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Management Of Post-Harvest Fungi in *Carica Papaya* L. By Plant Gums And Fruit Rinds

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ABSTRACT

Post-harvest fungal infections caused significant spoilage in *Carica papaya* fruits, leading to economic losses and reduced marketability. This study investigated the antifungal potential of selected plant gums and fruit rinds as eco-friendly alternatives to synthetic fungicides for managing post-harvest fungal pathogens. Infected papaya fruits were collected from markets in Chhatrapati Sambhajinagar and Dharashiv, and twelve fungal species were isolated and identified using standard morphological techniques. These included *Alternaria alternata, Aspergillus spp., Fusarium spp., Penicillium spp., Colletotrichum gloeosporioides, Curvularia lunata,* and *Rhizopus stolonifer.* The poisoned food technique was employed to evaluate the antifungal efficacy of aqueous extracts (1% v/v) from plant gums *viz. Acacia arabica, Acacia chundra, Boswellia serrata, Terminalia arjuna, and Mangifera indica* and fruit rinds like *Manilkara zapota, Citrus sinensis, Citrus reticulata, Punica granatum, Mangifera indica*, and *Carica papaya*. Among plant gums, *Terminalia arjuna* exhibited the highest inhibitory activity, particularly against *Penicillium digitatum* and *Colletotrichum gloeosporioides,* followed by *Acacia arabica and Acacia chundra*. Among fruit rinds, *Manilkara zapota* and *Citrus sinensis* showed strong antifungal effects, especially against *Alternaria alternata* and *Fusarium moniliforme*. In contrast, *Carica papaya* and *Punica granatum* rinds showed limited efficacy. Statistical analysis confirmed significant variation in antifungal performance ($p < 0.05$). Overall, plant gums demonstrated broader and more consistent antifungal activity than fruit rinds. These findings supported their potential as sustainable, biodegradable agents in post-harvest disease management strategies for papaya.

KEY WORDS: *Carica papaya*, Fruit rinds, Post-harvest, Poisoned food technique, Plant gums.

1. INTRODUCTION

Papaya (*Carica papaya* L.) is a tropical fruit of significant economic and nutritional value, widely cultivated in regions such as India. Despite its popularity, papaya is highly susceptible to post-harvest fungal infections, leading to substantial losses during storage and transportation. Studies have reported post-harvest losses of up to 75% in papaya, primarily due to fungal pathogens like *Colletotrichum gloeosporioides*, *Alternaria alternata*, *Aspergillus spp.*, *Fusarium spp.*, and *Rhizopus stolonifer* (Kumar *et al.*, 2021).

Traditional management of post-harvest diseases relies heavily on synthetic fungicides such as imazalil, thiabendazole, and sodium o-phenylphenate (D'Aquino & Palma, 2019). While effective, these chemicals pose several challenges, including the development of resistant fungal strains, environmental concerns, and potential health risks to consumers. Moreover, regulatory restrictions on chemical residues in food products have intensified the search for safer alternatives.

In response to these challenges, researchers have explored various natural and eco-friendly methods for controlling post-harvest fungal infections (Bhagwat & Datar, 2014). Biological control agents, such as antagonistic microorganisms, have shown promise but often require specific storage conditions and may not provide consistent results across different environmental settings (Nega, 2014). Similarly, physical treatments like hot water dips and irradiation can be effective but may affect the fruit's quality and consumer acceptance (Shahbaz *et al.*, 2016).

Among the natural alternatives, plant-derived substances, particularly plant gums and fruit rinds, have garnered attention for their antifungal properties. Plant gums from species like *Terminalia arjuna*, *Acacia arabica*, and *Boswellia serrata* have been reported to inhibit the growth of various fungal pathogens (Rathod, 2021). For instance, *T. arjuna* gum has demonstrated significant antifungal activity against *Penicillium digitatum*, a common post-harvest pathogen in citrus fruits. Similarly, fruit rinds from *Manilkara zapota and Citrus sinensis* have shown inhibitory effects against fungi such as *Alternaria alternata* and *Fusarium spp*. The antifungal efficacy of these natural substances is attributed to their rich content of bioactive compounds, including phenolics, flavonoids, and terpenoids (Castillo *et al.*, 2012).

Despite the promising antifungal properties of plant gums and fruit rinds, their application in managing post-harvest diseases in papaya remains underexplored. Most studies have focused on their effects against pathogens in other fruits, and comprehensive evaluations specific to papaya are limited. Furthermore, variations in the efficacy of these natural substances due to differences in extraction methods, concentrations, and environmental conditions necessitate systematic investigations to establish standardized protocols for their use

This study aimed to address these gaps by evaluating the antifungal efficacy of selected plant gums and fruit rinds against post-harvest fungal pathogens of papaya. By identifying effective natural substances and understanding their modes of action, the research seeks to develop sustainable and safe alternatives to synthetic fungicides for managing post-harvest diseases in papaya.

2. MATERIAL AND METHODS

2.1. Collection, isolation, and identification of post-harvest fungi

Fruits of *Carica papaya* showing signs of infection were collected from markets in Chhatrapati Sambhajinagar and Dharashiv across different seasons and stages of ripeness, with an emphasis on visibly affected specimens at the time of harvest and at market stages. Small tissue pieces (2 mm^2) from the infected regions were removed using sterile scalpels and placed on potato dextrose agar (PDA) plates, which were then incubated at 28 °C for a week, with daily monitoring for the growth of fungal colonies. Pure cultures were obtained by employing the single spore isolation technique as outlined by Leyronas *et al.* (2012) and were preserved on PDA slants. The identification of the fungal isolates was carried out by assessing their morphological traits, such as colony characteristics, spore production, and the structures of mycelium and conidia, following standard identification keys.

2.2. Management of post-harvest fungi by plant gums and fruit rinds

The fungitoxicity of plant gums and fruit rinds was evaluated using the poisoned food technique as described by Nene and Thapliyal (1979). Aqueous extracts were prepared from freshly collected plant gums and fruit rinds at a final concentration of 1% (v/v). Plant gums were obtained from *Boswellia serrata*, *Acacia arabica*, *Terminalia arjuna*, *Mangifera indica,* and *Acacia chundra*. Fruit rinds were sourced from *Carica papaya, Manilkara sapota, Citrus sinensis, Citrus reticulata, Mangifera indica,* and *Punica granatum*.

All samples were thoroughly washed to remove debris. Gums were used as-is or powdered if hardened, while rinds were finely chopped and homogenized in distilled water. Each aqueous extract was prepared by mixing 1 g of material in 100 ml of distilled water to yield a 1% suspension. These were stirred well and filtered through muslin cloth to obtain the test solution.

Glucose nitrate agar medium was prepared and sterilized in flasks. After cooling, 100 ml of the medium was mixed with 1 ml of the respective gum or rind extract (1% final concentration) under aseptic conditions. The media were poured into sterile Petri plates and allowed to solidify. Mycelial discs of test fungi were then inoculated onto the media and incubated at room temperature (28 ± 2°C) for six days. Media inoculated without any extract served as the control.

The fungal mycelium was harvested, dried, and weighed to determine the inhibitory effect. Percent inhibition of mycelial growth was calculated using the following formula:

$$\textbf{Percent mycelial inhibition} = \left(\frac{Wc-Wt}{Wc}\right) 100$$

Where Wc is dry mycelial weight of control, Wt is dry mycelial weight of test.

2.3. Statistical analysis

All experiments were conducted in triplicate to ensure reproducibility and accuracy. The results were expressed as mean values accompanied by their standard errors (Mean ± SE). Statistical significance among different treatments was determined using one-way Analysis of Variance (ANOVA), followed by Tukey's Honest Significant Difference (HSD) post hoc test at a 5% level of significance ($p < 0.05$).

3. RESULTS

3.1. Identification of post-harvest fungi

The pathogenic fungal isolates were identified primarily through morphological analysis, which included careful observation of colony characteristics, pigmentation, hyphal structures, and spore morphology. Distinct features of the conidia and hyphae were instrumental in the preliminary identification process. Based on these traits, the fungal isolates were identified as *Alternaria alternata*, *Aspergillus flavus*, *Aspergillus fumigatus*, *Aspergillus niger*, *Colletotrichum gloeosporioides*, *Curvularia lunata*, *Fusarium equiseti*, *Fusarium moniliforme*, *Fusarium oxysporum*, *Penicillium digitatum*, *Penicillium islandicum*, and *Rhizopus stolonifer*.

3.2. Control of post-harvest fungi by plant gums

The present study evaluated the antifungal efficacy of gum powders from *Acacia arabica*, *Acacia chundra*, *Boswellia serrata*, *Mangifera indica*, and *Terminalia arjuna* against ten post-harvest fungal pathogens (Table 1). Among them, *Acacia arabica* demonstrated strong inhibitory activity against eight fungi, with the highest mycelial growth reduction recorded against *Curvularia lunata* (74.7 ± 0%) and notable inhibition of *Fusarium oxysporum* (68.1 ± 0%), *Alternaria alternata* (63.7 ± 0%), and *Colletotrichum gloeosporioides* (60.9 ± 0%). *Acacia chundra* showed similar antifungal potential, effectively inhibiting eight pathogens, particularly *Alternaria alternata* (60.3 ± 0%) and several others ranging between 32.2 ± 0.01% and 12.8 ± 0.01%, though it was ineffective against *Aspergillus flavus* and *Rhizopus stolonifer*.

Terminalia arjuna gum powder exhibited broad-spectrum activity, significantly reducing growth in eight fungal isolates, with the highest inhibition observed against *Penicillium digitatum* (72.3 ± 0%) and *Colletotrichum gloeosporioides* (70.9 ± 0%). In contrast, *Boswellia serrata* showed limited efficacy, affecting only four fungi, while *Mangifera indica* demonstrated the weakest antifungal activity, significantly inhibiting *Alternaria alternata* (55.2 ± 0%) and *Fusarium oxysporum* (6.9 ± 0.01%). Notably, *Aspergillus niger* and *Rhizopus stolonifer* exhibited strong resistance to all tested gums. Tukey's HSD post hoc analysis confirmed that the mean percent growth inhibition across all treatments was significantly different ($p < 0.05$), indicating the distinct antifungal potential of each gum type. The negative readings in the data indicated that the mycelial growth of the test was poor in comparison to control mycelial growth.

3.3. Control of post-harvest fungi by fruit rinds

The antifungal activity of fruit rinds from *Carica papaya*, *Manilkara zapota*, *Citrus sinensis*, *Citrus reticulata*, *Mangifera indica*, and *Punica granatum* were evaluated against ten post-harvest fungal pathogens (Table 2). Among the tested rinds, *Manilkara zapota* exhibited the most promising antifungal efficacy, inhibiting nine fungal species, with maximum inhibition observed against *Alternaria alternata* (71.13 ± 0%) and substantial effects on *Curvularia*

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lunata (63.28 ± 0%) and *Colletotrichum gloeosporioides* (50.76 ± 0%). *Citrus sinensis* also showed strong inhibitory potential, particularly against *Alternaria alternata* (68.94 ± 0%) and *Fusarium moniliforme* (66.03 ± 0%), though it was less effective or even stimulatory against *Aspergillus niger, Rhizopus stolonifer, and Aspergillus flavus*. *Citrus reticulata* rind displayed moderate efficacy, suppressing seven fungi, with F. moniliforme (66.67 ± 0.01%) being the most susceptible.

By contrast, *Mangifera indica* and *Carica papaya* rinds demonstrated limited antifungal activity. *M. indica* showed moderate inhibition of *Fusarium oxysporum* (63.64 ± 0.01%) and selected Fusarium species but was largely ineffective against other fungi. *C. papaya* rind exhibited the weakest antifungal effects, with only minor inhibition against five fungi and promotion of *Penicillium digitatum* growth (-78.21 ± 0%). *Punica granatum* was slightly more effective than papaya, inhibiting four fungi, with highest suppression recorded against *Fusarium equiseti* (39.13 ± 0.01%). Post hoc analysis (Tukey's HSD) revealed that mean percent inhibition values for *Manilkara zapota* and *Citrus sinensis* were statistically similar, while all other treatments differed significantly ($p < 0.05$).

4. DISCUSSION

In the present study, among all the tested plant gums, *Terminalia arjuna* gum powder exhibited the most potent antifungal activity, particularly against *Penicillium digitatum*. This aligned with findings by Khan *et al.* (2022), who demonstrated that ethanolic extracts of *T. arjuna* gum were effective against Penicillium species. While various solvents such as ethanol, acetone, and chloroform have been utilized in earlier studies to extract bioactive compounds, the aqueous gum powder used in this investigation also proved significantly inhibitory. Following *T. arjuna*, gum powders of *Acacia arabica* and *Acacia chundra* were also found to be highly effective. Notably, *Colletotrichum gloeosporioides* showed substantial inhibition in the presence of both *T. arjuna* and *A. chundra* gums. In particular, *A. arabica* showed 60% inhibition of *C. gloeosporioides* in the current study, corroborating results reported by Maqbool *et al.* (2011), where a 10% gum arabic concentration resulted in 74% inhibition.

Boswellia serrata gum powder demonstrated high efficacy against *Curvularia lunata* but was ineffective against *Aspergillus niger*. This finding contrasts with the report of Rastogi *et al.* (2009), who found *B. serrata* gum extracts to be effective against *A. niger*. Such discrepancies in antifungal performance are likely due to differences in fungal strain sensitivity, plant chemotype variations, and the extraction methodologies employed. Among the gums tested, *Mangifera indica* showed the least antifungal effect, aligning with previous observations that considered this gum less potent in fungal control strategies. Nonetheless, plant gums continue to be recognized as sustainable options for post-harvest fungal management due to their biodegradable and non-toxic nature Sravani *et al.* (2014).

Regarding fruit rinds, *Manilkara zapota, Citrus sinensis, Citrus reticulata,* and *Punica granatum* were evaluated for antifungal efficacy. *Alternaria alternata* consistently showed high susceptibility to most fruit rinds, while *Aspergillus flavus* and *Rhizopus stolonifer* exhibited significant resistance. Among all tested rinds, *M. zapota* was the most effective, inhibiting almost all fungi except *Penicillium digitatum*. These results are consistent with Rakholiya *et al.* (2014), who reported moderate antimicrobial activity for the rinds of *M. zapota* and *Carica papaya*. However, *C. papaya and P. granatum* rinds were largely ineffective in this study. Interestingly, *P. granatum* rind has previously been reported to exhibit strong antifungal activity against *A. niger* Dahham *et al.* (2010) and *Fusarium oxysporum* f. sp. *lycopersici* Chen *et al.* (2020), indicating that extraction method and fungal strain may influence results.

The limited antifungal potential of fruit rinds observed in this study aligned with the conclusions drawn by Bosquez-Molina *et al.* (2010), who studied the impact of Mexican lime rinds against *Colletotrichum gloeosporioides* and *Rhizopus stolonifer*, reporting only 40–50% reduction in decay. Similarly, in the current investigation, *Rhizopus stolonifer* showed considerable resistance to most rinds tested. Overall, while fruit rinds demonstrated selective efficacy against certain fungi, their antifungal spectrum was narrow and inconsistent. Therefore, they may serve better as supplementary agents rather than standalone treatments in post-harvest fungal management strategies.

5. CONCLUSION

The study demonstrated that plant gums and fruit rinds exhibited varying degrees of antifungal efficacy against post-harvest fungal pathogens of *Carica papaya*. Among the plant gums, *Terminalia arjuna* showed the most effective inhibition, particularly against *Penicillium digitatum*, followed by *Acacia arabica* and *Acacia chundra*. In contrast, *Mangifera indica* gum exhibited the least antifungal activity. Among the fruit rinds, *Manilkara zapota* and *Citrus sinensis* displayed the highest inhibitory potential, while *Carica papaya* and *Punica granatum* were less effective. Overall, plant gums showed broader and more consistent antifungal activity than fruit rinds, indicating their greater potential for use in sustainable post-harvest fungal management.

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Table 1 Percent mycelial growth inhibition of post-harvest fungi by plant gums

Sr.no.	Plant gums (10 % v/v)	*Alternaria alternata*	*Aspergillus flavus*	*Aspergillus niger*	*Colletotrichum gloeosporioides*	*Curvularia lunata*	*Fusarium equiseti*	*Fusarium moniliforme*	*Fusarium oxysporum*	*Penicillium digitatum*	*Rhizopus stolonifer*
1	*Acacia Arabica*	63.7 ± 0	10.4 ± 0.01	-19 ± 0.01	60.9 ± 0	74.7 ± 0	5.3 ± 0.01	9.2 ± 0.01	68.1 ± 0	36.9 ± 0.01	-69.3 ± 0.01
2	*Acacia chundra*	60.3 ± 0	-43.7 ± 0.01	10.5 ± 0.01	28.2 ± 0.01	12.8 ± 0.01	32.2 ± 0.01	27.7 ± 0.01	13.6 ± 0.01	28.5 ± 0.01	-7.7 ± 0.01
3	*Boswellia serrata*	56.9 ± 0	-34 ± 0.01	-47.5 ± 0.01	62.7 ± 0	68.1 ± 0	16.5 ± 0.01	-2.3 ± 0.01	-2.4 ± 0.01	-10.8 ± 0.01	-59.5 ± 0.01
4	*Mangifera indica*	55.2 ± 0	-9.6 ± 0.01	-57.6 ± 0.01	-17.3 ± 0.01	-0.3 ± 0.01	-22.2 ± 0.01	-24.6 ± 0.01	6.9 ± 0.01	-48.5 ± 0.01	-50.4± 0.01^{a}
5	*Terminalia arjuna*	65.4 ± 0	14.1 ± 0.01	-48.5 ± 0.01	70.9 ± 0	47.5 ± 0	23.2 ± 0.01	70 ± 0	58.9 ± 0	72.3 ± 0	-50.4± 0.01^{a}

All means are the percent inhibition of the mycelial growth. Any mean followed by '±' is the standard error of the mean. The percent inhibition is relative to the growth observed in control flask. All the means are significantly different from each other at p<0.05 level of significance. The means with common superscripts denote significantly similar means (p>0.05)

Table 2 Percent mycelial growth inhibition of post-harvest fungi by different fruit rinds

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Sr.No.	Fruit rinds (10 % v/v)	*Alternaria alternata*	*Aspergillus flavus*	*Aspergillus niger*	*Colletotrichum gloeosporioides*	*Curvularia lunata*	*Fusarium equiseti*	*Fusarium moniliforme*	*Fusarium oxysporum*	*Penicillium digitatum*	*Rhizopus stolonifer*
1	*Manilkara zapota*	71.13±0	4.32±0.01	5.08±0.01	50.76±0	63.28±0	39.75±0.01[a]	48.08±0.01	32.17±0	-28.85±0.01	1.37±0.01
2	*Mangifera indica*	21.83±0	-1.23±0.01	-33.05±0.01	49.24±0.01	-7.81±0.01	56.52±0.01	52.56±0.01	63.64±0.01	-25±0.01	-12.33±0.01
3	*Citrus reticulate*	54.23±0	-17.9±0.01	16.1±0.01	42.42±0	39.84±0	61.49±0.01	66.67±0.01[b]	55.24±0.01	-21.79±0.01	-6.16±0.01
4	*Citrus sinensis*	61.27±0	-8.64±0.01	-44.07±0.01	68.94±0.01	55.47±0.01	26.71±0.01	66.03±0.01[b]	62.24±0.01	6.41±0.01	-9.59±0.01
5	*Carica papaya*	6.34±0	-2.47 ± 0.01	14.41 ± 0.01	26.52±0	-3.13±0	19.88±0.01	30.13±0	-9.09±0	-78.21±0	-69.86±0.01
6	*Punica granatum*	35.92±0	-16.05±0.01	-51.69±0.01	6.82±0.01	7.81±0.01	39.13±0.01[a]	-13.46±0.01	-48.25±0.01	-20.51±0.01	-48.63±0.01

All means are the percent inhibition of the mycelial growth. Any mean followed by '±' is the standard error of the mean. The percent inhibition is relative to the growth observed in control flask. All the means are significantly different from each other at $p<0.05$ level of significance. The means with common superscripts denote similar means.

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