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## Review Article

# Insights on Origins, Hosts, Impacts of Banana Anthracnose and its Management

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## ABSTRACT

Banana is a staple food of millions of people in almost all the tropical and subtropical regions of the world. The most critical factors affecting banana production are post-harvest diseases, which generally originate from the flowering to fruit maturity or at the time of harvesting and subsequent storage of fruits. The primary sources of such infection include superficial wounds during handling, leading to enormous economic losses. One major post-harvest pathogen is *Colletotrichum musae*, causing anthracnose, a pretty significant disease on banana fruits and other plant parts. The pathogen overwinters in plant residues, such as mycelia or sclerotia, produce acervuli that generate primary conidia. Conidia disseminated by rain infect the plant and initiate secondary infection cycles. However, it was mentioned that the growth and pathogenicity of *C. musae* were highly affected by the following environmental factors: pH and temperature. Moreover, the susceptibility of banana cultivars to anthracnose is varied, with resistant to highly susceptible cultivars. Besides prevailing environmental conditions that favor growth, knowledge of the disease cycle of *C. musae* becomes essential in devising effective management strategies to reduce post-harvest losses with disease-free bananas.

**Keywords:** Anthracnose, Banana, hosts, management, post-harvest.



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## INTRODUCTION

### Host

The banana fruit consists of several species belonging to the genus *Musa* of the family *Musaceae*, which is the staple food of millions of people cultivated in

tropical, subtropical countries (Anyasi et al., 2013). The primary cultivar “Cavendish” contributes 15% of the global production for export and the remaining 85% is obtained from locally grown cultivars (Aurore et al., 2009). Almost every part of the banana plant can be used, as antifungal and antibacterial properties are found in the peel and pulp. Kumar and Bhowmik (2012) documented using bananas for medicinal purposes, such as treating fever, acute dysentery and diarrhea, and insect stings.

#### **Importance of post-harvest diseases of fruits**

Post-harvest deterioration in fruits that leads to infections usually occurs at any stage: i) from flowering to fruit maturity and ii) from harvesting to storage. Surface wounds are the primary source of post-harvest infection during handling and processing (Eckert and Ogawa, 1985). It has also been observed that these losses have been minimized by applying fungicide in the field or after harvesting. Millions of dollars have been spent to overcome the post-harvest losses caused by microbial pathogens. Providing disease-free commodities is also a need of time Narayanasamy (2005). Post-harvest losses are higher in less developed countries due to a lack of proper facilities for storage, transport, and handling (Yonas and Amare, 2008). High production losses in fruits and vegetables in developing countries have been estimated (Food and Agriculture Organization [FAO], 1989).

#### **Causal agent of banana anthracnose**

*Colletotrichum musae* (Berk and Curt) Arx is one of the important pathogens causing crown rot, blossom-end rot, stem-end rot, and Anthracnose in bananas. Banana anthracnose is a devastating and widely distributed post-harvest disease (De costa, 2010; Tongsri and Sangchote, 2009). This fungus infects all parts of banana plants besides the banana fruits (Ploetz et al., 2003). Zakaria et al. (2009) isolated *C. musae* guava (*Psidium guajava*), which causes anthracnose disease. Both the isolates of *C. musae* from two different fruits were similar. Upon molecular characterization, both the isolates showed the same patterns in RAPD.

Srivastava and Lal (2009) observed incidences of post-harvest pathogens on major fruits during a survey in a fruit market in Allahabad. Among the 13 fungal species, *Rhizopusstolonifer* (20.76%) was isolated in abundance from different fruits. From the banana, *Colletotrichum musae* had (16.6%), *Fusarium sp* (28.3%), and *Curvularia* (23.39%) incidence. Other fungal species isolated were *Trichothecium sp*, *Penicillium*, *Alternaria*, and *Rhizopus*.

This work by Thangamani et al. (2020); explored the physiological and morphological characterization of *C. musae* on potato dextrose agar medium at various pH levels, temperature and light intensity under in vitro laboratory conditions. Maximum mycelial growth was seen at pH of 6.5 to 7 and temperatures of 25°C to 30°C, it found. Periods of light and dark were also associated with these conditions. Results indicate that optimal pH and temperature conditions must be maintained for controlling the growth of *C. musae*. Some of these environmental factors can be understood for agricultural practices and post harvest management and ways can be developed to curb fungal growth primarily by storage conditions and more effectively using resistant cultivars or fungicides to minimize post harvest losses.

In a study on the development of anthracnose and the effect of the exogenous pH on the development and growth of *C. musae* in several banana cultivars in Sri Lanka (De Costa and Chandima, 2014) studied. Results showed that Mondan (ABB) lacks Anthracnose. In contrast, Anamalu and Embon (AAA) reported as being highly susceptible to Anthracnose were desert cultivars. The authors reported that the pH of fruit peel exudates (FPE) and fruit pulp reduced with the ripening of the fruit. The highest pH of FPE was more significant than 6.0 at the mature-unripe stage for Seenikehel, Alukehel, and Mondan cultivars, whereas, at the ripe stage, the pH value was less than 4.5 for all cultivar types. It was also reported that an exogenous pH of 4.5 could be suitable for colonization using *C. musae* when the fruit was grown in culture media.

#### **Life cycle of *Colletotrichum* spp**

Sexual and asexual stages are part of the life cycle of *Colletotrichum* spp. Generally, genetic variability is linked to the sexual stage, while fungus dispersal is through the asexual stage. In nature, sexual recombination happens rarely in most *Colletotrichum* spp. Only eleven of twenty *Colletotrichum* spp. have *Glomerella* teleomorphs (Wharton and Diéguez-Uribeondo, 2004). In *Glomerella*, sexual reproduction is more complex than other most of the ascomycetes. Based on sexual reproduction, fungal species are classified as homothallic and heterothallic. However, both self and cross-fertility have been found within single species in some strains. Others are only cross-fertile (Chilton and Wheeler, 1949; Wheeler, 1954).

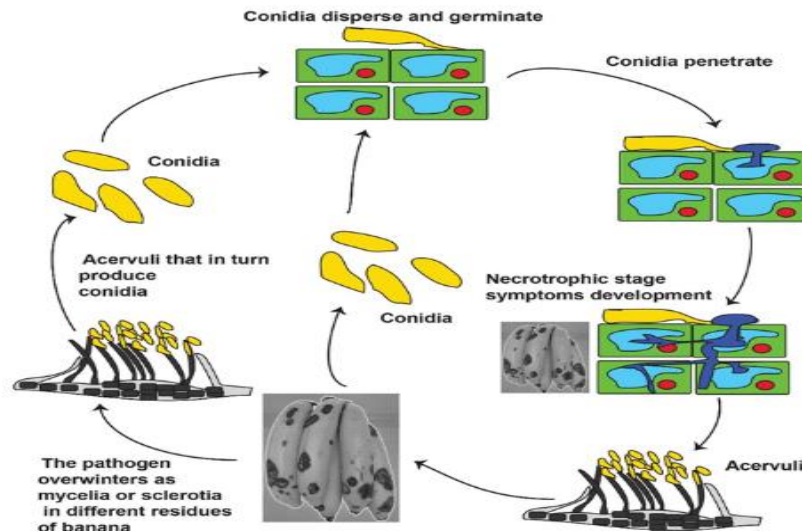


Figure 1. The disease cycle of *Colletotrichum*\* spp. on banana plants: The pathogen overwinters as mycelia or sclerotia in plant residues. These structures give rise to acervuli, which produce primary conidia. Rain disperses the conidia, leading to infections that form lesions on the plant. These lesions develop new acervuli, generating conidia responsible for secondary infection cycles.

### Host range and symptoms of Anthracnose of banana

Several crops like banana, Curcuma, and guava have been attacked by post-harvest disease caused by *C. musae* (Mahadatanapuk et al., 2007; Zakaria et al., 2009). This fungus is also pathogenic to apple, mango, avocado, and vigna sp. *C. musae* has been reported as one of the serious tropical diseases, especially Curcuma, in Thailand (Sutton and Waterston, 1970; Mahadatanapuk, 2005). Siam tulip, the best curcuma variety, is under attack from anthracnose disease, resulting in significant production losses (Holland, 1999). Severe losses in water yam production have also been severely affected by *C. musae* in the Caribbean, West Africa, and India. Ripening is stimulated due to infections; lesions run along with the ripening of fruits. Orange acervuli of *C. musae* develop, and brown spots are sunken on ripening fruits. (Stover and Simmonds, 1987). Spore masses are readily observed on overripe fruits. These spore masses are orange to salmon-pink, covering the typical brown lesions. Small circular, water-soaked, and sunken spots of size up to 1.2 cm can be seen on infected fruit. Pink spore masses come out from the older spots with blackish center. At maturity, the brown spots may increase in size and coalesce and covered with acervulli (Stover, 1972).

### GENERAL POST-HARVEST MANAGEMENT

Post-harvest management is critical in minimizing losses and maintaining the quality of bananas during storage and transportation. Faulty disease management and cultural practices followed by improper post-harvest handling leads (Nelson, 2008) to the banana anthracnose. Inefficient practices often lead to the proliferation of diseases like anthracnose caused by *Colletotrichum musae*, resulting in significant economic losses. Effective strategies combining chemical treatments, biological agents, and innovative techniques have been developed to control these pathogens and extend the shelf life of bananas. This section discusses various studies and approaches aimed at mitigating post-harvest losses.

Table 1. Summary of Studies on Post-Harvest Management and Control of Banana Anthracnose.

Study	Pathogens/Factors Studied	Methodology	Key Findings
Griffie and Burden (1974)	<i>C. musae</i> , <i>F. semitectum</i> , <i>N. sphaerica</i>	Pre-harvest benomyl sprays; post-harvest dip in benomyl (250 $\mu\text{g/ml}$ )	Controlled latent infections; crown rot remained unaffected.
Postmaster et al. (1997)	<i>C. musae</i>	Interaction with antagonistic microorganisms on banana	Infection reduction after 48 hours; no physical inhibition or hyphal degradation

		leaf discs	observed.
Ilyas et al. (2007)	<i>C. musae</i> , <i>A. tenuis</i> , <i>V. theobromae</i> , <i>B. theobromae</i>	Transport and storage study of bananas across regions	37â€“43% post-harvest losses; pathogens were pathogenic to injured and uninjured fruits.
Bokhari et al. (2013)	<i>C. musae</i>	UV-A, UV-B, and UV-C treatments in in vitro and in vivo bioassays	UV-C achieved complete inhibition after 45 minutes (in vitro) and 2 hours (in vivo).
Xueping et al. (2013)	<i>C. musae</i>	Benzothiadiazole (BTH) treatment (50â€“300 Åµg/ml)	Delayed ripening and controlled anthracnose at pre- and post-harvest stages.
Diedhiou et al. (2014)	<i>A. niger</i> , <i>A. flavus</i> , <i>Alternaria spp.</i> , <i>C. musae</i>	Dipping bananas in imazalil for 5 minutes	Reduced disease incidence and extended shelf-life.
Solgi et al. (2014)	Essential Oils (EOs)	Reviewed application of EOs for shelf-life enhancement	Approximately 300 EOs with antimicrobial properties are commercially important for horticultural crops.
Khleekorn et al. (2015)	<i>C. musae</i>	Antagonistic microorganisms ( <i>Pantoea agglomerans</i> , <i>Enterobacter sp.</i> ) application	Reduced anthracnose severity; weekly application before harvest was most effective.
Priyadarshanie and Vengadaramana (2015)	<i>C. musae</i> isolates	Fungicides Homai and Topsin; colony morphology studies	Complete inhibition of mycelial growth in in vitro tests.
Zhimo et al. (2017)	<i>C. musae</i>	Antagonistic yeast ( <i>Candida tropicalis</i> YZ27) treatment	Achieved 96% disease inhibition under ambient storage conditions.
Zhu et al. (2016)	<i>C. musae</i>	Benzothiadiazole (BTH) treatment for fruit ripening and disease control	Significantly delayed fruit ripening and lowered disease incidence.
Xueping et al. (2013)	<i>C. musae</i>	BTH (50-300 Åµg/ml) treatment; delayed ripening and disease incidence	BTH controlled anthracnose and delayed ripening in pre- and post-harvest stages.
Mohapatra et al. (2010)	<i>Post-harvest pathogens, ripening and shelf-life enhancement</i>	Pre-storage treatments: biological, chemical, and packaging modifications	Presented pre-storage techniques like biological and chemical treatments to enhance shelf-life.

### Plant Extracts

Plant extracts can replace synthetic fungicides to manage banana anthracnose disease (Thangavelu et al., 2004). Extracts of fifty plants were examined to monitor the antifungal activity against banana anthracnose. The results showed that *Solanum torvum* extract effectively reduced the occurrence of the disease when compared against a standard treatment. Additionally, shelf-life was prolonged by 16-20 days. The authors concluded that the application of *S. torvum* not only manages anthracnose but also increases the storage life of bananas.

Antifungal activities of three plant extracts, namely cinnamon, piper, and garlic, and their combined effect on the quality and banana crown rot were reported by Win et al., (2007). The results showed that cinnamon extract was the most effective fungal pathogen compared to the piper and garlic extract. Moreover, the ripening of the fruit in terms of color, soluble solids, firmness, and the severity of the disease was delayed by the chitosan. The shelf-life of the fruit was increased using cinnamon extract, and no impact of quality on the fruit was recorded.

Antifungal activities of extracted pomegranate rind, seeds, and whole fruit with 80% methanol and water extracts were practical (Dahham et al., 2010) against *Penicillium citrinum*, *Aspergillus niger*, *Trichoderma reesei*, *Rhizopusoryzae*, and *Mucor indicus*. Methanolic rind extract had the maximum efficacy against *Aspergillus niger*, with an inhibition zone of 23 mm. Similar to this, rind extract exhibited strong antifungal activity (23 mm) in comparison to

whole fruit (10.0 mm) and juice (20 mm). The extracts of various parts of pomegranate, viz. leaves, bark, fruits, flower, and pulp, inhibited (Dutta et al., 1998) the growth of *Dreschlerarostrata* and *Curvularialunata*.

Chen and Dai (2012) demonstrated that *Colletotrichum lagenarium* is widespread in greenhouse and field cultivation. Eight plants from China were screened for the control of cucumber anthracnose. The extract of *Cinnamomum camphora* showed a 95% control against *C. legendarium*. The microscopic study revealed that the extract was associated with inhibiting mycelial growth.

Cruz et al. (2013) conducted experiments to evaluate plant extracts and essential oils for effectively controlling the post-harvest Anthracnose of banana fruit. The authors reported that fruits treated with citric extracts were more effective than fruits immersed in distilled water. Citric extracts showed less disease severity (9.34%) and more control (90.16%) at 4°C. Essential oils also showed significant results, with less disease severity in berries.

*In vitro* pathogenic activity of different pathogenic fungi, including *Alternaria solani*, *Fusarium solani*, *Botryti cinerea*, *Botrytis fabae*, and *Fusarium oxysporum* against methanolic leaf extract and photochemical constituent of Thompson and Flame seedless grapes, zizyphus, pomegranate and fig was investigated by El-Khateeb et al., (2013). The result revealed the saponins detection only in fig and zizyphus samples, while other phytochemical (tannin, terpenes, alkaloids, carbohydrates, phenolic glycosides, and resins) and polyphenolic compounds (protocatechuic, catechin, *p*-hydroxy the benzoic acid, *p*-coumaric acid, *o*-coumaric acid, and coumarin) were found in all extracts having a maximum concentration in zizyphus leaves. Moreover, the inhibitory effect of mycelium growth of *B. fabae* was optimum in zizyphus (95.56%), followed by pomegranate (95.56%) and (91.11%) extract.

Bazie et al. (2014a) reported managing post-harvest banana anthracnose using hot water and plant extracts. The results showed that 20% of plant extracts of two species, *Acacia albida* and *Prosopis juliflora*, reduced anthracnose development when treated at 50°C. The author reported that the shelf life and market value were also improved as the treatment did not affect the bananas' physicochemical properties.

Bazie et al. (2014b) used the paper disc technique and the spore germination assay to assess the methanolic extracts of 21 plant species against *C. musae*. Research shows the *P. juliflora* extract demonstrated the most potent antifungal ability (30.7 mm) and outranked *A. albida* (19 mm) against untreated samples. Researchers confirmed that all tested plant extracts retained their antifungal properties when heat treated.

Research shows that pomegranate extractions work well to prevent many types of disease-causing and food-wasting organisms including viruses and fungi (Tanveer et al. 2015). The research analyzed the effectiveness of using pomegranate extracts as potential treatment agents. The study results show pomegranate extracts strongly fight bacteria and healthcare teams may produce new drugs based on this discovery.

Several pathogenic fungi including *Botrytis cinerea*, *Colletotrichum dematium*, *F. oxysporum*, *F. solani*, *Phomasp* and *Rhizoctonia solani* linear growth was inhibited by the pomegranate peel methanolic extract (Mohamad and Khalil, 2015). The peel extract successfully blocked spore growth of *F. oxysporum* during laboratory testing. Applying pomegranate peel powder successfully reduced both early and later-stage *F. oxysporum* *sp. lycopersicif* effects when compared to untreated tomatoes. Soil treatment was superior to the seedling treatment with peel extract in controlling the tomato damping off disease. Bhutia et al., (2016) planned a study to evaluate the effect of different solvent extracts on antifungal activity against banana anthracnose fungus and found methanol extract more effective against mycelial growth than chloroform and hexane extract. Best antifungal activity was found in *Zizyphus officinale* while spore germination inhibition was observed in *Z. officinale* and *P. longifolia* extract.

### Acids

Al Zaemy et al. (1993) studied the potential of twelve fruit-coating polymers and eight organic acids to control anthracnose in bananas. Out of twelve coating material tested, two coating materials at 0.1-1% concentration were most effective for control of post-harvest pathogen of banana. On the other hand, malic, citric, oxalic and maleic acids reduced the growth of *C. musae*.

Niranjala and Karunaatne (2001) checked the effect of pressurized infiltrated acetic acid on banana shelf life and found that 0.2% acetic acid significantly reduced the disease score, and citric acid showed less disease incidence than other treatments. They also found that post-harvest application of these acids enhanced the fruit's resistance against *C. musae*. The application of acetic acid also delayed the peel color development.

Khan et al. (2001) compared the potential of fungicides imazalil and thiabendazole (TBZ) against two isolates of *C. musae*, malt extract agar mixed with antioxidants, namely, benzoic acid, ascorbic acid, propionic acid, butylated hydroxytoluene, butylated hydroxyanisole (BHA), dimethyl sulphoxide, propyl gallate (PG), thiourea, BHA and propylparaben (PP), benzoic acid, PP and PG were the compounds with the most excellent antifungal activity. They

found that conidial germination and mycelial growth of isolate CM100 was inhibited at concentrations of 15 mM or less of these chemicals whereas isolate CM103 showed high levels of inhibition. Combinations of BHA (0.5 mM) and imazalil (1.8  $\mu$ M) at low concentrations completely inhibited germination and mycelial growth of the two isolates tested *In vitro* and showed some synergism was observed when lower concentrations of BHA were used. Experiments showed that the activity of fungicides currently used to control *C. musae* can be increased by combining them with food-grade chemicals to decrease the fungicide concentration.

Friedman et al. (2003) evaluated benzaldehydes, benzoic acids and benzoic acid methyl ester to control the *Listeria monocytogenes*, *Campylobacter jejuni*, *Salmonella enteric* and *E. coli*. Out of seventy compounds, twenty-four were effective against all four pathogens. El-Mougy et al. (2008) conducted experiments to study the effects of organic acids as well as organic salts on disease incidence and growth of pathogens like *Penicillium italicum* (blue mold), *Penicillium digitatum* (green mold) and *Geotricum candidum* (sour rot) causing post-harvest diseases of citrus fruits in Egypt. Benzoic, sorbic, and citric organic acids, as well as sodium benzoate or potassium sorbate, completely inhibited the linear growth of all examined fungus. Additionally, compared to untreated fruits, all treated fruits shown a decrease in sour rot and green and blue mold infections under *in vivo* circumstances. 48 hours following inoculation under the same conditions, lemon fruits coated with a 4% water or wax combination showed a significant decrease in the occurrence of mold. Only 4% of the water combination of benzoic and sorbic acids demonstrated 100% protection against the occurrence of mold, indicating that tested organic acids had a smaller influence on the occurrence of mold and were more effective against it when dissolved in water than wax.. Furthermore, the severity of infection records followed the same trend. They concluded that sodium benzoate and potassium sorbate have potential as eco-friendly products, post-harvest fungicides against sour rot, blue and green mould incidence of stored citrus fruits.

Abdel-Kader et al. (2011) studied the effect of organic acid (sorbic acid, benzoic acid) and salts (potassium sorbate and sodium benzoate) against green and blue mould of grapefruit. They found that all the tested acids and salts have great potential to manage the pathogens. They also found that fruit coated with wax + organic acids and wax + salts inhibited the growth of moulds and fruit decay.

De Costa et al. (2012) investigated the potential use of sodium bicarbonate to control post-harvest diseases of bananas while determining its effects on the pathogenicity of *C. musae*. They proved that the fruit peel's pH, soluble solids, and thickness were increased when bananas were dipped in 300 mM sodium bicarbonate for 10 minutes. They concluded that their findings would be beneficial in designing management measures in order to lessen the frequency and severity of Anthracnose.

### Essential oils

Essential oils have a great capacity to manage plant pathogens. Various researchers have reported their efficacy against post-harvest pathogens. To evaluate the effect of essential oil on controlling post-harvest disease incidence, Anthony et al. (2003) treated the banana fruits with different concentrations of Ceylon citronella, lemon grass, and sweet basil oil emulsion followed by storage under modified atmospheric conditions. Fruits treated with basil oil extract-controlled Anthracnose and crown rot efficiently show it as a cost-effective commercial and safe method to control postharvest diseases and to improve shelf life.

Bosquez-Molina et al. (2010) studied the effect of essential oils on inhibiting the growth of *Colletotrichum gloeosporioides* and *Rhizopus stolonifera* in papaya fruit. *In-vitro* evaluated essential oils for their impact on the mycelial growth of two fungi. Fruits were dipped in essential oils for *in-vivo* studies. Thyme and Mexican lime essential oils before and after inoculation. Both essential oils were used for coating in different formulations. Thyme essential oil was more effective against fungi than Mexican lime oil. They also observed that concentrations were not a key factor in reducing fungal activity. The disease incidence can be reduced by up to 100% with the combination of these essential oils. Essential oils were evaluated to check their efficacy against anthracnose disease and the post-harvest quality of the banana fruit in storage (Maqbool et al., 2010). The experiments were carried out with four concentrations of cinnamon oil against Anthracnose of bananas. The results showed a significant inhibition when all the treatments were analyzed with cinnamon oil using mycelial growth and conidial germination of *C. musae*. The authors also reported that the occurrence of the disease was delayed using cinnamon oil treatments while maintaining the quality during storage; however, at higher concentrations, some phototoxic effects were noticed. Concentration up to 0.3% was more effective in extending the storage life of bananas for about four weeks. Hong et al. (2015) evaluated the antifungal activities of fifteen plant essential oils to control pepper anthracnose caused by *Colletotrichum gloeosporioides* in outdoor fields in Korea. It was found that *In vitro* conidial germination was the most

significantly inhibited when vapor treatments were carried out with carvacrol, citral, p-cymene, cinnamon oil, linalool and trans-cinnamaldehyde. Furthermore, the indirect vapor treatment with essential oils that inhibited mycelial development was contrasted with the untreated control approach. When compared to infected control fruits devoid of essential oils, it was found that the essential oils' plant protection efficacy was demonstrated by decreasing the lesion width on the immature green pepper fruits inoculated with *C. gloeosporioides*. Essential oils from all plant sources showed equal protection against pepper anthracnose in the study. The researchers found that essential oils from plants provide an environmentally safe solution for anthracnose control during pepper fruit production. Idris et al. (2015) analyzed the ability of essential oils to guard bananas against *C. musae* anthracnose. They created a pure Anthracnose culture on a PDA medium with rosemary, cinnamon, and basil essential oils. In the second experiment, they sprayed banana fruits (of the Giant Cavendish and Williams varieties) with EOs emulsions after experimentally infecting them with *C. musae*. In the in vitro experiment, mycelial growth was inhibited in all treatments except the control after seven days of incubation at 25. Similarly, after using EO, in-vivo studies showed a substantial decrease in illness incidence and the percent disease index (PDI). After 19 days of storage, they found that the treatment with basil EO produced the lowest PDI. They verified that essential oils of rosemary, cinnamon, and basil have antifungal properties against banana fruit anthracnose. Ali et al. (2016) conducted an experiment to control post-harvest Anthracnose of papaya by using *Zingiber officinalis* (ginger oil) and ginger extract with a combination of Arabic gum (10%), The results showed inhibition of spore germination and delayed ripening in papaya by using a combination of ginger oil and Arabic gum extract.

The effect of basil oil with a combination of modified atmospheric at a temperature of 12-14 Celsius was investigated by Siriwardana et al. (2017) to control crown rot and to enhance the shelf life of Embul banana (*Musa acuminata*). Fruits were treated with aluminum sulfate and its combination with basil oil and then stored at 12-14°C temperature for 14 days, and the result showed controlled crown rot. Moreover, it also improved the fruit taste and sweetness compared to non-treated ones. Libs and Salim (2017) presented a study of controlling vegetable diseases using essential oils to save organic agriculture production in Sudan. Different aspects of controlling vegetable diseases were addressed, including the diseases of vegetables, chemical treatment of vegetable crops, their hazards, and biological control. The results demonstrated that the control of vegetable diseases by using essential oils has several benefits, including saving land, efficient control, low-cost techniques, rich in health, being easy to use, increased incomes, and a safe green environment. The authors concluded that essential oils can potentially be used to control the vegetable diseases in Sudan.

## CONCLUSION

In conclusion, bananas are one of the staple foods millions consume. In recent decades, much attention has been given to banana post-harvest diseases; among them, anthracnose is one of the major problems. This pathogen can overwinter in infected plant residues and start new cycles of infection, thus constituting a continuous threat to banana crops that involve high economic losses. Banana cultivars exhibit different levels of susceptibility to anthracnose, and proper management is needed. Future research should be directed toward improving the resistance of banana cultivars through genetic improvements and assessing the use of natural plant extracts and organic acids as an eco-friendly alternative to synthetic fungicides. Besides, post-harvest handling and storage conditions should be optimized to reduce the incidence of infections. What this calls for, in essence, is an integrated practice of old arts with modern technologies that will enable the longevity of banana production, reducing losses after harvesting. We must also enhance our knowledge of anthracnose and its interaction with the banana plant for potentially new strategies to ensure efficient crop protection and livelihood support for millions worldwide.

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All authors contributed equally to this research.

## AUTHOR CONTRIBUTIONS

**Muhammad Awais Fareed, Sara Anum and Aqleem Abbas:** Writing original draft and Figure preparations. **Talha Riaz, Sonum Bashir, Talha Shafique, Moazzma Anwar, Humera Aslam, Talib Hussain, Eman Fatima and Tooba Khan:** Collecting literature, Software, Visualization, Validation, Project administration, Finalization, Writing–review & editing. **Qaiser Shakeel:** Conceptualization Writing–review & editing.

## COMPETING OF INTEREST

The authors declare that the research was carried without any commercial or financial relationships that could be construed as a potential conflict of interest.

## REFERENCES

- Abdel-Kader, M., El-Mougy, N., Lashin, S. 2011. Evaluation of grapefruit coating with chemical preservatives as control measure against post-harvest decay. *Phytopathol.* 59:25-38.
- Ali, A., Hei, G.K., Keat, Y.W. 2016. Efficacy of ginger oil and extract combined with gum arabic on Anthracnose and quality of papaya fruit during cold storage. *J. Food Sci. Technol.* 53(3):1435-1444.
- Anthony, S., Abeywickrama, K., Wijeratnam, S.W., 2003. The effect of spraying essential oils of *Cymbopogon nardus*, *Cymbopogon flexuosus* and *Ocimum basilicum* on post-harvest diseases and storage life of Embul banana. *J. Hortic. Sci. Biotechnol.* 78(6):780-785.
- Anyasi, T.A., Jideani, A.I., Mchau, G.R. 2013. Functional properties and post-harvest utilization of commercial and noncommercial banana cultivars. *Compr. Rev. Food Sci. Food Saf.* 12(5):509-522.
- AsghariMarjanlo, A., Mostofi, Y. Shoeibi, S. et al 2009. Effect of cumin essential oil on post-harvest decay and some quality factors of strawberry. 3(31):25-43.
- Aurore, G., Parfait, B., Fahrasmane, L 2009. Bananas, raw materials for making processed food products. *Trends Food Sci. Technol.* 20(2):78-91.
- Bailey, J.A., Jeger, M.J. 1992. *Colletotrichum*: Biology, Pathology and Control. CAB Int., Wallingford.
- Bazie, S., Ayalew, A., Woldetsadik, K. 2014a. Antifungal activity of some plant extracts against (*Colletotrichum Musae*) the cause of post-harvest banana anthracnose. *J. Plant Pathol. Microbiol.*
- Bazie, S., Ayalew, A. Woldetsadik, K. 2014b. Integrated management of post-harvest banana anthracnose (*Colletotrichum musae*) through plant extracts and hot water treatment. *Crop Prot.* 66:14-18.
- Bhutia, D.D., Zhimo, Y. Kole, R. et al 2016. Antifungal activity of plant extracts against *Colletotrichum musae*, the post harvest anthracnose pathogen of banana cv. Martaman. *Nutr. Food Sci.* 46(1):2-15.
- Bokhari, N.A., Siddiqui, I. Siddique, K.P.I. et al 2013. Management of Anthracnose of banana by UV irradiation. *J. Anim. Plant Sci.* 23(4):1211-1214.
- Bosquez-Molina, E., Ronquillo-de Jesús, E. Bautista-Baños, S. et al 2010. Inhibitory effect of essential oils against *Colletotrichum gloeosporioides* and *Rhizopus stolonifer* in stored papaya fruit and their possible application in coatings. *Postharvest Biol. Technol.* 57(2):132-137.
- Castillo, F., Hernández, D. Gallegos, G. et al 2010. In vitro antifungal activity of plant extracts obtained with alternative organic solvents against *Rhizoctonia solani* Kühn. *Ind. Crops Prod.* 32(3):324-328.
- Centeno, D.C., Osorio, S., Nunes-Nesi, A., et al 2011. Malate plays a crucial role in starch metabolism, ripening, and soluble solid content of tomato fruit and affects post-harvest softening. *Plant Cell*, 23(1):162-184.
- Chen, Y., Dai, G 2012. Antifungal activity of plant extracts against *Colletotrichum lagenarium*, the causal agent of Anthracnose in cucumber. *J. Sci. Food Agric.* 92(9):1937-1943.
- Chilton, S.J.P., Wheeler, H.E. 1949. Genetics of *Glomerella*. VII. Mutation and segregation in plus cultures. *Am. J. Bot.* 717-721.
- Cruz, M.E.S., Schwan-Estrada, K.R.F., Clemente, E. 2013. Plant extracts for controlling the postharvest Anthracnose of banana fruit. *Rev. Bras. Plantas Med.* 15:727-733
- Dahham, S.S., Ali, M.N., Tabassum, H. et al 2010. Studies on antibacterial and antifungal activity of pomegranate (*Punicagranatum L.*). *Rev. Bras. Plantas Med.* 9(3):273-281.
- De Costa, D.M. 2010. Quality retention of dessert banana and other tropical fruits by controlling postharvest diseases using non-chemical methods. *New Trends in Postharvest Management of Fresh Produce II. Fresh Produce*, 4(1):1-14.
- De Costa, D.M., Chandima, A.A.G. 2014. Effect of exogenous pH on development and growth of *Colletotrichum musae* and development of anthracnose in different banana cultivars in Sri Lanka. *J. Natl. Sci. Found. Sri Lanka.* 42(3).
- De Costa, D.M., B. S. Amaradasa, and R. N. B. P. M. R. C. L. Wegiriya, 2012. Antagonists of *Colletotrichum musae* associated with banana fruit skin. *J. Natl. Sci. Found. Sri Lanka.* 25(2).
- Dutta, B.K., Rahman, I., Das, T.K., 1998. Antifungal activity of Indian plant extracts: antimyzetische Aktivität indischer Pflanzenextrakte. *Mycoses*, 41(11-12):535-536.
- Eckert, J.W., Ogawa, J.M., 1985. The chemical control of postharvest diseases: subtropical and tropical fruits. *Annu. Rev. Phytopathol.* 23(1):421-454.
- El-Khateeb, A.Y., Elsherbiny, E.A., Tadros, L.K. et al 2013. Phytochemical analysis and antifungal activity of fruit leaves extracts on the mycelial growth of fungal plant pathogens. *J. Plant Pathol. Microbiol.* 4:1-6.
- El-Mougy, N.S., El-Gamal, N.G., Abd-El-Kareem, F. 2008. Use of organic acids and salts to control post-harvest diseases of lemon fruits in Egypt. *Arch. Phytopathol. Plant Prot.* 41(7):467-476.

- Food and Agriculture Organization. 1989. Prevention of post-harvest food losses fruits, vegetables and root crops a training manual FAO, Rome, Italy
- Holland, K.P., 1999. Consumer Info. Available: <http://www.kpholland.nl>
- Idris, F.M., Ibrahim, A.M. Forsido, S.F. 2015. Essential oils to control *Colletotrichum musae* in vitro and in vivo on banana fruits. *Am.-Eurasian J. Agric. Environ. Sci.* 15(3):291-302.
- Ilyas, M.B., Ghazanfar, M.U., Khan, M.A. et al 2007. Postharvest losses in apple and banana during transport and storage. *Pak. J. Agri. Sci.* 44(3):534-539.
- Khan, S.H., Aked, J. Magan, N. 2001. Control of the anthracnose pathogen of banana (*Colletotrichum musae*) using antioxidants alone and in combination with thiabendazole or imazalil. *Plant Pathol.* 50 (5):601-608
- Kumar, K.S., Bhowmik, D. 2012. Traditional and medicinal uses of banana. *J. Pharm. Phytochem.* 1(3).
- Libs, E.R.S., Salim, E.A. 2017. Vegetable diseases control by using essential oils to access organic production in Sudan. *Agri. Res. Tech: Open Access J.* 6(4).
- Mahadatanapuk, S., 2005. Molecular Cloning of cDNA Encoding ACC Synthase and Application of Antagonistic Bacteria for Disease Control in *Curcuma alismatifolia* Gagnep. PhD thesis Chiang Mai, Thailand: University of Chiang Mai.
- Mahadatanapuk, S., Sanguansersri, M., Cutler, M.A. 2007. Control of anthracnose caused by *Colletotrichum musae* on *Curcuma alismatifolia* Gagnep. using antagonistic *Bacillus spp.* *Am. J. Agric. Biol. Sci.*
- Maqbool, M., Ali, A.S.G.A.R., Alderson, P.G. 2010. Effect of cinnamon oil on incidence of anthracnose disease and post-harvest quality of bananas during storage. *Int. J. Agric. Biol.* 12(4):516-520.
- Mohamad, T.G., Khalil, A.A. 2015. Effect of pomegranate (*Punica granatum* L.) Fruits peel on some phytopathogenic fungi and control of tomato damping-off. *J. Plant Prot. Pathol.* 6(2):359-374.
- Mohapatra, D., Mishra, S., Sutar, N. 2010. Banana post-harvest practices: current status and future prospects-a review. *Agric. Rev.* 31(1).
- Narayanasamy, P. 2005. Post-harvest Pathogens and Disease Management. Australia.
- Nelson, S. 2008. Post-harvest rots of banana.
- Niranjala, O.D.A.N., Karunaratne, A. 2001. Response of bananas to postharvest acid treatments. *J. Hortic. Sci. Biotechnol.* 76(1):70-76.
- Ploetz, R.C., Thomas, J.E., Slabaugh, W.R. 2003. Diseases of banana and plantain. In R. C. Poetz. (Ed.), Diseases of tropical fruit crops (pp. 73-134). CABI
- Postmaster, A., Kuo, J., Sivasithamparam, K., et al 1997. Interaction between *Colletotrichum musae* and antagonistic microorganisms on the surface of banana leaf discs. *Sci. Hortic.* 71(1):113-125.
- Priyadarshanie, H.R., Vengadaramana, A. 2015. Some preliminary studies of *Colletotrichum musae* associated with banana anthracnose disease in Jaffna district, Sri Lanka. *Univ. J. Agric. Res.* 3(6):197-202.
- Siriwardana, H., Abeywickrama, K. Kannangara, S. 2017. Basil oil plus aluminium sulfate and modified atmosphere packaging controls Crown rot disease in Embul banana (*Musa acuminata*, AAB) during cold storage. *Sci. Hortic.* 217:84-91.
- Solgi, M., Ghorbanpour, M. 2014. Application of essential oils and their biological effects on extending the shelf-life and quality of horticultural crops. *Trakia J. Sci.* 2:198-210.
- Srivastava, R., Lal, A.A. 2009. Incidence of post-harvest fungal pathogens in guava and banana in Allahabad. *J. Hortic. Sci.* 4(1):85-89.
- Stover, R.H., 1972. Banana, Plantain and Abaca Diseases. Wallingford, UK: CAB International.
- Stover, R.H., Simmonds, N.W. 1987. *Bananas*. London, UK: Longman. 3rded.
- Su, Y.Y., Noireung, N., Liu, F., et al 2011. Epitypification of *Colletotrichum musae*, the causative agent of banana anthracnose. *Mycoscience.* 52(6):376-382.
- Tanveer, A., Farooq, U., Akram, K., et al 2015. Pomegranate extracts: A natural preventive measure against spoilage and pathogenic microorganisms. *Food Rev. Int.* 31(1):29-51.
- Thangamani, G., Raja, P., Abitha, M., et al 2020. Standardization of UV-C treatment, Ozonization and chlorination for reducing microbial growth in carrot under laboratory conditions. *J. Pharmacogn. Phytochem.* 9(6):557-563.
- Thangavelu, R., Sundararaju, P., Sathiamoorthy, S. 2004. Management of anthracnose disease of banana caused by *Colletotrichum musae* using plant extracts. *J. Hortic. Sci. Biotechnol.* 79(4):664-668.
- Tongsri, V., Sangchote, S. 2009. Yeast metabolites inhibit banana anthracnose fungus *Colletotrichum musae*. *Asian J. Food Agro-Ind.* 2:807-816.
- Wharton, P.S., DiéguezUribeondo, J. 2004. The biology of *Colletotrichum acutatum*. In *Anales del Jardín Botánico de Madrid* (Vol. 61, No. 1). Consejo Superior de Investigaciones Científicas.
- Wheeler, H.E., 1954. Genetics and evolution of heterothallism in *Glomerella*. *Phytopathol.* 44:342-353.
- Win, N.K.K., Jitareerat, P., Kanlayanarat, S., et al 2007. Effects of cinnamon extract, chitosan coating, hot water treatment and their combinations on crown rot disease and quality of banana fruit. *Postharvest Biol. Technol.* 45(3):333-340.
- Xueping, L., Jingying, S., Xiaoyang, Z., et al 2013. Pre-harvest and postharvest application of benzothiadiazole for controlling anthracnose and extending shelf life of harvested banana. *Int. J. Agric. Biol. Eng.* 6(4):76-83.

- Yonas. K., Amare, A., 2008. Post-harvest biological control of Anthracnose (*Colletotrichum gloeosporioides*) on mango (*Mangifera indica* L.). *Postharvest Biol. Technol.* 50: 8-11.
- Zakaria, L., Sahak, S., Zakaria, M., et al 2009. Characterisation of *Colletotrichum* species associated with anthracnose of banana. *Trop. Life Sci. Res.* 20(2):119.
- Zhimo, V.Y., Dilip, D., Sten, J., et al 2017. Antagonistic Yeasts for Biocontrol of the Banana Postharvest Anthracnose Pathogen *Colletotrichum musae*. *J. Phytopathol.* 165(1):35-43.
- Zhu, X., Lin, H., Si, Z., et al 2016. Benzothiadiazole-mediated induced resistance to *Colletotrichum musae* and delayed ripening of harvested banana fruit. *J. Agric. Food Chem.* 64(7):1494-1502.