Jurnal Ilmu Pertanian Indonesia (JIPI), April 2026
(Indonesian Journal of Agricultural Sciences)
ISSN 0853-4217 EISSN 2443-3462

Vol. 31 (2): 193–200
http://journal.ipb.ac.id/index.php/JIPI
DOI: 10.18343/jipi.31.2.193

Application of Maggot-based Chitosan for Edible Coating on Cut Papaya (Carica papaya L.)

Sri Wahyuni[1]*, Hanaa Ashiilah[2], Laksmi Ambarsari[2], Haryo Tejo Prakoso, Siswanto[1]

(Received September 2022/Accepted December 2025)

ABSTRACT

Minimally processed papaya fruits are susceptible to postharvest losses due to *Colletotrichum* sp. infection during storage, necessitating additional postharvest treatments such as putting an edible coating to the surface to minimize microbial growth and weight loss. Exuviae from *Hermetia illucens* maggots, which are rarely utilized, contain chitin, which can be converted into chitosan. It also possesses antibacterial properties, making it a viable candidate for edible coatings on papaya fruits. There are various approaches for using edible coating processes. Two of these are spray and immersion methods. In this study, the antifungal activity of synthesized chitosan was tested against *Colletotrichum* sp. and applied as an edible coating to sliced papaya fruit via spray and immersion ways. The effectiveness of the two strategies was compared. The findings revealed that black soldier fly-derived chitosan at varied concentrations (25 to 100 ppm) had antifungal action against the tested fungus. and can be used as an edible coating on sliced papaya fruit. When applied by spray and stored at 10°C, chitosan coating at a concentration of 100 ppm is highly effective in inhibiting *Colletotrichum* sp. growth and fruit weight loss, extending its shelf life by more than 20 days.

Keywords: chitosan, *Colletotrichum* sp., cut papaya, edible coating

INTRODUCTION

Papaya fruit (*Carica papaya* L.) is a climacteric plant that grows in the tropic and subtropical regions. The papaya plant originated in Mexico and migrated throughout Asia, finally reaching Indonesia (Farid 2015). Papaya fruit has a wide range of nutrients, including proteins, lipids, dietary fiber, carbohydrates, and antioxidant vitamins. According to Vij and Prashar (2015), it contains antioxidants, antihypertensive compounds, and hepatoprotective properties. Papaya is one of the most popular fruits due to its numerous health advantages. However, it has a short shelf life of only 7 to 14 days when stored at room temperature. Therefore, additional postharvest treatment is required to extend its shelf life (Farina *et al.* 2020).

Minimally treated papaya fruit is prone to harm. One of the disease that causes postharvest loss is anthracnose, which is caused by *Colletotrichum gloeosporioides* infection. Anthracnose can infect a wide variety of plants, including chili, guava, and banana (Zakaria 2021). Anthracnose on papaya can be found on the fruit, the leaves, or both. It is characterized by dark brown lesions with a softer texture that emerge on the fruit's surface (Rangkuti *et al.* 2017). Anthracnose can develop during the early phases of plant growth, even before the fruits can be harvested. Fungicides and chemicals were employed to manage anthracnose disease, but overuse of fungicides can be harmful to human health and the environment (Zakaria 2021). Humidity, fruit condition, inoculum concentration, and temperature are all known factors that influence *Colletotrichum* sp. infection. This fungus can remain latent inside host tissues and reactivate when fruits ripen, resulting in postharvest losses (Zakaria 2021).

Edible coatings and edible films are now being researched as postharvest packaging solutions to reduce postharvest losses. Okcu *et al.* (2018) described edible film as a thin, edible film that covers the surface of a fruit or vegetable, whereas edible coating is edible film in liquid form. Edible films can be made from protein, polysaccharide, or fat. Polysaccharide-based edible coatings, such as starches, pectin, and chitosan, are widely employed in the food sector due to their abundance (Farina *et al.* 2020).

Chitosan is a linear polymer composed of glucosamine and *N*-acetylglucosamine, with β-1,4-glycosidic bonds as monomers. Chitosan is frequently made from crustacean waste, such as shrimp shells or crab shells, although it can also be synthesized from black soldier fly maggot (*Hermetia illucens*) excretions. Maggot larvae are extensively utilized as a high-protein feed source and for recycling biomass waste. Maggot exuviae are byproducts produced when maggot pupae mature into their next life stage. These exuviae include chitin, which can be converted into chitosan by

[1] Indonesian Oil Palm Research Institute- Bogor Unit, Bogor City 16128, Indonesia
[2] Department of Biochemistry, Faculty of Mathematics and Natural Sciences, IPB University, IPB Darmaga Campus, Bogor 16680, Indonesia
* Coressponden Author: Email: sri09wahyuni@gmail.com

demineralization, deproteination, depigmentation, and chitin deacetylation (Wahyuni *et al.* 2020).

Chitosan molecules have been shown to have antibacterial activity against a variety of bacterial strains, including *Staphylococcus aureus*, *Listeria monocytogenes*, and *Escherichia coli*, as well as antifungal activity against *Colletotrichum* sp., a fungus strain that causes anthracnose on papaya. Chitosan coating has been put to many fruits, including whole papayas. In addition to inhibiting microbial growth, they can produce selective permeable coatings on fruit surfaces, preventing additional weight loss by delaying fruit transpiration and respiration (Firmansyah *et al*. 2016; Shiekh *et al*. 2013). Chitosan coating for fruits can be applied by immersion or spraying. Ali *et al*. (2011) and Lavinia *et al*. (2020) found that chitosan coating may be applied to papaya fruit, however the effectiveness of immersion and spraying methods remains unknown. As a result, this study aims to apply a black soldier fly-based chitosan edible covering to cut papaya fruit via spraying and immersion.

METHODS

Materials

This study was conducted from January to June 2021 in the Biochemistry and Molecular Biology Laboratory of the Indonesian Oil Palm Research Institute-Unit Bogor. The fruits were obtained from vendors at Pasar Anyar in Bogor, West Java. Maggot exuviae were sourced from PT Biomagg Indonesia in Depok.

This research used papaya fruits, distilled water, maggot exuviae, 3M HCl, 2M NaOH, $KMnO_4$ (1% w/v), oxalic acid (1% w/v), potato dextrose agar, acetic acid (2% v/v), commercial antifungal agent (Dithane, 0.75% w/v), beaker glasses, magnetic stirrer, petri dishes, micropipettes, and plastic wrap.

Chitosan Synthesis

Wahyuni *et al*. (2020) synthesized chitosan using maggot exuviae. Black soldier fly maggot exuviae were demineralized with 3M HCl (1:10), then deproteinized with 2M NaOH (1:10). The deproteinated exuviae were next steeped in 100 mL of 1% $KMnO_4$ to remove any pigments, followed by 100 mL of 1% oxalic acid. The synthesized chitin was neutralized and dried before being deacetylated with 50% w/v NaOH and homogenized with a magnetic stirrer for 8 h at 80°C. The synthesized chitosan was then utilized to create an edible coating solution containing 2% v/v acetic acid at concentrations of 25, 50, 75, and 100 ppm.

Isolation of *Colletotrichum* sp.

Colletotrichum sp. was isolated from infected papaya fruits and inoculated onto potato dextrose agar for use in Koch's postulate test and bioassay. The isolates were then cultured at ambient temperature (25 ± 2°C).

Koch's Postulate Test

Koch's hypothesis was tested in duplicate using healthy papaya fruits. Whole fruits were properly cleansed with distilled water before making a slit on their surface. *Colletotrichum* sp. isolate was inoculated between the flesh and skin of papayas before being wrapped in plastic. The control group consisted of papaya fruit that had not been contaminated. The fruits were monitored for 5 d at room temperature (25 ± 2°C).

Bioassay

The bioassay was carried out in quadruplicate by pouring 2 mL of edible coating solutions (25, 50, 75, and 100 ppm) onto 18 mL of potato dextrose agar. *Colletotrichum* sp. were inoculated on agar medium and incubated for 10 d at room temperature (25 ± 2°C). Dithane solution (0.75% w/v) was utilized as positive control, while sterile distilled water served as a negative control. Isolate diameter was measured with calipers and used to calculate growth inhibition using the following equation:

$$\%\, Inhibition = \frac{C - T}{C} \times 100\%$$

where:

C = Mycelium diameter of *Colletotrichum* sp. inoculated on negative control at 10 d

T = Mycelium diameter of *Colletotrichum* sp. inoculated on treatments (25, 50, 75, and 100 ppm) at 10 d

Edible Coating Application

The edible coating was applied in triplicate using immersion and spray methods. Both were stored at ambient temperature (25 ± 2°C) and cold storage (10 ± 2°C). Papaya fruits were washed, sliced into smaller parts, and weighed before applying an edible coating solution. Each triple includes five pieces of chopped fruit. Cut fruit that had been coated with chitosan was placed in styrofoam container and sealed in clear plastic wrap. Both room temperature and cold storage fruits were examined until spoiling occurred, and their final weight was assessed to quantify weight loss during storage using the following equation:

$$\%\, Weight\ loss = \frac{initial\ weight - final\ weight}{initial\ weight} \times 100\%$$

Statistical Analysis

Data were examined using One-Way ANOVA, and significant differences were investigated using the Duncan technique ($p < 0.05$).

RESULTS AND DISCUSSION

Colletotrichum sp. Virulence

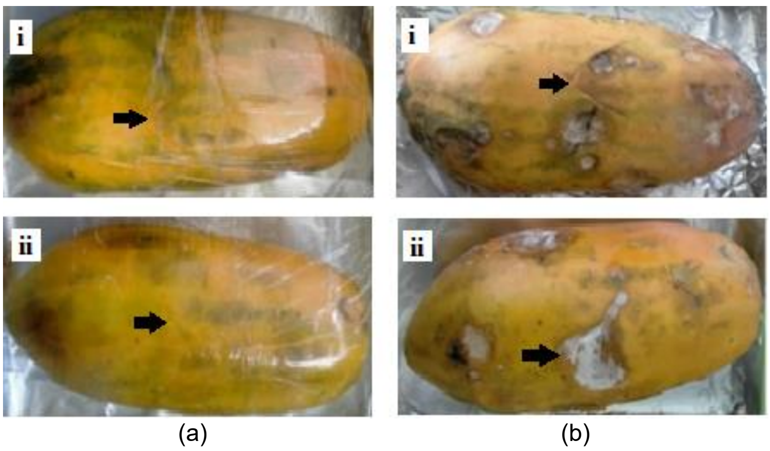
Koch's postulate test is a series of tests commonly used to determine a pathogen's virulence on its host. The test is a series of experiments used to assess a pathogen's pathogenicity on its host. A Koch's postulate needs finding the organism that causes a certain disease in its host. *Colletotrichum* sp. is known to produce anthracnose on papaya, which manifests as color and texture alterations on papaya fruits. The postulate test on *Colletotrichum* sp. is considered effective if the bacterium can induce anthracnose on papaya fruits (Breitschwerdt *et al*. 2013). This study uses the test in duplicate on healthy, unripe papaya fruits. After cleaning the fruit's surface, one group was injected with *Colletotrichum* sp., while the other remains untreated. Both fruits were then stored at room temperature for observation.

Several changes occurred on both papaya fruits used during the observation period, including microbial growth and variations in color, texture, and odor. Microbial growth was seen in a slit on the fruit's surface intended to be injected with *Colletotrichum* sp. Figure 1 shows that no changes occurred on the first day of observation for both control and inoculated fruit. The color, texture, and odor began to change on the second day of observation. Both peels turn from green to yellow-orange, and their texture softens over time. On the third day, both fruits began to emit a slightly strong odor. Signs of spoiling appeared on the fruits inoculated with *Colletotrichum* sp. and in the control group on the third and fourth days of observation, respectively. During the observation period, the peel color and texture of papaya in the infected and control groups changed from green to yellow-orange and hard to soft, respectively. Brown lesions, spoiling, and the formation of white mycelia on the fruits inoculated with *Colletotrichum* sp. demonstrate that the fungus employed can reinfect healthy fruit and induce the same disease, indicating that it is a virulent fungal species that can be used for future bioassay testing. Although the control group's fruits were not inoculated with *Colletotrichum* sp., they did show evidence of deterioration and microbial development outside of the testing region, which could be attributed to microbial contamination from surrounding areas prior to testing. Temperature and humidity can increase microbial growth, which promotes rotting of uninoculated papaya fruit.

Colletotrichum sp. promotes infection by producing phytotoxic metabolites such as colletodiol, colletotric acid, and colletotrichin. They could potentially create cellulase enzymes, which degrades its host's cell wall and causes rotting (Joshi 2018). According to Zakaria (2021), a separate strain of *Colletotrichum* sp. could produce the same anthracnose that occurred in one host. *C. gloeosporioides* and *C. capsici* are known causes of papaya anthracnose, although other *Colletotrichum* species such as *C. magnum*, *C. acutatum*, and *C. karstii* have also been linked to anthracnose on papaya fruit. In addition to papaya fruit, *C. gloeosporioides* has been found to induce anthracnose on other plants such shallot (Hekmawati *et al*. 2018) and chili (Nurbailis *et al.* 2019).

Chitosan Antifungal Activity

An edible coating must possess antibacterial characteristics against pathogens that might cause food degradation. The antifungal activity of black soldier fly-based chitosan must be evaluated against *Colletotrichum* sp. using an *in vitro* bioassay before it can be employed as an edible chitosan coating for papaya fruit. There are various ways for determining an agent's antimicrobial activity against certain microorganisms, including the agar disk-diffusion method and antimicrobial gradient approach. Such approaches are frequently employed to assess a substance's antibacterial activity, but the poisoned food technique is more commonly used to assess antifungal activity against molds. This technique involves mixing an antifungal agent with molten agar and allowing it to



(a) (b)

Figure 1 *Colletotrichum* sp. growth on day 1 (a) and day 5 (b): (i) uninoculated papaya; (ii) inoculated papaya.

solidify before inoculating it with a specific fungus species (Balouiri *et al*. 2016). *Colletotrichum* sp. colonies growing on PDA media have white mycelium with a cotton-like feel. The antifungal activity of a black soldier fly-based chitosan solution against *Colletotrichum* sp. was determined by mixing it with a sterile PDA solution before solidifying. Growth inhibition was assessed by mycelium diameter, with a smaller diameter indicating stronger antifungal efficacy.

Chitosan's bioassay on *Colletotrichum* sp. was performed in quadruplicates, with distilled water serving as a negative control and Dithane, a commercial antifungal compound (0.75% w/v), as the positive control. The incubation period began after inoculating agar media with fungal isolate and ended when the negative control's mycelia completely covered the agar medium, which took 10 d. As shown in Figure 2, *Colletotrichum* sp. growth reduces as concentration increases, with the medium containing 100 ppm coating solution having the shortest diameter of 0.84 cm. The diameter of each medium and control group on day 10 was then utilized to measure growth inhibition. Statistical examination of chitosan solutions at concentrations of 25, 50, 75, and 100 ppm revealed that they all have antifungal activity against *Colletotrichum* sp. It also demonstrates that increasing the concentration of chitosan solution utilized enhanced its antifungal effectiveness, as chitosan at 100 ppm has the closest antifungal activity to a commercial antifungal agent, with a 90.28% growth inhibition.

Although the antifungal method of action of chitosan is unknown, Ing *et al*. (2012) suggested that its antifungal activity is influenced by its molecular weight, degree of substitution, concentration, or the species of fungi itself. Chitosan has been shown to suppress a variety of mycoparasitic fungi, including *Colletotrichum* spp. and *Trichoderma* spp. However, certain fungal species, including *Pochonia chlamydosporia* and *Trichoderma koningiopsis*, are chitosan resistant (Lopez-Moya *et al*. 2019).

Chitosan's structure comprises of hydroxyl and an amino group with a positive charge. Positively charged amino groups may interact with negatively charged cell membranes, resulting in intracellular constituent leakage and cell death (Ahmed *et al*. 2014; Ing *et al.* 2012). Plasma membranes containing polyunsaturated free fatty acids are typically more susceptible to chitosan (Lopez-Moya *et al*. 2019). Depending on its molecular weight, chitosan can interact with nutrients, inhibiting cell growth due to nutrient chelation, or, if small enough, it can interact with a cell's DNA, disrupting protein synthesis and causing cell death (Ke *et a*l. 2021).

Chitosan as Edible Coating

Papaya fruits, being climacteric fruits, can continue to ripen even after they have been harvested. The flesh of fruits softens as they ripen, and the skin color swiftly changes from green to yellow-orange. A burst of ethylene during the ripening process alters the metabolism of papaya fruits. Ethylene production regulates hydrolase expression, one of which is polygalacturonases, which soften papaya pulp by solubilizing pectin on the cell wall. Aside from pulp softening, ethylene production influences acid invertase expression, which converts sucrose into fructose and glucose, resulting in pulp sweetness (Fabi & Frado 2019). Metabolic changes in climacteric fruit during postharvest may enhance respiratory activity and water transpiration rate (Paul & Pandey 2014). Widodo *et al*. (2018) also noted that papaya fruit's high respiration and transpiration rate promotes microbial growth, resulting in spoiling of rapidly ripening postharvest fruits. Several strategies have been used to slow the quick ripening process, one of which is to apply edible coatings on papaya fruits.

Before selecting a material for edible coating, numerous factors must be addressed, including

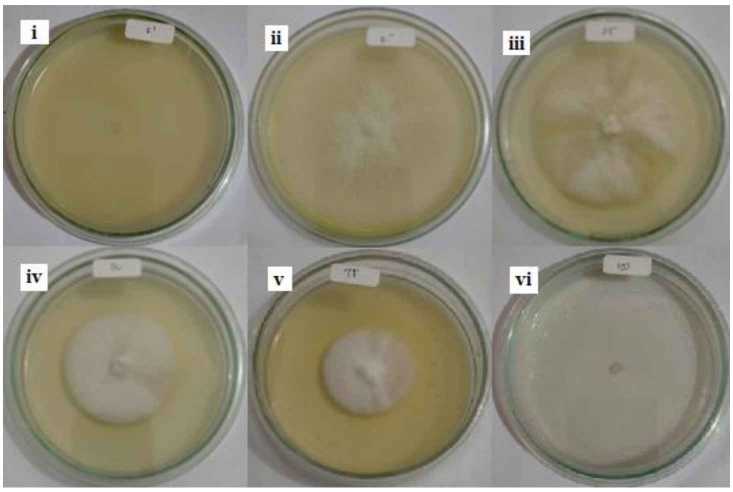


Figure 2 *Colletotrichum* sp. growth on PDA–chitosan medium with varying concentrations: (i) positive control; (ii) negative control; (iii) 25 ppm; (iv) 50 ppm; (v) 75 ppm; and (vi) 100 ppm.

availability, affordability, and adhesive qualities on food surfaces. Polysaccharides such as starches, celluloses, pectin, and chitosan are readily available and have excellent film-forming capabilities. Polysaccharides are structurally stable; hence they are commonly employed as edible films and coatings (Ulusoy *et al*. 2018). Applying a coating to the surface of a fruit can reduce its respiration and transpiration rate, allowing it to keep its original weight and prevent microbial development, extending its shelf life.

Aside from the application of edible coatings, storage circumstances influenced the ripening of papaya fruits. Fruits are sensitive to chilling injury when stored at lower temperatures (<10°C). However, climacteric fruits may become overripe and deteriorate when stored at room temperature for an extended period, especially in humid environments. Papaya fruits are often stored at a cool temperature (10°C) to lengthen their shelf life, however those stored at exceptionally low temperatures are prone to skin scald, drying out, and hard lumps on the surface (Zou *et al*. 2014). The fresh-cut papaya fruits were coated in an edible coating solution (25–100 ppm) via immersion and spray techniques. Tables 2 and 3 demonstrate that coated papaya fruits were stored at room and low temperatures (25 ± 2°C and 10 ± 2°C, respectively). Its look, odor, and texture, as well as microbial development, were all observed over the storage time.

On the second day of observation, uncoated papaya fruits and coated papaya with concentrations of 25, 50, and 75 ppm, held at room temperature, showed evidence of decomposition, but fruits coated with 100 ppm chitosan solution showed signs of spoilage on the third day. On the fourth day, all cut fruits were entirely rotten, as evidenced by their mushy texture, foul stench, and *Colletotrichum* sp. growth on the surface. Each chopped fruit was weighed to determine the weight loss percentage, which was then employed in statistical analysis.

Table 1 shows that the weight loss of coated and untreated papaya fruits is significantly different. When compared to other coated papaya with lower concentrations, the fruit coated with 100 ppm chitosan solution by immersion lost the least amount of weight (17.87%). Although 100 ppm chitosan coated with immersion method has the least weight loss, it is not statistically different from those coated with spray method.

Weight loss is one of the signs of declining fruit quality. Fruit weight loss during storage is caused by the loss of water through transpiration and respiration, which breaks down complex chemicals into simpler molecules. Weight loss in minimally treated fruits rises with time, and significant water loss might cause the fruit to wilt and shrivel (Marpaung *et al*. 2015). Water loss during storage not only reduces weight but also lowers quality and causes harm. Excessive water loss causes fruit wilting and shriveling. Papaya fruits maintained at low temperatures survived longer than those kept at room temperature (Figure 2 dan Figure 3). Uncoated sliced fruits showed evidence of decomposition on the 21st day of observation, while coated fruits indicated spoilage on the 45th day. Both coated and uncoated fruits dried and stiffened during storage. Statistical examination of their weight loss revealed that fruit coated with 100 ppm chitosan solution by immersion method had the lowest weight loss of 27.64%, albeit it did not differ significantly from that coated by spraying method.

Both coated papaya fruits with an edible coating concentration of 100 ppm were able to limit weight loss and microbial development when stored at room or low temperatures, as it had the highest antiviral activity compared to the other concentrations. Because *Colletotrichum* sp. grows more slowly at lower temperatures, the fruits maintained at low temperature live longer than those stored at room temperature. The ideal temperature for *Colletotrichum* sp. growth is between 22 and 30°C; consequently, storing papaya fruits at low temperatures may prevent its growth, resulting in a longer shelf life for the fruits.

There has been research on edible coating applications on papaya fruits using various coatings. For example, putting a covering comprised of aloe vera and papaya leaf extract could reduce sliced papaya fruit water loss by 8% compared to uncoated fruits (Singh & Chaubal 2019). Incorporating essential oils into sodium alginate coating reduced sliced papaya weight loss considerably while stored at 4°C (Tabassum & Khan 2020). Fresh sliced fruits are even

Table 1 Cut papaya's weight loss during room temperature storage and low temperature storage

Treatment		Average weight loss (%)	
		Room temperature storage	Low temperature storage
Control		33.54 ^{a}	69.20 ^{a}
25 ppm	Spray	26.55 ^{b}	44.68 ^{b}
	Immersion	26.30 ^{b}	63.22 ^{a}
50 ppm	Spray	25.91 ^{b}	44.46 ^{b}
	Immersion	24.67 ^{bc}	62.87 ^{a}
75 ppm	Spray	21.94 ^{bcd}	43.50 ^{b}
	Immersion	19.17 ^{cd}	34.77 ^{bc}
100 ppm	Spray	19.80 ^{cd}	30.14 ^{bc}
	Immersion	17.87 ^{d}	27.64 ^{c}

Remark: Different letters indicate significant difference (α = 5%).

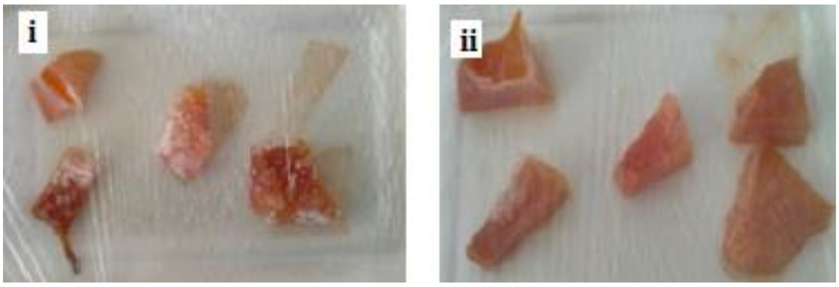


Figure 2 *Colletotrichum* sp. growth on cut papaya slices (room temperature storage): (i) uncoated papaya slices and (ii) sprayed coated (100 ppm) papaya slices.

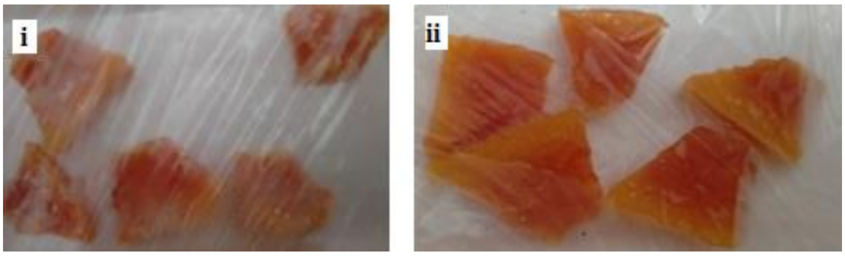


Figure 3 *Colletotrichum* sp. growth on cut papaya slices (low temperature storage). (i) uncoated slices and (ii) sprayed coated (100 ppm) of papaya slices.

more perishable than whole fruits because they lack protective cover, leaving exposed tissue fragile and fast deteriorating (Tabassum & Khan 2020). Kohli *et al*. (2018) found that putting an edible coating to fresh cut fruits can reduce O_2 and CO_2 transpiration, preventing early deterioration. Aside from chopped papaya fruits, chitosan-based edible covering, primarily derived from crustacean shells, has been applied to other fruits, including ber (*Ziziphus mauritiana*) fruit (Hesami *et al*. 2021) and Thomson orange (Taghinezhad & Sharabiani 2018). Wahyuni *et al*. (2021) coated grapes with chitosan derived from black soldier fly exuviae, which has been shown to prevent spoiling when dipped in a 2.5% w/v chitosan solution for 10 min. When a layer of coating is applied to the surface of food, the materials diffuse and adhere to the surface (Kumar *et al*. 2021). Different methods of applying edible coating result in variations in coating dispersion and film formation (Atieno *et al*. 2019).

Dipping (immersion), spraying, panning, and solvent casting are all common ways for putting edible coatings on food. Different surface qualities necessitate distinct application techniques. Because of their convenience, fruits and vegetables are typically covered using dipping or spraying methods. The dipping process involves soaking the food product in a coating solution, then allowing the solvent to evaporate, leaving a thin layer of coating on its surface. In contrast, the spraying approach involves spraying a liquid solution onto the surface of food. Spraying them converts the solution into tiny droplets that can cover larger portions of the product (Kumar *et al*. 2021). Spraying is more popular in the food industry than dipping because it is more convenient and takes less time (Atieno *et al*. 2019). As there is no significant difference in weight loss between sprayed and dipped coatings on cut papaya fruit, the spraying method would be more efficient when done on a large scale because it takes less time than the dipping method.

CONCLUSION

Chitosan derived from black soldier fly maggot exuviae shows antifungal activity against *Colletotrichum* sp. and so can be utilized as an edible covering for sliced papaya fruits. Spraying 100 ppm chitosan on sliced papaya fruit and storing it at 10 ± 2°C can increase its shelf life.

REFERENCES

Ahmed S, Ahmad M, Ikram S. 2014. Chitosan: A natural antimicrobial agent–A review. *Journal of Applicable Chemistry*. 3(2): 493–503.

Ali A, Muhammad MTM, Sijam K, Siddiqui Y. 2011. Effect of chitosan coatings on physicochemical characteristics of Eksotika II papaya (*Carica papaya* L.) fruit during cold storage. *Food Chemistry*. 124: 620–626. https://doi.org/10.1016/j.foodchem.2010.06.085

Atieno L, Owino W, Ateka EM, Ambuko J. 2019. Influence of coating application methods on the postharvest quality of cassava. *International Journal of Food Science*. 2019: 1−16. https://doi.org/10.1155/2019/2148914

Balouiri M, Sadiki M, Ibnsouda SK. 2016. Methods for *in vitro* evaluating antimicrobial activity: A review. *Journal of Pharmaceutical Analysis*. 6(2): 71–79. https://doi.org/10.1016/j.jpha.2015.11.005

Breitschwerdt EB, Linder KL, Day MJ. Maggi RG, Chomel BB, Kempf VAJ. 2013. Koch's postulates and the pathogenesis of comparative infectious disease causation associated with *Bartonella* species. *Journal Comp Path*. 148(2): 115–125. https://doi.org/10.1016/j.jcpa.2012.12.003

Fabi JP, Prado SBR. 2019. Fast and furious: ethylene–triggered changes in metabolism of papaya during ripening. *Frontiers in Plant Science*. 10: 535. https://doi.org/10.3389/fpls.2019.00535

Farid AM. 2015. Effectivity of papaya leaves (*Carica papaya* L.) as inhibitor of *Aedes aegypti* larvae. *Journal Majority*. 4(5): 1–4.

Farina V, Passafiume R, Tinebra I, Scuderi D, Saletta F, Gugliuzza G, Gallotta A, Sortino G. 2020. Postharvest application of *Aloe vera* gel-based edible coating to improve the quality and storage stability of fresh-cut papaya. *Journal of Food Quality*. 2020: 1–10. https://doi.org/10.1155/2020/8303140

Firmansyah Y, Efendi R, Rahmayuni. 2016. Pemanfaatan kitosan untuk memperpanjang umur simpan buah pepaya varietas California. *Sagu*. 15(2): 11–20.

Hekmawati, Poromarto SH, Widodo S. 2018. Resistensi beberapa varietas bawang merah terhadap *Colletotrichum gloeosporioides*. *Jurnal Penelitian Agronomi*. 20(2): 40–44. https://doi.org/10.20961/agsjpa.v20i2.26342

Hesami A, Kavoosi S, Khademi R, Sarikhani S. 2021. Effect of chitosan coating and storage temperature on shelf life and fruit quality of *Ziziphus mauritiana*. *International Journal of Fruit Science*. 21(1): 509–518. https://doi.org/10.1080/15538362.2021.1906825.

Ing LY, Zin NM, Sarwar A, Katas H. 2012. Antifungal activity of chitosan nanoparticles and correlation with their physical properties. *International Journal of Biomaterials*. 2012: 1–9. https://doi.org/10.1155/2012/632698

Joshi R. 2018. A review on *Colletotrichum* spp. virulence mechanism against host plant defensive factors. *Journal of Medicinal Plants Studies*. 6(6): 64–67. https://doi.org/10.22271/plants.2018.v6.i6b.02

Ke CL, Deng FS, Chuang CY, Lin CH. 2021. Antimicrobial actions and applications of chitosan. *Polymers*. 13(6): 904–924. https://doi.org/10.3390/polym13060904

Kohli D, Srivastava A, Kumar S, Upadhyay S, Kaur G. 2018. Effect of edible coating on quality of fresh cut sliced papaya. *International Journal of Food Science and Nutrition*. 3(2): 64–66.

Kumar L, Ramakanth D, Akhila K, Gaikwad KK. 2021. Edible film and coatings for food packaging applications: a review. *Environmental Chemistry Letters*. 20(4): 26. https://doi.org/10.1007/s10311-021-01339-z

Lavinia M, Hibaturrahman SN, Harinata H, Wardana AA. 2020. Antimicrobial activity and application of nanocomposite coating from chitosan and ZnO nanoparticle to inhibit microbial growth on fresh-cut papaya. *Food Research*. 4(2): 307–311. https://doi.org/10.26656/fr.2017.4(2).255

Lopez–Moya F, Suarez–Fernandez M, Lopez–Llorca LVL. 2019. Molecular mechanisms of chitosan interactions with fungi and plants. *International Journal of Molecular Science*. 20(2): 332. https://doi.org/10.3390/ijms20020332

Nurbailis, Djamaan A, Rahma H, Liswarni Y. 2019. Potential of culture filtrates from *Trichoderma* spp. as biofungicide to *Colletotrichum gloeosporioides* causing anthracnose disease in chili. *Biodiversitas*. 20 (10): 2915–2920. https://doi.org/10.13057/biodiv/d201020

Okcu Z, Yavuz Y, Kerse S. 2018. Edible film and coating applications in fruits and vegetables. *Alinteri Journal of Agricultural Sciences*. 33(2): 221–226. https://doi.org/10.28955/alinterizbd.368362

Paul V, Pandey R. 2014. Role of internal atmosphere on fruit ripening and storability: A review. *Journal of Food Science and Technology*. 51(7): 1223–1250. https://doi.org/10.1007/s13197-011-0583-x

Rangkuti EE, Wiyono S, Widodo. 2017. Identifikasi *Colletotrichum* spp. asal tanaman pepaya. *Jurnal Fitopatologi Indonesia*. 14(5): 175–183. https://doi.org/10.14692/jfi.13.5.175

Shiekh RA, Malik MA, Al–Thabaiti SA, Shiekh MA. 2013. Chitosan as a novel edible coating for fresh fruits. *Food Science and Technology Research*. 19(2): 139–155. https://doi.org/10.3136/fstr.19.139

Singh N, Chaubal S. 2019. Innovations of edible coating for enhancement of shelf life and quality management of papaya fruit (*Carica papaya* L.). *International Journal of Advanced Research*. 7(8): 1084–1095. https://doi.org/10.21474/IJAR01/9596

Tabassum N, Khan MA. 2020. Modified atmosphere packaging of fresh-cut papaya using alginate based edible coating: quality evaluation and shelf life study. *Scientia Horticulurae*. 259: 108853. https://doi.org/10.1016/j.scienta.2019.108853

Taghinezhad E, Sharabiani VR. 2018. Effect of chitosan coating on some quality properties of Thomson orange during storage (a case study in Iran). *Agricultural Engineering International: CIGR Journal*. 20(1): 157–161.

Ulusoy BH, Yildirim FK, Hecer C. 2018. Edible films and coatings: a good idea from past to future technology. *Journal of Food Technology Research*. 5(1): 28–33. https://doi.org/10.18488/journal.58.2018.51.28.33

Vij T, Prashar Y. 2015. A review on medicinal properties of *Carica papaya* Linn. *Asian Pacific Journal of Tropical Disease*. 5(1): 1–6. https://doi.org/10.1016/S2222-1808(14)60617-4

Wahyuni S, Selvina R, Fauziyah R, Prakoso HT, Priyono, Siswanto. 2020. Optimasi suhu dan waktu deasetilasi kitin berbasis selongsong maggot (*Hermetia illucens*) menjadi kitosan. *Jurnal Ilmu Pertanian Indonesia*. 25(3): 373–381. https://doi.org/10.18343/jipi.25.3.373

Wahyuni S, Selvina R, Puspita PJ, Prakoso HT, Priyono, Siswanto. 2021. Ekstraksi, karakterisasi, dan aplikasi kitosan berbasis limbah selongsong maggot (black soldier fly) sebagai edible coating pada buah anggur merah *Vitis vinifera*). *Jurnal Penelitian Pascapanen Pertanian*. 18(1): 45–56. https://doi.org/10.21082/jpasca.v18n1.2021.45-56

Widodo SE, Zulferiyenni, Dirmawati SR, Wardhana RA, Fitria, Firi, Fajryah. 2018. Effects of fruit coatings, fungicide, and storage temperature on fruit shelf life and qualities of 'California' papaya. *Journal of Agro Science*. 6(1): 1–8. https://doi.org/10.18196/pt.2018.074.1-8

Zakaria L. 2021. Diversity of *Colletotrichum* species associated with anthracnose disease in tropical fruit crops: A review. *Agriculture*. 11(297): 1–23. https://doi.org/10.3390/agriculture11040297

Zou Y, Zhang L, Rao S, Zhu X, Ye L, Chen W, Li X. 2014. The relationship between the expression of ethylene-related genes and papaya fruit ripening disorder caused by chilling injury. *PLoS ONE*. 9(12): e116002. https://doi.org/10.1371/journal.pone.0116002