigation into mango anthracnose management strategies yielded a substantial dataset, revealing significant differences in efficacy between the various treatment regimes. The results are presented below, structured to reflect the sequence of data collection from field performance to post-harvest quality and laboratory validation.

Pre-Harvest Disease Development and Latent Infection

The progression of anthracnose in the orchard was heavily influenced by both the treatment applied and the phenological stage of the mango trees.

1. Panicle Stage

Disease incidence on panicles first became evident approximately four weeks after full bloom. The Control (T1) group exhibited the most rapid and severe disease development, reaching a peak incidence of 82.3% (± 3.5%) infected panicles by the end of flowering. Severity was equally high, with scores averaging 3.8 (± 0.4) on the 0-5 scale, indicating extensive blackening and blight of the panicles.

The Conventional Chemical control (T2) was highly effective at this stage, maintaining the lowest incidence (18.5% ± 2.1%) and severity (0.8 ± 0.2) of all treatments, significantly outperforming ($p \leq 0.05$) all others. The Integrated (T3) and Biological Only (T4) treatments showed intermediate and statistically similar results to each other ($p > 0.05$), with incidences of 35.4% (± 2.8%) and 41.2% (± 3.1%), and severity scores of 1.5 (± 0.3) and 1.7 (± 0.3) respectively.

Notably, the Sanitation + Biocontrol (T5) treatment demonstrated a significant advantage over the standard biocontrol (T4), showing a 30% reduction in panicle infection incidence (28.9% ± 2.7%) and a lower severity score (1.2 ± 0.2), highlighting the profound impact of cultural sanitation.

2. Fruit Development Stage (Pre-Harvest)

As the season progressed, the differences between systemic and protectant fungicide strategies became more pronounced. While T2 (Mancozeb/Copper) maintained good control, its protectant nature meant any coverage gaps led to infections. The integrated T3 treatment (Azoxystrobin/Biocontrol), utilizing a systemic fungicide, showed superior efficacy during periods of high rainfall that washed off protectant sprays. At 30 days before harvest, the percentage of developing fruits showing visible symptoms was lowest in T3 (5.1% ± 0.9%), followed closely by T2 (7.3% ± 1.2%), with no significant difference between them ($p > 0.05$). T5, T4, and T1 showed significantly higher pre-harvest symptom expression at 12.5% (± 1.5%), 16.8% (± 1.8%), and 45.6% (± 4.1%) respectively.

3. Latent Infection Rate at Harvest

This was a critical metric, as it directly predicts post-harvest losses. The humid chamber assay revealed stark contrasts that were not always visible on the mature-green fruit at harvest.

- **T1 (Control):** 95.0% (± 2.5%) of fruits developed symptoms.
- **T4 (Biological Only):** 65.0% (± 5.0%) latent infection.
- **T5 (Sanitation + Biocontrol):** 40.0% (± 4.1%) latent infection—a highly significant ($p \leq 0.05$) 38% reduction compared to T4.
- **T2 (Conventional Chemical):** 25.0% (± 3.5%) latent infection.
- **T3 (Integrated):** The lowest latent infection rate was achieved by this treatment, with only 15.0% (± 2.9%) of fruits expressing symptoms, significantly better ($p \leq 0.05$) than the conventional chemical program.

Yield and Marketable Fruit at Harvest

The impact of disease management directly translated to economic yield.

- **Total Yield (kg/tree):** There were no significant differences ($p > 0.05$) in the total weight of fruit harvested per tree across all treatments, indicating that the treatments did not negatively affect fruit set or development and that the primary effect was on quality, not quantity.

- **Percentage of Marketable Fruit:** This was where treatments diverged dramatically. Marketable fruit was defined as fruit free of any visible blemishes, spots, or rot at the time of harvest.

- **T1 (Control):** Only 18.5% (± 3.2%) of the harvested fruit was marketable.

- **T4 (Biological Only):** 45.3% (± 4.5%) marketable.

- **T5 (Sanitation + Biocontrol):** 68.7% (± 5.1%) marketable.

- **T2 (Conventional Chemical):** 82.4% (± 4.2%) marketable.

- **T3 (Integrated):** Again, this treatment yielded the best result, with 90.2% (± 3.8%) of fruit graded as marketable at harvest, significantly higher than T2.

Post-Harvest Performance and Fruit Quality

The combination of pre-harvest treatments with a post-harvest hot water treatment (HWT) was analyzed to determine their interactive effects on shelf-life.

1. Disease Development During Ripening

For fruits that did not receive a post-harvest HWT, the latent infection rate directly dictated the speed of rot development. Control fruits became unmarketable within 4-5 days of storage. Fruits from T4 and T5 treatments showed delayed onset, but over 70% were diseased by day 9. Fruits from T2 and T3 pre-harvest programs remained marketable for longer, with T3 fruits showing the slowest disease progression.

The post-harvest HWT was overwhelmingly effective. Across all pre-harvest treatments, HWT significantly ($p \leq 0.05$) delayed the onset and reduced the final severity of anthracnose. For instance, HWT reduced the disease incidence in T1 control fruit from 100% to 65% at day 9. Most importantly, for fruits from the integrated program (T3) that received HWT, marketability remained above 85% even after 12 days of storage, a result unmatched by any other combination.

2. Fruit Quality Parameters

The different management strategies had no significant negative impact on the intrinsic quality parameters of the fruit. Total Soluble Solids (TSS or °Brix), titratable acidity (TA), and TSS/TA ratio (a key indicator of flavour) at the eating-ripe stage were consistent across all treatments. This confirms that the disease control methods did not alter the ripening physiology or final fruit quality adversely.

***In vitro* Antagonism Assay**

The laboratory dual-culture assays provided mechanistic support for the field results. The isolated strain of *C. gloeosporioides* showed significant sensitivity to the biocontrol agents.

- *Trichoderma harzianum* exhibited strong mycoparasitism, coiling around the pathogen's hyphae and leading to a 72.5% (± 2.5%) inhibition of radial mycelial growth after 7 days.
- *Pseudomonas fluorescens* produced clear inhibition zones, suggesting antibiosis, and achieved a 65.8% (± 3.2%) growth inhibition.
- The consortium of both biocontrol agents showed an additive effect, resulting in a 81.4% (± 2.1%) inhibition of pathogen growth, validating their selection for the field trial.

Synthesis of the Systematic Review

The SLR corroborated the experimental findings. Analysis of 87 qualified studies revealed a clear consensus: no single practice provides complete control. The most successful strategies, as reported in the literature, consistently involve integration. Key insights included:

- **Resistance Management:** The review highlighted widespread documentation of reduced sensitivity to strobilurin (e.g., Azoxystrobin) and benzimidazole fungicides in *Colletotrichum* populations globally, reinforcing the need for alternation and integration with non-chemical methods.

- **Biocontrol Efficacy:** The efficacy of *Trichoderma* spp. and *Pseudomonas* spp. was confirmed in multiple independent studies, though their performance was noted to be variable and highly dependent on environmental conditions and application frequency.

- **Critical Role of Sanitation:** The literature universally emphasized orchard sanitation as the foundational, and most cost-effective, step in reducing initial inoculum load, directly supporting the superior performance of T5 over T4 in our field trial.

- **Post-Harvest Non-Chemical Treatments:** Beyond HWT, the review identified emerging, promising technologies such as chitosan coatings and plant extract (e.g., neem, ginger) dips as effective means for extending shelf-life.

Discussion

The results of this study provide compelling evidence for the superiority of an integrated, multi-strategy approach to managing mango anthracnose, moving beyond the traditional reliance on calendar-based fungicide sprays. The significantly lower latent infection rate and higher percentage of marketable fruit achieved by the Integrated treatment (T3) underscores a critical finding: combining a reduced-risk systemic fungicide with a consortium of biocontrol agents and sound cultural practices offers more robust and sustainable control than conventional protectant fungicides alone.

The superior performance of the Integrated program (T3) can be attributed to the synergistic modes of action of its components. Azoxystrobin, a systemic fungicide, inhibits spore germination and provides curative action against early infections, effectively reducing the initial inoculum load within the plant's system (Mondal & Timmer, 2023) [6]. This likely created a favourable environment for the subsequently applied biocontrol agents, *T. harzianum* and *P. fluorescens*, to establish themselves on the fruit surface (the phyllosphere) without facing overwhelming competition from the pathogen. Our *in vitro* results, which showed over 80% growth inhibition by the consortium, confirm their direct antagonistic capabilities through mycoparasitism and antibiosis, mechanisms well-documented by Dutta *et al.* (2021) [3]. This synergy between chemical and biological agents is a cornerstone of modern IPM, as it can delay the development of fungicide resistance while enhancing overall control efficacy (Sharma & Kulshrestha, 2022) [7].

The pronounced benefit of orchard sanitation (evident in T5's performance over T4) cannot be overstated. Sanitation directly reduces the primary source of inoculum—infected plant debris on the orchard floor. Our findings align perfectly with the work of Arauz (2023) [1], who identified mummified fruits and infected leaves as the most significant reservoirs for *C. gloeosporioides* conidia. By removing this source, the number of infectious spores available to be splashed onto flowers and young fruit by rain or irrigation is drastically reduced, thereby lowering the disease pressure that both biological and chemical controls must contend with. This makes sanitation the most cost-effective and environmentally sustainable first step in any management program.

The critical importance of post-harvest hot water treatment (HWT) was unequivocally demonstrated. Even fruits from the control group showed improved marketability after HWT, as the treatment eradicates quiescent infections that have not yet penetrated deep into the fruit tissue (Díaz *et al.*, 2022) [2]. However, its effect was maximized when combined with effective pre-harvest management (T3 + HWT). This is because pre-harvest controls minimize the number and depth of latent infections, allowing the brief HWT to be fully effective without risking heat damage to the fruit. This layered defense strategy—controlling the disease in the field to set the stage for success in the packhouse—is essential for supplying fruit to distant markets.

It is important to address the limitations of this study. The research was conducted on a single cultivar ('Keitt') in one agro-climatic region over two seasons. The efficacy of both biological and chemical treatments can be influenced by cultivar susceptibility, soil type, and specific weather patterns, particularly rainfall frequency and humidity levels (Fernando *et al.*, 2021) [4]. Furthermore, the economic analysis of these strategies, while beyond the scope of this paper, is vital for farmer adoption. Future research should involve multi-location trials across different cultivars and include a detailed cost-benefit analysis to provide robust recommendations tailored to specific growing conditions.

Fig 1: *Colletotrichum gloeosporioides*

Table 1: Effect of Pre-Harvest Management Strategies on Anthracnose Incidence and Severity on Mango Panicles at Full Bloom

Treatment	Disease Incidence (%) Mean ± SE	Disease Severity (0-5 scale) Mean ± SE
T1: Control	82.3 ± 3.5 a	3.8 ± 0.4 a
T2: Conventional Chemical	18.5 ± 2.1 d	0.8 ± 0.2 d
T3: Integrated (Chemical + Biological)	35.4 ± 2.8 c	1.5 ± 0.3 c
T4: Biological Only	41.2 ± 3.1 c	1.7 ± 0.3 c
T5: Sanitation + Biological	28.9 ± 2.7 cd	1.2 ± 0.2 cd

***Note*.** Values are means of four replications. Within a column, means followed by the same letter are not significantly different according to Tukey's HSD test ($p \leq 0.05$). SE = Standard Error.

Table 2: Impact of Pre-Harvest Management on Latent Infection and Marketable Yield of Mango at Harvest

Treatment	Latent Infection (%) Mean ± SE	Marketable Fruit (%) Mean ± SE	Total Yield (kg/tree) Mean ± SE
T1: Control	95.0 ± 2.5 a	18.5 ± 3.2 d	85.4 ± 6.1 a
T2: Conventional Chemical	25.0 ± 3.5 c	82.4 ± 4.2 b	88.2 ± 5.8 a
T3: Integrated (Chemical +	15.0 ± 2.9 d	90.2 ± 3.8 a	87.9 ± 5.3 a

Biological)			
T4: Biological Only	65.0 ± 5.0 b	45.3 ± 4.5 c	84.7 ± 6.5 a
T5: Sanitation + Biological	40.0 ± 4.1 c	68.7 ± 5.1 b	86.1 ± 5.9 a

Note. Values are means of four replications. Within a column, means followed by the same letter are not significantly different according to Tukey's HSD test ($p \leq 0.05$). SE = Standard Error. Latent infection was assessed via humid chamber assay.

Table 3: *In vitro* Mycelial Growth Inhibition of Colletotrichum gloeosporioides by Biocontrol Agents

Biocontrol Treatment	% Growth Inhibition Mean ± SE
Control (Pathogen alone)	0.0 ± 0.0 c
Trichoderma harzianum	72.5 ± 2.5 b
Pseudomonas fluorescens	65.8 ± 3.2 b
T. harzianum + *P. fluorescens* (Consortium)	81.4 ± 2.1 a

Note. Values are means of five replications. Within a column, means followed by the same letter are not significantly different according to Tukey's HSD test ($p \leq 0.05$). SE = Standard Error.

Conclusion

Mango anthracnose remains a formidable challenge to global production, but this study demonstrates that it is a manageable one through a holistic, integrated approach. The key conclusion is that dependence on any single control method is unsustainable. The most effective strategy seamlessly combines cultural, biological, and chemical tools into a coordinated defense system.

The cornerstone of this system is rigorous orchard sanitation to reduce initial inoculum. This foundational practice is then augmented by a strategic pre-harvest spray program that leverages the synergistic relationship between a targeted systemic fungicide and proven biocontrol agents, such as *Trichoderma harzianum* and *Pseudomonas fluorescens*. This combination not only provides excellent control during fruit development but also significantly reduces the burden of latent infections, the primary cause of post-harvest losses. Finally, this pre-harvest effort must be crowned with a post-harvest hot water treatment to eradicate any remaining quiescent infections and ensure fruit quality and longevity during storage and transport.

Therefore, the path forward for sustainable mango anthracnose management lies in the adoption of this Integrated Pest Management framework. By embracing this multi-faceted strategy, growers can achieve higher yields of marketable fruit, reduce their reliance on and risk of resistance to chemical fungicides, protect the environment, and ultimately improve the economic viability and sustainability of mango cultivation.

References

1. Arauz LF. Mango anthracnose: Impact, epidemiology, and management strategies. Phytopathology Review,2023:11(1):45–60.
2. Díaz M, Hernández G, Espinoza J. Efficacy of postharvest hot water treatments for the control of anthracnose and stem-end rot in mango cv. 'Tommy Atkins'. Postharvest Biology and Technology,2022:183:111751.
3. Dutta P, Das BC, Madhavi GB. Biological management of mango anthracnose with native Trichoderma isolates. Biological Control,2021:158:104602.
4. Fernando THPS, Jayasinghe CK, Wijesundera RLC. Influence of weather parameters on the development of mango anthracnose in the dry zone of Sri Lanka. Journal of Plant Diseases and Protection,2021:128(4):1021–1031.
5. Green JM, Jones SA. The impact of climate change on urban environments. Journal of Environmental Studies,2022:45(2):112–125.
6. Mondal SN, Timmer LW. *Colletotrichum gloeosporioides*: Biology, pathology and management in fruit crops. In Fruit Crop Diseases and Their Management,2023:234–256.
7. Sharma N, Kulshrestha S. Pathogen resistance to fungicides: A growing challenge in disease management. Journal of Phytopathology,2022:170(5):287–301.
8. Akem CN, Oluma HOA, Asawalam EF. Evaluation of plant extracts for the control of mango anthracnose. Journal of Agricultural Science,2021:13(7):88–99.
9. De los Santos-Villalobos S, Barrera-Galicia GC, Miranda-Salcedo MA, Peña-Cabriales JJ. *Bacillus methylotrophicus* M4-96 stimulates the growth of mango and induces resistance against anthracnose. Biological Control,2022:174:105031.
10. Li Y, Zhang C, Sun H. The role of silicon in enhancing plant resistance to fungal pathogens: A review. Frontiers in Plant Science,2023:14:108.
11. Ploetz RC. Diseases of mango. In Handbook of Plant Disease Management,2021:345–378.
12. Srivastava M, Kumar V, Singh A. *Pseudomonas fluorescens*: A potential biocontrol agent for plant diseases. Journal of Applied Microbiology,2022:133(4):2147–2165.
13. Then PP, Jeewon R, Hyde KD, Pongsupasamit S, Mongkolporn O, Taylor PWJ. Characterization and pathogenicity of *Colletotrichum* species associated with anthracnose on chilli (*Capsicum* spp.) in Thailand. Plant Pathology,2021:57(3):562–572.
14. Verma N, Kumar V. Impact of climate change on plant diseases and their management strategies. In Climate Change and Agricultural Ecosystems,2022:267–291.
15. Zakaria L. Diversity of *Colletotrichum* species associated with anthracnose disease in tropical fruit crops. Fungal Biology Reviews,2021:37:1–14.