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Post-harvest fungal diseases of Vazhakulam pineapple: Isolation, identification, and management strategies

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Abstract

Post-harvest losses in pineapple are predominantly driven by microbial spoilage, resulting in substantial quality deterioration during storage and distribution. This study aimed to characterize the major fungal pathogens, including yeasts, associated with post-harvest diseases of pineapple in the Vazhakulam market, and to assess the in vitro antifungal efficacy of selected microbial biocontrol agents and tea tree oil.

Fungal isolates recovered from symptomatic fruits were identified based on cultural and morphological characteristics as *Ceratocystis paradoxa*, *Curvularia* spp., *Penicillium* spp., and *Candida* spp. Pathogenicity was confirmed through inoculation assays, fulfilling Koch's postulates.

The antifungal activity of selected microbial biocontrol agents, namely *Bacillus subtilis*, *Trichoderma viride*, *Pseudomonas fluorescens*, and *Ampelomyces quisqualis*, along with tea tree oil, was evaluated using the agar well diffusion method. The microbial agents did not exhibit measurable inhibition under in vitro conditions. In contrast, tea tree oil demonstrated pronounced antifungal activity, with maximum inhibition observed against *Penicillium* spp.

These findings underscore the diversity of fungal pathogens involved in pineapple spoilage and highlight the potential of tea tree oil as a natural antifungal alternative. Further investigation under in vivo conditions is warranted to optimize its application for post-harvest disease management.

Keywords: Pineapple; Post-harvest diseases; Fungal pathogens; Biocontrol agents; Tea tree oil; Antifungal activity

Introduction

Pineapple (*Ananas comosus*) is one of the most valuable and widely cultivated fruits globally, with India ranking among its major producers. This tropical fruit is highly appreciated for its exceptional juiciness, vibrant flavor, and notable health-promoting properties. As a non-climacteric fruit with rich nutritional content, pineapple is consumed fresh or processed into various products, including canned slices, juices, jams, jellies, fiber, and even wine (Lalhruaitluangi *et al.*, 2024) ^[11].

Fruits are broadly classified as climacteric or non-climacteric based on their ripening behavior. Climacteric fruits exhibit a marked rise in respiration and ethylene production during ripening and can continue to ripen after harvest. In contrast, pineapple is a non-climacteric fruit, showing no post-harvest respiratory peak and little improvement in flavor or sweetness once removed from the plant. As a result, pineapples must be harvested at optimum maturity and handled with great care during post-harvest operations to preserve their quality, as ripening cannot compensate for poor harvesting, storage, or transport conditions. (Coates *et al.*, 1997) ^[4]. Pineapple availability in most markets fluctuates with the seasons, and its naturally high perishability makes it difficult to store and transport for long periods. As a result, substantial post-harvest losses occur, which significantly reduce the volume that actually reaches consumers and processors. Consequently, these losses have been identified as a major factor contributing to the overall decline in pineapple production. Such losses result around 24 percent reduction with gross margin of pineapple farmers. The reasons may be attributed to cultivable area, transportation, storability and number of bruised fruits (Mirza *et al.*, 2016) ^[18].

Apart from the direct economic impact, infected fruits and vegetables can also threaten consumer health. Several fungal genera, including *Penicillium*, *Alternaria*, and *Fusarium*, are capable of producing mycotoxins under favourable conditions. The likelihood of mycotoxin contamination is highest when diseased produce enters the processing chain for food products or animal feed. Post-harvest diseases are typically categorized based on the mode of infection initiation. In the case of quiescent or latent infections, the pathogen penetrates the host most often prior to harvest and subsequently remains dormant until a shift in host physiology permits further development. The substantial biochemical and structural changes associated with fruit ripening frequently serve as the stimulus that reactivates these dormant infections, leading to disease manifestation during storage, transport, or marketing. The other major group of post-harvest diseases are those which arise from infections initiated during and after harvest. Often these infections occur through surface wounds created by mechanical or insect injury (Coates *et al.*, 1997) [4].

The process of infection follows the development of fungal penetrating structure called appressorium. The colonization process by fungi involves their ability to establish themselves within the host. This is initiated when the fungi following adhesion and release of enzymes depolymerize certain cell wall polymers such as pectin, the cementing substance of the produce (Onuorah *et al.*, 2013) [20]. The pineapple primary cell wall contains roughly 10% proteins and 90% polysaccharides, mainly comprising cellulose, hemicellulose, and pectin. Many fungal pathogens secrete a wide range of cell wall-degrading enzymes that enable them to penetrate and utilize these structural components as nutrients. Their abundant production of extracellular pectinases and hemicellulases is a key factor contributing to pineapple spoilage, ultimately shortening post-harvest life and causing quality deterioration and fruit rot.

The long-standing challenge of post-harvest decay in fruits and vegetables remains unresolved, as evidenced by consumers who continue to discard spoiled produce despite selecting high quality fresh items. Traditional reliance on post-harvest fungicide applications has diminished due to increasing pathogen resistance, limited availability of alternative chemicals, public concerns over pesticide safety, and resulting regulatory constraints (Janisiewicz and Lise, 2002) [8]. Effective post-harvest fungal management is vital for maintaining fruit quality, ensuring food safety, and minimizing economic losses, and can be achieved through diverse biological strategies that enhance the commodity's natural defence systems while employing antagonistic microorganisms and natural antimicrobial agents (Mari *et al.*, 1998) [16].

Materials and methods

Samples collection

Pineapple fruits (both diseased and healthy) were collected from Vazhakulam, one of Asia's largest pineapple markets supplying fruit across India. The samples were placed in separate sterile polythene bags and transported to the Plant Pathology Laboratory, Pineapple Research Station, Vazhakulam, for further analysis

Isolation and identification of fungus: The collected fruits were aseptically cut into small segments (approximately 3

mm in diameter) using a sterile blade. The segments were surface sterilized in 1% sodium hypochlorite for 1 min, followed by rinsing with sterile water to remove residual sterilant. The sterilized tissue pieces were then placed on sterile Potato Dextrose Agar (PDA) plates supplemented with antibiotics to suppress bacterial growth. The plates were incubated in an inverted position at room temperature for 5 days. Emerging fungal colonies were sub-cultured to obtain pure cultures (Guo *et al.*, 2023) [7].

For microscopic examination, fungal isolates were mounted on clean glass slides and observed under a compound microscope. Identification of the isolates was carried out based on cultural and morphological characteristics, including colony growth pattern, pigmentation, and conidial morphology, following standard identification manuals (Onuorah *et al.*, 2013; Ferreira *et al.*, 2014; Oniah *et al.*, 2018; Mbenoun *et al.*, 2014; Korres *et al.*, 2010) [20, 6, 19, 17, 20].

Pathogenicity test & Re-isolation

Pathogenicity tests were conducted to verify Koch's postulates. Healthy pineapple fruits were washed with tap water, rinsed with sterile distilled water, and surface sterilized with 75% ethanol. The fruits were wounded and inoculated by injecting the fungal suspension using a sterile syringe. Non-inoculated fruit served as control.

All fruits were incubated at room temperature and observed regularly for symptom development (Fig. 1). After symptom appearance, the pathogen was re-isolated and compared with the original culture to confirm Koch's postulates (Guo *et al.*, 2023) [7].

Evaluation of Antifungal Activity of Biocontrol Agents and Natural Oil

Microbial biocontrol agents-*Bacillus subtilis* (Sting), *Ampelomyces quisqualis* (Biodewcon), *Trichoderma viride* (Biocure F), and *Pseudomonas fluorescens* (Biocure B)-at 1.5% concentration, along with 100% tea tree oil as a botanical treatment, were evaluated for their antifungal efficacy using the agar well diffusion method (Magaldi *et al.*, 2004) [13] with slight modifications.

The plates were incubated at room temperature, and antifungal activity was assessed by measuring the zone of inhibition around each well. All experiments were conducted in triplicate.

Results

Symptomatology and Identification of fungus

Examination of the symptomatic pineapple fruits revealed distinct post-harvest fungal diseases including those caused by molds (figure 2, figure 3, figure 4) and yeast (figure 5). Samples showing dark, water-soaked lesions beginning at the stalk end, progressing internally with firm black necrosis and characteristic tar-like mycelial masses were diagnosed as *Ceratocystis paradoxa*, confirming black rot. Fruits exhibiting irregular brown to black surface lesions, tissue softening, and rapid decay were associated with *Curvularia* spp., and cultural and microscopic characteristics verified *Curvularia* fruit rot. In contrast, fruits that appeared externally healthy but displayed internal browning of individual fruitlets, tissue breakdown around the core, and blue-green sporulation were identified as *Penicillium* spp., consistent with fruitlet core rot. *Candida* spp. produced

cream-colored, smooth, moist, circular, convex colonies with distinct margins. (Table 1)

Activity of biocontrol agents & natural oil against isolated fungus

The in vitro inhibition assay revealed limited antifungal activity of the tested biological control agents. *Bacillus subtilis* (Sting), *Ampelomyces quisqualis* (Biodewcon), *Trichoderma viride* (Biocure F), and *Pseudomonas fluorescens* (Biocure B) did not produce measurable zones of inhibition against *Ceratocystis paradoxa*, *Curvularia* spp., *Penicillium* spp., or *Candida* spp. under the experimental conditions. (figure 6).

In contrast, tea tree oil exhibited notable antifungal activity (table 2), with the highest inhibition observed against *Penicillium* spp. followed by *Ceratocystis paradoxa*, *Curvularia* spp. and *Candida* spp. The antifungal efficacy of tea tree oil is likely associated with its volatile bioactive constituents that disrupt fungal cell membrane integrity.

Discussion

Post-harvest diseases of pineapple are caused not only by filamentous fungi but also by yeasts and yeast-like fungi, which contribute to fruit decay, off-flavors, and reduced marketability during storage and distribution (Snowdon, 2010) [22]. The isolation of *Ceratocystis paradoxa*, *Curvularia* spp., *Penicillium* spp. and *Candida* spp. from market samples highlights the complex fungal and yeast-associated microbiota involved in post-harvest deterioration of pineapple. The present findings align well with previously documented post-harvest pathogens associated with pineapple. *Penicillium* spp., identified in the current samples as the causal agent of fruitlet core rot, has also been reported from decaying pineapple fruits by Onuorah *et al.*, 2013 [20], confirming its relevance as a major spoilage fungus in the supply chain. Similarly, the isolation of *Curvularia* spp. corresponds with the work of Ferreira, who demonstrated its role in inducing post-harvest fruit rot in pineapple. In addition, the detection of *Ceratocystis paradoxa* causing characteristic black rot supports earlier observations by Oniah *et al.*, 2018 [19] emphasizing its importance as a destructive pathogen particularly under poor handling and storage conditions. Yeast-associated pineapple fruit rot has been reported by Korres *et al.* (2010) [10], who identified yeasts such as *Candida* spp., *Saccharomyces* spp., and *Kloeckera* spp. in collapsed pineapple fruits and demonstrated their role in fruit decay through pathogenicity tests.

Previous studies report that during harvesting, storage, packaging, and transportation, fruits are prone to physical damage, which increases post-harvest losses and the

likelihood of fungal contamination. This risk is further amplified by inadequate fruit management in markets. Unsanitary marketing environments characterized by poor vendor hygiene, the use of microbially unsafe containers, improper handling practices, and unfavorable environmental conditions create situations that promote contamination and spoilage (Mailafia *et al.*, 2017) [14].

The effectiveness of essential oils observed in the present study is consistent with earlier reports. Post-harvest application of essential oils has been shown to improve quality and extend the shelf life of Indian pineapple (Mandal & Vanlalawmpuia, 2020) [15] and to effectively control fusariosis (Vilaplana *et al.*, 2018) [24]. Similarly, tea tree oil has been reported to reduce post-harvest decay in strawberries (Shao *et al.*, 2013) [21]. The antifungal potential of tea tree oil has been further demonstrated against *Botrytis cinerea* in strawberries, where concentrations of 125 and 1000 $\mu\text{L L}^{-1}$ resulted in 10% and 48% reductions in the mycelial growth index, respectively, indicating a concentration-dependent suppression of pathogen development (Lorenzetti *et al.*, 2011) [12]. Comparable inhibitory effects were also reported by Souza *et al* in 2015, who observed a reduction in the mycelial growth rate of *Stemphylium* spp. following treatment with tea tree oil. These findings, together with the results presented in Table 2, highlight the potential of tea tree oil as a natural alternative for managing post-harvest fungal diseases of pineapple, warranting further in vivo evaluation.

Botanical antifungal agents have gained increasing attention in post-harvest disease management due to growing concerns over fungicide residues, pathogen resistance, and environmental safety. Essential oils, including tea tree oil, are particularly attractive as they are of natural origin and generally well accepted by consumers seeking residue-free and eco-friendly alternatives (Bakkali *et al.*, 2008) [2]. Tea tree oil demonstrated strong in vitro antifungal activity against the isolated post-harvest pathogens, corroborating earlier reports of its broad-spectrum efficacy against fungi and yeasts through membrane disruption and interference with cellular metabolism (Carson *et al.*, 2006) [3].

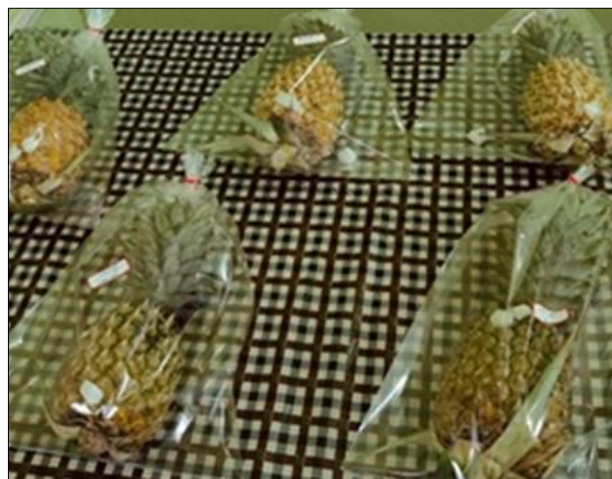
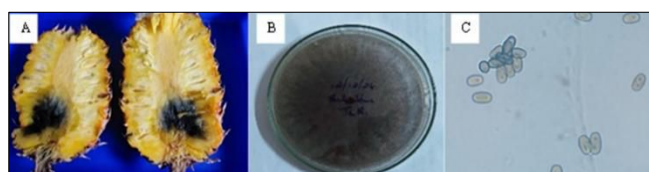
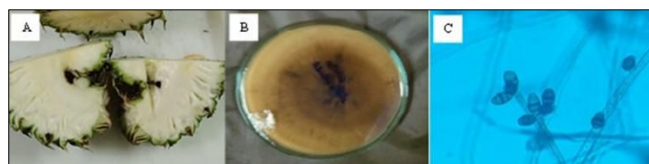
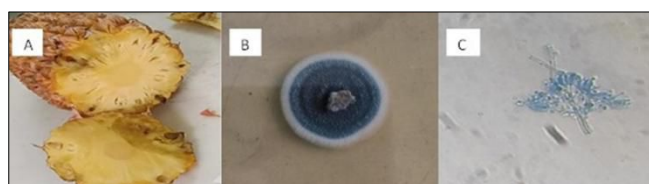
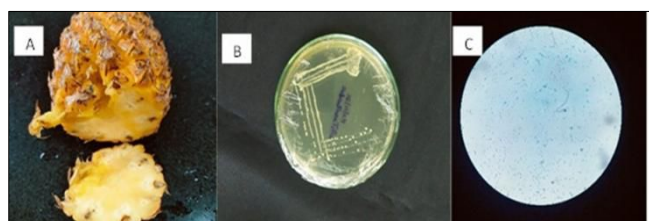
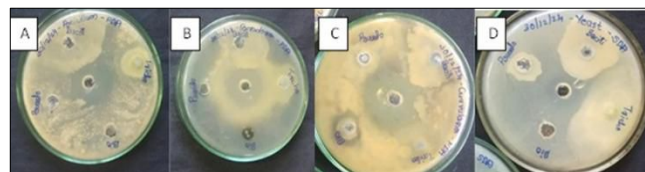
Consumer acceptance plays a critical role in the adoption of botanical treatments in post-harvest systems. While essential oils are perceived as safe and natural, their strong aroma and volatility may influence sensory quality, necessitating careful dose optimization and formulation strategies. In addition to post-harvest application, pre-harvest use of botanicals has been reported to reduce field inoculum levels, thereby lowering post-harvest disease incidence and delaying symptom development during storage (Tripathi *et al.*, 2008) [23].

Table 1: Characterization of fungal isolates from spoiled pineapple fruits

Isolates	Colonial features	Morphological features	Organism
1 (Black rot)	Flat filamentous velvety black colonies	White to dark septate mycelium, black perithecia with long necks, hyaline kidney-shaped ascospores, and hyaline cylindrical to oval conidia	<i>Ceratocystis paradoxa</i>
2 (Fruit rot)	Powdery grey-brown colonies	Dark, septate mycelium with curved, multi-septate conidia having a swollen central cell	<i>Curvularia</i> spp.
3(Fruitlet core rot)	Rapidly growing, flat filamentous velvety blue green colonies	Brush like branched conidiophores bearing chains of spherical conidia	<i>Penicillium</i> spp.
4 (Fruit rot)	Creamy, smooth, circular and convex colonies	Oval cells reproducing by budding	<i>Candida</i> spp.

Table 2: In vitro inhibition assay of various treatments against fungal isolates

Treatments	Zone diameter(mm)			
	<i>Ceratocystis paradoxa</i>	<i>Curvularia spp.</i>	<i>Penicillium spp.</i>	<i>Candida spp.</i>
<i>Bacillus subtilis</i> (Sting)	0	0	0	0
<i>Ampelomyces Quisqualis</i> (Biodewcon)	0	0	0	0
<i>Trichoderma viride</i> (Biocure F)	0	0	0	0
<i>Pseudomonas fluorescens</i> (Biocure B)	0	0	0	0
Tea tree oil	4.9	3.5	6.43	1.2

**Fig 1:** Pathogenicity assessment using the syringe inoculation method**Fig 2:** A) Disease symptom expression, B) cultural features, and C) microscopic characteristics of *Ceratocystis paradoxa***Fig 3:** A) Disease symptom expression, B) cultural features, and C) microscopic characteristics of *Curvularia spp.***Fig 4:** A) Disease symptom expression, B) cultural features, and C) microscopic characteristics of *Penicillium spp.***Fig 5:** A) Disease symptom expression, B) cultural features, and C) microscopic characteristics of *Candida spp.***Fig 6:** Zone of inhibition produced by various treatments against A) *Penicillium spp.*, B) *Ceratocystis paradoxa*, C) *Curvularia spp.*, and D) *Candida spp.*

Conclusion

Post-harvest deterioration of pineapple is caused by a diverse group of fungal pathogens that significantly compromise fruit quality during marketing and storage. The present investigation confirmed the occurrence of major post-harvest diseases in the Vazhakulam market, including black rot caused by *Ceratocystis paradoxa*, fruit rot associated with *Curvularia spp.* and *Candida spp.* and fruitlet core rot caused by *Penicillium spp.*, highlighting the persistent risk of microbial spoilage during post-harvest handling and distribution. Among the evaluated treatments, tea tree oil exhibited notable in vitro antifungal activity against *Penicillium spp.*, *Ceratocystis paradoxa*, *Curvularia spp.* and *Candida spp.*, indicating its potential as a botanical alternative for post-harvest disease management, while the tested biocontrol agents were ineffective under the experimental conditions. The growing consumer demand for natural and residue-free treatments further supports the exploration of botanical fungicides such as tea tree oil. However, successful commercial application will require optimized formulations, assessment of sensory impacts, and validation of both pre-harvest and post-harvest application strategies, along with improved market hygiene practices including sanitation of handling equipment, minimization of mechanical injury, and proper storage conditions to effectively reduce inoculum spread and disease incidence.

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References

- Adriano-Anaya L, Pardo-Girón LF, Salvador-Adriano M, Salvador-Figueroa M, Ovando-Medina I, Moreno-Castillo B. Effectiveness of *Bacillus subtilis* ANT01 and *Rhizobium sp.* 11B on the control of Fusarium wilt in pineapple (*Ananas comosus*). PeerJ. 2024;12:e16871.
- Bakkali F, Averbeck S, Averbeck D, Idaomar M. Biological effects of essential oils: a review. Food Chem Toxicol. 2008;46(2):446–75.
- Carson CF, Hammer KA, Riley TV. *Melaleuca alternifolia* (tea tree) oil: a review of antimicrobial and other medicinal properties. Clin Microbiol Rev. 2006;19(1):50–62.
- Coates LM, Johnson GI. Postharvest diseases of fruit and vegetables. In: Brown GE, Eckert JW, editors.

- Compendium of tropical fruit diseases. St. Paul: APS Press; 1997. p. 533–47.
5. Duangkaew P, Monkhung S. Antifungal activity of *Bacillus subtilis* subsp. *spizizenii* BL-59 to control postharvest diseases of mango fruits (*Mangifera indica* L.). *Int J Agric Technol*. 2021;17(6):2053–66.
 6. Ferreira AP, Pinho DB, Machado AR, Pereira OL. First report of *Curvularia eragrostidis* causing postharvest rot on pineapple in Brazil. *Plant Dis*. 2014;98(9):1277.
 7. Guo TR, Zeng Q, Yang G, Ye SS, Chen ZY, Xie SY, *et al*. Isolation, identification, and antifungal efficacy of sodium bicarbonate combined with natamycin on *Aspergillus niger*. *Front Microbiol*. 2023;13:1075033.
 8. Janisiewicz WJ, Korsten L. Biological control of postharvest diseases of fruits. *Annu Rev Phytopathol*. 2002;40:411–41.
 9. Juge N. Plant protein inhibitors of cell wall degrading enzymes. *Trends Plant Sci*. 2006;11(7):359–67.
 10. Korres AM, Ventura JA, Fernandes PM. First report of bacteria and yeasts associated with pineapple fruit collapse. *Plant Dis*. 2010;94(12):1509.
 11. Lalhruaitluangi N, Mandal D. Medicinal and nutritional characteristics of pineapple in human health: a review. *J Postharvest Technol*. 2024;12(2):1–3.
 12. Lorenzetti ER, Monteiro FP, Souza PE, Souza RJ, Scalice HK, Diogo R Jr, *et al*. Essential oils bioactivity in strawberry grey mould control. *Rev Bras Plantas Med*. 2011;13:619–27.
 13. Magaldi S, Mata-Essayag S, De Capriles CH, Pérez C, Colella MT, Olaizola C, *et al*. Well diffusion method for antifungal susceptibility testing. *Int J Infect Dis*. 2004;8(1):39–45.
 14. Mailafia S, Okoh GS, Olabode HO, Osanupin R. Isolation and identification of fungi associated with spoiled fruits. *Vet World*. 2017;10(4):393–7.
 15. Mandal D, Vanlalawmpuia C. Impact of postharvest use of essential oils on pineapple quality and shelf life. *J Postharvest Technol*. 2020;8(3):96–105.
 16. Mari M, Guizzardi M. Postharvest phase: technologies for control of fungal diseases. *Phytoparasitica*. 1998;26(1):59–66.
 17. Mbenoun M, De Beer ZW, Wingfield MJ, Wingfield BD, Roux J. Species boundaries in *Ceratocystis paradoxa* complex. *Mycologia*. 2014;106(4):757–84.
 18. Mirza AA, Senthilkumar S, Singh SK. Trends in post-harvest handling of pineapple. *J Chem Pharm Sci*. 2016;9(4):2885–9.
 19. Oniah T, Tawose FO. Fungi associated with black rot disease of pineapple fruits. *ISABB J Food Agric Sci*. 2018;8(3):18–24.
 20. Onuorah SC, Udemezue OI, Uche JC, Okoli IC. Fungi associated with spoilage of pineapple fruits. *Bioscientist*. 2013;1(1):22–7.
 21. Shao X, Wang H, Xu F, Cheng S. Tea tree oil vapor treatment on postharvest strawberry diseases. *Postharvest Biol Technol*. 2013;77:94–101.
 22. Snowdon AL. Post-harvest diseases and disorders of fruits and vegetables. London: Manson Publishing; 2010.
 23. Tripathi P, Dubey NK, Shukla AK. Essential oils as postharvest fungicides against *Botrytis cinerea*. *World J Microbiol Biotechnol*. 2008;24(1):39–46.
 24. Vilaplana R, Pérez-Revelo K, Valencia-Chamorro S. Essential oils for control of fusariosis in pineapple. *Sci Hortic*. 2018;238:255–63.