Edible Packaging Incorporated Nanotechnology To Improve Papaya Fruit Quality And Shelf Life

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Abstract: Papaya fruit is a world-renowned tropical horticultural commodity. It's due to useful nutritional content and relatively low prices. The fruit is susceptible to post-harvest qualitative and quantitative losses. During post-harvest, papaya is easily damaged by moisture and improper storage temperature, microorganism activity, and physiological activity. Efforts to overcome this problem can be made by spraying hot water combined with chemicals, irradiation, low-temperature storage, and controlled-modified atmosphere packaging. Edible packaging in the form of edible film and coating is one of the environmentally friendly, controlled-modified atmosphere packaging applications. Various materials that can be used as edible films and coatings consist of chitosan, protein isolate, aloe vera, vegetable essential oils, and composites. These ingredients have been proven to maintain physico-chemical properties and extend papaya fruit's shelf life without adverse effects on their organoleptic qualities and are environmentally friendly. In the future, applying this technology is very feasible to be developed while still paying attention to the primary function of protecting products from physical, chemical, mechanical, and microbiological damage, being cheap, easy to use, and having adverse effects on papaya fruit.

Index Terms: Eco-friendly, edible, fruits, papaya, packaging, technology

1. INTRODUCTION

Papaya is a fruit of the Caricaceae family, originates in Central America that can grow in tropical areas [1]. In Indonesia, papaya is a leading commodity because of its relatively affordable price compared to other fruits. It has full nutrition to meet the body's daily vitamin and mineral needs [2]. Papaya is usually served as fresh fruit. Asia contributes 60% of papaya production globally, followed by Latin America with 29% and Africa with 10 % of total production at 13,080,000 tons a year, while Indonesia produces 875,112 tons/year [3], [4]. Most of the papaya's nutritional content is water (89%), carbohydrates (7.2 grams), protein (0.6 grams), fat (0.1 grams), vitamin (A, C, E), niacin, folate, riboflavin, and several essential minerals such as Fe, Mg, K, Ca [2]. There is also a high sugar content, fibers, and bioactive compounds such as phenolics, lycopene, and β-carotene [5], [6]. The high-water content can make it easier to cause damage during post-harvest. Fresh fruits and vegetables contain 80-90% moisture content in the ingredients, of which almost 90% of the weight loss factor occurs due to the transpiration process [7]. Papaya fruit has a climacteric respiration pattern characterized by biochemical changes and rapid post-harvest ripening [8], [9]. This accelerated metabolism causes excessive softening of the fruit, so it is prone to microbial attack and mechanical damage [10]. Generally, around 30%-50% of the crop is damaged during harvest and decomposes before reaching the consumer [11]. The fruit lacks a source of nutrients, water, and anti-senescence hormones after harvest [12]. Due to transpiration and aging, the fruit experiences weight loss [13].
Fruit weight is one of the papaya's quality parameters. Weight loss causes losses, both qualitatively and quantitatively. Moreover, these losses are also accompanied by nutritional degradation to reduce papaya fruit's health benefits [14]. Papaya fruit post-harvest technology is carried out by modified atmosphere packaging, the controlled atmosphere, and the coating after harvesting and during storage to maintain quality. It can also reduce biological activities such as ripening and senescence [15]. The concept of product packaging is to maintain food quality and safety and minimize physical, chemical, and microbiological damage to increase shelf life [16], [17]. However, packaging must pay attention to environmental factors such as ease of degradation to reduce pollution and dependence on using fossil-based packaging materials [18]. Furthermore, it must also consider functional aspects such as smart packaging with its ability to act as an antimicrobial, antioxidant, and to detect other substances that can be used to indicate product quality [19]. Edible films and coatings are known as eco-friendly packaging materials that can replace synthetic packaging material. It can reduce post-harvest fruit and vegetable losses [20]. The edible coating can protect food products from various microbial contaminants, increase shelf life, reduce the effect of deterioration, minimize lipid oxidation, and decrease food products. The main features of edible films and coatings must be protecting or coating the entire food surface, low oxygen transfer permeability, and minimizing other solutes' penetration in fruits and vegetables [21]. Edible films and coatings comprise one or more biopolymers based on carbohydrates, proteins, and fats [22]. Currently also developed smart packaging using nanotechnology with bioactive compounds to make it more functional [23]. This review will discuss post-harvest technology with edible packaging technology to improve papaya fruit's quality and life.

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2. PAPAYA POST-HARVEST TECHNOLOGY AND FACTORS AFFECTING ITS QUALITY

After the harvesting process, the risk of quality degradation in tropical fruits is very high, especially during the transport and storage process. Because of biological changes and the transpiration process, the decline in fruit quality happens. Biological alterations are due to the respiration rate and production of ethylene gas. Meanwhile, transformation causes changes in the fruit's color, taste, aroma, and nutritional content [24]. The degree of ripening and aging in papaya fruit is a factor determining shelf life and final quality. Harvesting papaya fruit should be optimally ripe as underripe fruit tends to wither and suffer mechanical damage easily. Overripe fruit shortens shelf-life. Hence, the right harvesting time is one-factor determining quality, including the papaya nutrients and bioactive compounds [24]. The enzyme endoxylanase increases during papaya fruit ripening. It enzyme plays an essential role in soft texture in papaya [25]. Papaya fruit skin changes color from dark green to light green, and a yellowish color appears on the surface at the final maturation stage. The papaya is declared ripe when the yellow color begins to dominate. According to Singh and Sudhakar Rao [26], the tree's dominant yellow color will age faster during post-harvest on the variety of Venezuelan papaya. Good maturity in papaya when fruit skin yellow has reached 75-100%, without differences in physical and chemical qualities [24]. Papaya peeling functions to protect the fruit from microorganisms, chemical factors, maintain internal temperature, and fruit water loss [27]. Papaya fruit is classified as a climacteric fruit and therefore has a high risk of damage. It's due to increased respiration rate and higher ethylene gas production than non-climatic fruit [28]. Papaya fruit ripens faster after harvesting. It's the main factor of papaya fruit quality [29]. During transportation, the risk of reducing papaya's water content is high, shortening its shelf life [13], [30], [31]. Also, the growth of microorganisms can increase the risk of fruit damage during post-harvest [24]. Low storage temperature adjustment can be controlled as it can slow enzymatic reactions [32]. But papayas are sensitive to low storage temperatures [33]. Keeping the fruit at an inappropriately low temperature causes chilling injury [34]. Therefore, other ways are carried out: using Controlled and Modified Atmosphere Packaging, edible coatings and films, chemicals such as fungicides, irradiation, and heating treatment to extend shelf life [35]–[38]. However, there is still a possibility that pathogenic bacteria such as Escherichia coli will continue to grow, and some other pathogenic fungi [39], [40]. Therefore, factors affecting papaya fruit shelf life include transportation from the farm to market, chilling injuries, and post-harvest diseases [41]. Table 1 shows the various post-harvest handling methods of papaya fruit and their effect on shelf-life.

***Table 1**. Post-harvest handling methods of papaya fruit and their effect on shelf-life*

Papaya fruit types	Post-harvesting methods	Shelf-life quality	Ref.
'Bangkok' papaya	Papaya fruit storage at 14-16 ^{o}C; 20-22 ^{o}C; and 27-30 ^{o}C	Papaya storage at a temperature of 14-16 ^{o}C can extend shelf life of up to 3 days	[42]
'Frangi' papaya	Papaya fruit with gamma-ray exposure (Cobalt-60) at a dose of 0.47-0.50 kGy/h on a cardboard package, 10-minute irradiation at a dose of 0.078-0.083 kGy with hot water pretreatment	The best amount of irradiation was obtained at a 10-minute exposure dose of 0.08 kGy, which can extend the shelf-life of papaya fruit up to 13 days at 11^{o}C and reduce damage from anthracnose and stem-root wilt	[43]
'Golden' papaya	Papaya fruit storage at low temperatures (16 ^{o}C, 11 ^{o}C, 6 ^{o}C, and 1 ^{o}C)	Papaya fruit stored at 1 ^{o}C can last up to 48 days without chilling injury, indicates	[44]
'Maradol' papaya	Hot water immersion at 48 ^{o}C and 1% calcium chloride for 20 minutes. Storage at 12 ^{o}C for 20 days	In this condition, it was able to suppress anthracnose growth at 12 ^{o}C for up to 10 days	[45]
Papaya (cultivar not described)	Papaya immersion used a solution of 0.5 mM and 1.0 mM salicylic acid, 1% and 2% calcium chloride, 1 mM and 2 mM nitrogen monoxide, respectively, for 7 minutes at ambient conditions. Aquadest immersion was used as a control	Soaking with salicylic acid, nitrogen monoxide, and calcium chloride has been shown to extend the shelf life of papaya to 6 days of storage	[46]
Papaya (cultivar not described)	Combination of hot water (49 ^{o}C) and chitosan (concentration 0 M, 5 M, 10 M, 15 M, and 20 M) for 20 minutes; low-temperature storage 28 days	For 30 minutes, 20 M chitosan with hot water at 49 ^{o}C was able to suppress the growth of anthracnose disease in papayas with a shelf life of 28 days and 35 days when stored at 10 ^{o}C	[47]

2.1 Papaya fruit during transport

The distribution chain of papaya fruit will go through transportation, which takes time to reach the consumer. The time taken may be up to 42 days, depending on the market chain's targeted location. During the transportation time to maintain fruit quality, storage temperature, gas composition in the storage room atmosphere such as minimum oxygen concentration and maximum carbon dioxide concentration are required so that papaya fruit is not quickly damaged [48], [49] In developing countries like Indonesia, 30-80% of the fruit is damaged during post-harvest transport. Only about 30-50% of quality papaya fruit reaches consumers. Many post-harvest losses in this distribution chain are detrimental to farmers and consumers, and the market as this factor causes papaya's prices to increase. Common cases occur because of short shelf-life, chilling injury, papaya skin disease, and fruit water loss [13].

2.2 Chilling injury

Chilling injury is a fruit injury due to low-temperature storage, which is below 10 ^{o}C. Generally, tropical fruits such as papaya with fruit skin symptoms such as browning points, submerged fruit flesh, and taste changes fail fruit ripening [50]. Controlling oxygen and carbon dioxide concentrations and coatings can minimize the impact of papaya's physiological changes [30].

2.3 Post-harvest disease

Post-harvest tropical fruit diseases like papayas are usually caused by bacteria and fungi injury. The presence of bacteria and fungi in papayas occurs naturally since pre-harvest. As physiological activity increases, the fruit bacteria and fungi begin to re-infect during the maturing process [51]. Anthracnose disease frequently occurs in papaya. This disease is mainly caused by growth fungi Colletotrichum gloeosporioides and Colletotrichum brevisporum.

3. EDIBLE FILM AND COATING

The application of technology in post-harvest handling systems in papaya aims to maintain the fruit quality for consumers, including efforts to maintain its shelf life. Controlled and modified atmosphere is a technology long used to increase fruit and vegetables' shelf life. This technology's principle controls atmospheric gas in the storage bin by replacing other gases such as carbon dioxide, nitrogen, and hydrogen. In papaya, this technology plays a role in suppressing the incidence of disease in the fruit's skin to increase its shelf life [49], [52]. Low oxygen concentrations of around 1-3% and high Carbon dioxide levels of about 12% can prevent weight loss during the maturing process and inhibit anaerobic metabolism in papayas [53]. The application of modified atmospheric packaging for papaya using edible films and coatings is currently used during transportation to prevent deterioration in fruit quality [54]. Edible films and coatings are primary packaging in a thin layer with environmentally friendly materials. The fruit can be dipped, sprayed, soaked, or wrapped with these ingredients. The edible is useful for inhibiting gas and water vapor release and avoiding contact with oxygen to suppress fruit quality degradation. The main requirement for product edible films and coatings is to use safe materials for human consumption. The fundamental difference between edible film and coating is their application. When applied to fruit, the edible film has a solid layer. In the meantime, the edible coating is done by immersing the fruit into a dispersion solution [22], [55], [56]. The main requirement for edible films and coatings on products is to use materials that are safe for human consumption. Furthermore, they can protect the entire fruit surface, have low water vapor and O_2 gas permeability, do not affect organoleptic properties when applied to fruit, have good mechanical strength for edible films, and are readily biodegradable. The fundamental difference between edible film and coating is the application they use. The edible film has a solid layer when applied to fruit. Meanwhile, the edible coating is carried out by immersing the fruit in a dispersion solution [55], [56]. The use of edible films and coatings has a positive effect on maintaining fruit quality with environmentally friendly materials. It can also preserve sensory properties and weight loss due to gas exchange in the fruit with the environment. Edible films and coatings can even replace the packaging materials of fossil-based plastics challenging to break down. Generally, edible coatings are made with polysaccharide-based materials, fat, protein, and their combination [22], [48]. Among these materials, polysaccharide-based materials are mostly used as edible coatings such as chitosan [57], algae [58], carrageenan [59], starch [60], aloe vera gel [61]. Besides, non-polysaccharide ingredients can also be used both as a main ingredient and as a filler, for example, bee honey [62], protein isolates [63], beeswax [64], essential oils [40], a combination of essential oils and polysaccharides [65]–[67]. Table 2 shows edible coatings and films on papaya with various base materials

***Table 2**. Edible film and coating on papaya with various base materials*

Structural material	Main ingredient	Advantages	Ref.
Polysaccharides	Chitosan, acetic acid, and tween 80	Chitosan concentrations of 1% and 1.5% can maintain hardness, color, acidity, dissolved solids and suppress internal papaya O_2 and CO_2 concentrations at 12 °C, 85-90% humidity for 5 weeks	[57]
Polysaccharides	Chitosan, pectin, and calcium chloride	Multilayer edible coating can increase fresh papayas' shelf-life to 15 days at 4 °C	[68]
Polysaccharides	Hydroxypropyl methylcellulose (HPMC) and silver nanoparticles	Active HPMC-based coating added with 0.25% silver nanoparticles has antifungal properties against Colletotrichum gloeosporioides and controls anthracnose development. Papaya coated with this active ingredient may last over 14 days of storage.	[69]
Polysaccharides	Hot water treatment and chitosan solution	Combining hot water dip (49 °C for 20 minutes) and chitosan coating (20 g/L) significantly reduces anthracnose, papaya aging. The combination doesn't affect papaya's physicochemical and sensory qualities. So, for export, this alternative method can extend papaya's shelf life	[47]
Polysaccharides	Chitosan and Mentha essential oil	The combination of chitosan coating and Mentha essential oil is proven to delay papaya fruit ripening without adverse effects on papaya post-harvest quality	[67]
Polysaccharides	Aloe vera gel, citric acid, ascorbic acid, and gelling agent	Aloe vera gel papaya coating can extend shelf life to 14.3 days. It is not recommended, however, to combine edible coating with plastic packaging	[13]
Protein	Whitemouth croaker fish protein isolate, glycerol, and Montmorillonite K10	It can retain papaya's sensory properties, reduce weight loss by 5.26%, and extend papaya's shelf life by up to 12 days	[63]
Essential oil	Thyme oil and Mexican lime	Thyme oil 0.1% and Mexican lime 0.5% were able to inhibit Colletotrichum gloeosporioides and Rhizopus stolonifera 100% growth	[40]
Fat/ oil	Honey, glycerol, and tween 20	Honey concentrations of 1% and 1.5% maintain weight loss, hardness, dissolved solids, acidity, color for 12 days	[62]
Polysaccharides-essential oil	Lippia sidoides essential oil and carboxymethyl cellulose (CMC)	Essential oils inhibit the growth of anthracnose. Using CMC with essential oils can extend papaya fruit shelf-life	[70]
Polysaccharides-essential oil	Alginate, thyme, and oregano essential oils	Fresh cut papaya coated with alginate adding essential oils of thyme and oregano 1% is the most effective in inhibiting the degradation rate of physicochemical properties of papaya, increasing microbiological protection and being most acceptable to consumers for 12 days of storage at 4 °C	[58]
Polysaccharides-essential oil	Chitosan, and Ruta graveolens L.'s essential oil	Chitosan emulsion and Ruta graveolent L. essential oil can slow papaya fruit's ripeness without affecting its organoleptic properties. Also, anthracnose in papaya fruit may be controlled by this treatment	[65]
Plant	Aloe vera gel	Aloe vera coated papaya at a 50% gel concentration was shown to maintain quality after storage at room temperature for more than 15 days, whereas uncoated only lasted up to 12 days	[61]
Polysaccharides	Potato starch	During drying, it can reduce the thermal loss of bioactive compounds on papaya slices	[60]
Polysacchar	Aloe vera,	It can reduce the thermal loss of	[71]

Structural material	Main ingredient	Advantages	Ref.
ides-essential oil, plant	chitosan, and essential oils	bioactive compounds on papaya slices during drying	
Polysaccharides-fat/ oil	Chitosan and beeswax	The coating can extend Callina papayas' shelf life by inhibiting the fruit's respiratory rate during storage. The combination of these ingredients preserves physical and chemical qualities	[64]
Polysaccharides-fat/ oil	Carrageenan and glycerol	Useful for delaying fruit maturity	[59]

3.1 Polysaccharides

Polysaccharide-based edible coatings are widely used as fruit and vegetable coatings due to their adhesion and flexibility on the surface. Some commonly used polysaccharides are chitosan, galactomannan, pectin, alginate, carrageenan, and starch. Hydrophilic characteristics of polysaccharide-based coatings include low water vapor resistance. However, some polysaccharides can increase high humidity in combination with other compounds such as fat, protein, cross-linking polymers, and multi-layer films to prevent water loss from coated materials [48]. Chitosan concentrations of 1.5% and 2% reduced papaya fruit's weight loss at low temperatures (12 ^{o}C, 85-90% humidity) to <6% compared to controls without chitosan. The use of chitosan as a coating retains the sensory properties of coated papaya fruit. It relates to chitosan's efficiency as a coating that can reduce the respiration rate. Papaya without chitosan coating showed an increase in papaya fruit concentration in internal O_2 [57].

3.2 Fat/ oil

Essential oil is obtained from plant parts extraction and has proven antifungal properties. The functional compounds found in essential oils can suppress papaya fruit skin damage. The essential oil mixture characteristics with CMC inhibit the exchange of oxygen gas from papaya fruit, and this layer can maintain carotenoid discoloration. Papaya's shelf life can last up to nine days [70]. Using 1-1,5% honey as a coating also provides almost similar characteristics to essential oils. Papaya fruit quality can be maintained for up to 12 days [62]. Generally, fat/oil coatings give adequate moisture a glossy appearance [72].

3.3 Composite

It combines more than one component (polysaccharide-lipid) to produce each material's desired characteristics [48]. Combining chitosan concentration (5 mg/mL) with Piperita Mentha oil (0.3-1.25 µL/mL) inhibited 100% growth of Colletotrichum gloeosporioides and Colletotrichum brevisporum. This inhibitory ability increases the papaya shelf life to 10 days at room temperature (25 ^{o}C) [67]. Composite coating characteristics can retain water and gas vapor. However, it has a non-homogeneous emulsion [73].

3.4 Protein

Protein sources commonly used in making edible coatings include whey protein, collagen, gelatin, wheat gluten, soy protein, peanut protein, cotton protein, and corn protein. Edible protein coating usually has good mechanical properties because it consists of 20 different monomers (amino acids), so it has potential for electrostatic forces, forming a hydrophobic layer. This coating has the advantage of reducing the exchange of O_2 at low RH without creating anaerobic conditions in the material, but it is not good because it has low humidity [74]. Using Whitemouth croaker fish protein isolate with nanoparticle technology reduced weight loss by 5.26 % during 12 days of storage while maintaining papaya fruit's sensory properties. It is due to an inhibition of microorganisms' growth on fresh papaya [63].

4. CONCLUSION

Papaya is a climatic fruit with high water content prone to damage due to microorganism growth and physiological activity. During papaya fruit storage and transportation, it experiences weight loss, chilling injury, and skin surface disease. It affects papaya fruit's quality and shelf-life. Papaya post-harvest handling technology has been widely used to overcome these problems, such as combining hot water and chemical immersion, irradiation, low-temperature storage, and edible packaging technology. Edible packaging on papaya is carried out in the form of edible film and coating with the application of controlled and modified atmosphere packaging technology to extend papaya fruit shelf life. Edibles are made of polysaccharide, protein, fat/ oil-based, and composites. Each of these main ingredients has different permeability, water vapor, and hardness characteristics. Edible packaging technology is currently combined with essential oils containing bioactive compounds proven to be useful as antimicrobials and antioxidants without altering the fruit's organoleptic properties. Nanotechnology is also developed in the form of edible nanocoating. Besides improving quality and shelf life and quality, it also provides specific functional properties to commodities.

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