Research Article

Preharvest Shellac Fruit Coating at Mature Green Stage Delays Ripening Process and Alleviates Translucent Flesh Disorder of Harvested Mangosteen (*Garcinia mangostana* L.)

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Abstract
Translucent flesh disorder (TFD) is a major physiological problem in mangosteen fruit, often triggered by heavy rainfall during fruit maturation. This study demonstrated that preharvest applications of shellac coating effectively mitigated TFD. Mature–green fruits on the tree were coated with shellac (0, 5, and 10%) and exposed to simulated rainfall prior to harvest. Uncoated fruits subjected to water treatment exhibited a three–fold higher incidence of TFD upon ripening. In contrast, shellac–coated fruits, regardless of water treatment, showed a marked reduction in the disorder, with higher shellac concentrations offering greater protection. The shellac coating functioned as a physical barrier, preventing water infiltration and maintaining normal pericarp moisture at approximately 70%, whereas the pericarp of TFD–affected fruit reached 74%. Sequential pectin extraction from affected arils revealed elevated levels of Na_2CO_3–soluble pectin, suggesting that cell wall modifications contribute to increased aril firmness and the characteristic translucency of the tissue. In addition to preventing TFD, the shellac coating delayed ripening and extended postharvest shelf life by approximately one week. These results indicate that preharvest shellac coating during the rainy season is a promising strategy to reduce the incidence of TFD and extend the postharvest shelf life of mangosteen fruits.

Keywords: Capillary water, Hypoxia, Lignin, Postharvest, Wax coating

1 Introduction

Mangosteen (*Garcinia mangostana* L.), a member of the Clusiaceae family, is an evergreen fruit tree that thrives in tropical regions [1]. In Thailand, mangosteen is considered a significant economic crop, ranking among the world's top exporters. The export value reached $427.28 million in 2024, with China

serving as the primary destination, accounting for 91% of total exports, followed by Vietnam, South Korea, the United States, and the United Arab Emirates [2]. Despite its economic importance, mangosteen exports face a critical challenge from a physiological disorder known as "translucent flesh disorder (TFD)". This disorder develops during fruit ripening and imparts a crisp, glass-like texture to the flesh. Mangosteen fruit development typically occurs during the rainy season, and the incidence of TFD becomes particularly severe during periods of heavy rainfall.

The precise mechanisms underlying translucent flesh disorder development in mangosteens remain unclear and require further investigation. Nevertheless, numerous studies have identified factors highly correlated with TFD incidence, including excess water availability, imbalances in calcium and boron concentrations, and mechanical injuries during handling and harvesting [3]. Several management approaches have been explored to mitigate this disorder. For instance, maintaining the soil water potential at approximately −70 kPa before harvest has been shown to reduce symptom severity [4]. Additionally, foliar applications of $CaCl_2$ and H_3BO_3 have demonstrated potential in decreasing TFD incidence [5], [6]. Our previous studies revealed that water droplets from rainfall on the fruit surface create hypoxic conditions within the fruit by saturating capillary water in the pericarp of on–tree mature green fruits. These hypoxic conditions trigger increased lignin accumulation in the cell walls of aril tissue [7], which activates oxidative stress mechanisms and lignification, ultimately leading to TFD in ripen fruits, through elevated lignin levels [7]–[9].

Shellac is a natural resin secreted by the female lac insect, specifically *Kerria lacca*. Although the lac insect is found on many tree species, it occurs in abundance only in Thailand and India. The main constituents of shellac are polyhydroxy acids, predominantly aleuritic acid, jalaric acid, and shellolic acid. This biodegradable material is a versatile and multifunctional biopolymer with unique properties and sustainable sourcing [10], [11]. Although shellac was historically restricted to non–edible industries, its approval by the U.S. Food and Drug Administration (U.S. FDA) and the European Union (EU) for safe human consumption has enabled rapid expansion of its utilization in the food and pharmaceutical industries [12]–[14].

Several advantages have been demonstrated when applying shellac coatings to fruits after harvest, including prevention of weight loss and disease, reduction of respiration and ethylene production rates, and extension of postharvest shelf life [15], [16]. Numerous fruits such as apples, bananas, green chilies, mangoes, peppers, and tomatoes have been successfully coated with this environmentally friendly and edible resin, authentically demonstrating prolonged shelf lives and improved quality maintenance [15], [17], [18]. In addition to postharvest management, preharvest handling practices have proven effective in improving fruit quality. Preharvest sprays of water–soluble wax on raspberries increased berry size and decreased softening during storage [19], while carnauba wax sprays applied in the field significantly reduced sunburn symptoms in citrus fruits [20]. Preharvest sprayings of essential oils (carvacrol, eugenol, thymol, or glycerol) directly on lemon or orange fruits on the tree have been shown to decrease fungal incidence, reduce fruit weight loss, and minimize decay [21], [22]. These findings suggest that preharvest protective coatings represent a viable strategy for addressing fruit quality issues before harvest, potentially preventing rather than merely treating postharvest disorders.

Building on our previous findings [7]–[9] and considering the limited information on the use of shellac as a preharvest fruit coating, the present research was designed to fill this knowledge gap. We hypothesized that applying shellac coating to on–tree mangosteen fruits at the mature green stage would create a physical barrier that prevents water infiltration into the pericarp, thereby reducing TFD development along with associated changes in cell wall composition, including pectin fractionation and lignin accumulation.

2 Materials and Methods

2.1 *Plant materials*

Mature mangosteen trees (approximately 15 years old) were selected from Phunphon Farm in Thung Nonsi Subdistrict, Khao Saming District, Trat Province, eastern Thailand. Nine trees were used for the field experiment.

2.2 *Coating material preparation*

Shellac solution was prepared according to Wang *et al.* [23]. Shellac powder (Union Shellac Part., Ltd., Bangkok, Thailand) was dissolved in 0.1 N NaOH

solution to prepare 5 and 10% (w/v) shellac coating solutions. A beaker containing the mixture was placed in a hot water bath and stirred gently until the shellac powder was fully dissolved and adjusted to 100 mL.

2.3 *Fruit coating experiment*

The procedure was modified from Noichinda *et al.* [7]. Mature green fruits on the tree, exhibiting uniform physiological maturity (11 weeks after anthesis) with a minimum circumference of 20 cm were randomly selected. Each fruit surface was coated by dipping in 0, 5, and 10% shellac solution for several seconds, followed by draining of excess solution before a second application. For subsequent water treatments, fruits were wrapped in three layers of gauze and covered with a plastic cup with a bottom hole (Figure 1(A)). The cup was further enclosed in a plastic bag to provide complete protection from rainwater exposure. Water was supplied from an overhead hanging plastic container via a drip line (Figure 1(B)) at a flow rate of 0.6 mL/min for 2 days. Most parameters included 4 replicates per treatment, except TFD assessment, which included 10 replicates per treatment. Fruits were collected on day 3 and transported to the laboratory within a day.

Figure 1: An individual mangosteen fruit was wrapped in gauze and covered with a plastic cup (A) and a plastic cup was covered with a plastic bag to wholly prevent rainwater (B).

2.4 *Determination of translucent flesh disorder percentage*

In the laboratory, coated and uncoated mature green mangosteen fruits, subjected to either watering or no watering treatment on the tree, were allowed to ripen at ambient conditions (28 ± 3 °C, 78 ± 2% relative humidity (RH)) until fruits reached a purple–red color. Fruits were classified into normal and translucent flesh categories by immersion in a 4% NaCl solution. Fruits that sank were classified as having translucent flesh, while those that floated were considered normal [24]. The percentage of translucent flesh disorder (TFD) was calculated using the following formula:

$$TFD(\%) = \frac{Number\ of\ translucent\ flesh\ fruits \times 100}{Total\ number\ of\ fruits}$$

2.5 *Determination of water content*

Mangosteen pericarp (peel) and aril (flesh) were finely chopped with a sharp knife. Moisture cans were pre–dried at 105 °C and weighed to determine tare weight. Three grams of sample were placed in each moisture can, and oven–dried at 105 °C for 12 h before being placed in a desiccator for at least 30 min. The cans were reweighed to calculate the sample water content.

2.6 *Determination of firmness*

Firmness of normal and translucent mangosteen aril was evaluated using a modified method from Noichinda *et al*. [7]. Aril segments were removed and placed horizontally on a TA–XT2i texture analyzer (Stable Micro Systems, USA). Measurements were taken using a 2 mm spherical plunger at a test speed of 1.5 mm/s and expressed in Newtons.

2.7 *Determination of pectin*

Three types of pectin, water-soluble pectin (WSP), EDTA–soluble pectin (EDTA–SP), and Na_2CO_3–soluble pectin (Na_2CO_3–SP), were analyzed.

2.7.1 Alcohol Insoluble Residue (AIR) preparation

Alcohol Insoluble Residue (AIR) was prepared using modified methods from Barbier and Thibault [25] and Rosli *et al.* [26]. Five grams of aril sample were refluxed in 95% ethanol (four times the sample volume) for 30 min. After cooling, the mixture was filtered through Whatman No. 1 filter paper. The residue was washed three times with 15 mL of 95% ethanol and incubated at 50 °C for 12 h.

Extractions of subsequent pectins were carried out using modified methods of Martin–Cabrejas *et al.* [27] and Dangcham [28] as follows.

2.7.2 Extraction of water-soluble pectin (WSP)

Thirty mg of AIR were mixed with 20 mL of distilled water and shaken at 80 rpm, 20 °C for 2 h before centrifuging at 15,300×g for 30 min. The supernatant was collected. The residue was extracted 2 more times for 1 h each. All supernatants were combined for WSP analysis.

2.7.3 Extraction of EDTA–soluble pectin (EDTA–SP)

The residue from WSP extraction was further extracted 3 times with 20 mL of 0.05 M sodium citrate buffer (pH 4.5) containing 0.04 M EDTA. Supernatants were combined for EDTA–SP analysis.

2.7.4 Extraction of Na_2CO_3–soluble pectin (Na_2CO_3–SP)

The residue from EDTA–SP extraction was further extracted 3 times with a mixture of 20 mM sodium borohydride and 20 mM sodium carbonate. Supernatants were combined for Na_2CO_3–SP analysis.

2.7.5 Quantitative analysis of three types of pectin

Quantification of the 3 pectin types followed a modified method from Blumenkrantz and Asboe–Hansen [29]. A 0.5 mL sample extract was mixed with 2.5 mL of 0.0125 M sodium tetraborate in conc. H_2SO_4, on ice, and then heated at 100 °C for 10 min. After cooling, 0.1 mL of 0.15% *m*–hydroxydiphenyl dissolved in 0.5% NaOH solution was added and mixed. Following 15 min incubation, absorbance was measured at 520 nm and compared with a polygalacturonic acid standard curve.

2.8 ***Determination of lignin***

Lignin content was determined using a modified method from Bruce and West [30]. Four grams of mangosteen aril were homogenized with 16 mL of 99.8% methanol for 1 min and filtered through Whatman GF/A filter paper. The resulting AIR was dried at 60 °C for 24 h. Fifty mg of dried AIR were then dissolved in 5 mL of 2 N HCl containing 0.5 mL of 98% thioglycolic acid and then heated at 100 °C for 4 h. After cooling, the solution was centrifuged at 12,000×g for 30 min. The pellet was washed with 5 mL of distilled water and resuspended in 5 mL of 0.5 N NaOH. The mixture was sealed with parafilm and gently agitated at 25 °C for 18 h before being centrifuged at 12,000×g for 30 min. The supernatant was then combined with 1 mL of conc. HCl and precipitated at 4 °C for 4 h. Following centrifugation at 10,000×g for 10 min, the orange-brown pellet was dissolved in 25 mL of 0.5 N NaOH, and absorbance was measured at 280 nm.

2.9 ***Preliminary evaluation of consuming quality***

Normal mangosteen aril from fully ripe mangosteen fruits, coated and uncoated with shellac, with and without on–tree surface watering, was analyzed for soluble solids content and titratable acidity.

2.9.1 Determination of soluble solids

Mangosteen aril was finely chopped and ground in a mortar to extract juice. A drop of juice was placed onto a hand refractometer, and the reading was recorded.

2.9.2 Determination of titratable acidity

Four mL of distilled water were mixed with 1 mL of aril juice and 2 drops of phenolphthalein were added. The mixture was titrated with 0.1 N NaOH solution until a pale pink endpoint was reached. The volume of NaOH solution used was calculated as a percentage of citric acid as follows:

$$\%\ Citric\ acid = \frac{N\ base \times mL\ base \times meq.wt\ CA \times 100}{mL\ of\ sample}$$

Where: N base = 0.1 N
meq.wt of CA (citric acid) = 0.06406
mL of sample = 1 mL

2.10 ***Statistical analysis***

A completely randomized design (CRD) was used for this study. Statistical analysis was initially performed on data from firmness, pectin content, lignin content, soluble solids, titratable acidity, and water content. Analysis of variance (One–way ANOVA) was subsequently conducted with a confidence interval of 95%. Where appropriate, mean values of CRD combinations were compared using Duncan's New Multiple Range Test (DMRT).

3 Results and Discussion

3.1 *Postharvest quality of mangosteen fruits*

In a preliminary study, a 20% (w/v) shellac coating caused injury to the mangosteen peel (data not shown). Therefore, in the present study, shellac concentrations of 0%, 5%, and 10% were selected. Shellac coating and subsequent water–dropping treatments revealed that uncoated fruits (0% shellac) required 3 days after harvest to reach ripening (determined by peel color change to purple–red), regardless of water treatment (Table 1). Among water–applied fruits, the incidence of TFD was threefold higher than in untreated fruits. Notably, TFD incidence of 5% was still observed in non–water–applied fruits, likely due to rainfall that occurred in the area prior to the experiment (Figure 2).

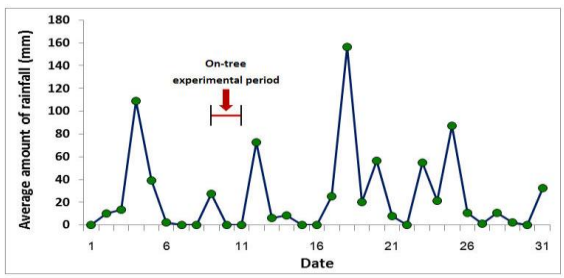


Figure 2: Average amount of rainfall in the experimental area during the investigational month.

Table 1: Postharvest properties of on–tree shellac–coated or uncoated mangosteen fruits after harvest.

Treatments	TFD (%)	DR (Days)	SS (%)	TA (%)
0% Shellac: NWA	10	3	16.3±0.5 a	0.47±0.04 a
0% Shellac: WA	30	3	15.6±1.2 ab	0.41±0.07 a
5% Shellac: NWA	10	7	14.0±1.0 bc	0.41±0.10 a
5% Shellac: WA	10	7	14.0±0.0 bc	0.43±0.04 a
10% Shellac: NWA	0	10	13.7±0.6 c	0.51±0.07 a
10% Shellac: WA	0	10	13.7±1.5 c	0.53±0.08 a

Note: The different letters after means value ± the standard deviation (SD) in the same column indicate significant differences at *p*–value < *0.05* according to DMRT. TFD = Translucent flesh disorder, DR = Duration time of ripening, SS = Soluble solids, TA = Titratable acidity, NWA = non–watered and WA = watered.

Although a 5% shellac coating failed to prevent TFD development, it effectively extended the ripening duration to 7 days (Table 1). Remarkably, a 10% shellac coating completely inhibited TFD and prolonged shelf life to 10 days, regardless of water application. In terms of consumer quality, uncoated fruits exhibited slightly higher soluble solids (an indicator of sweetness) than shellac–coated fruits. However, titratable acidity (an indicator of sourness) did not differ significantly between treatments (Table 1). These findings suggest that higher shellac concentrations more effectively suppress TFD, albeit with a corresponding delay in ripening, irrespective of water applications.

3.2 *Water component in pericarp and aril*

Mangosteen pericarp (peel) and aril (flesh) contained approximately 70% and 85% water content, respectively (Figure 3). In the water–applied, non–shellac–coated fruits, pericarp water content increased to 74%. This 4% increase appears to have contributed to the development of a translucent flesh disorder in the aril of ripened fruits (Table 1). Although the additional water volume was relatively small, it likely penetrated the fruit surface through lenticels via capillary forcing action [7]. This capillary water subsequently prevented gas movement and exchange across the pericarp structure, creating hypoxic conditions in the fruit cells. Importantly, the aril is morphologically connected to the pericarp through a vascular network, allowing pericarp internal conditions to influence aril development. The mangosteen pericarp undergoes ripening concurrently with the aril, characterized by a color change to purple and softening, respectively. Despite treatment differences, the water content in the aril remained relatively constant across all samples. These results suggest that excess capillary water primarily altered the pericarp's internal environment and enhanced hypoxic conditions, which subsequently influenced translucent disorder development in the aril via the vascular network.

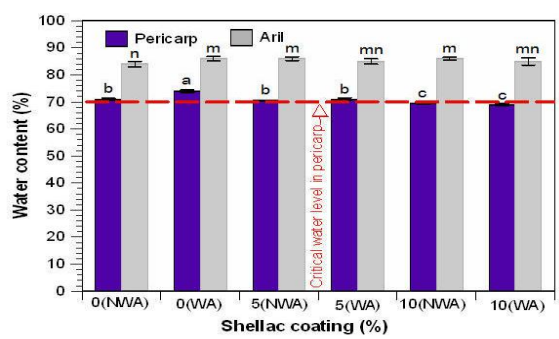


Figure 3: Percentage of water content in mangosteen pericarp and aril. NWA = non–watered and WA = watered. Vertical bars represent the mean ± SD. The different letters on the bars indicate significant differences at *p*–value < *0.05* according to DMRT.

3.3 *Aril firmness*

Aril firmness, an indicator of fruit maturity, declined progressively during ripening. In non–water–applied mangosteen fruits, aril firmness measured 0.2 N, approximately half that of water–applied fruits. In contrast, translucent arils exhibited significantly higher firmness at 1.9 N (Figure 4). Translucent flesh may retain structural rigidity from the unripe stage or undergo cell wall remodeling during ripening, resulting in a firmer, less pliable texture with an altered mouth feel. Our previous research reported that the firmness of unripe mangosteen aril was 4.6 Newtons [7]. Compared to the non–coated control, 10% shellac surface coating effectively maintained aril firmness by delaying the fruit ripening (Table 1).

Wax coatings have been shown to reduce gas exchanges at postharvest in many fruits [31]–[33]. Ripening was delayed in coated mangosteen fruits due to the delay of peel color changes and aril softening. Shellac–based coatings, as a non–polar compound, are well–known to reduce gas and moisture exchange by creating a barrier on the fruit's surface. This barrier effect can lower internal oxygen, increase internal carbon dioxide, and reduce the rate of ethylene production, all of which contribute to slowing the metabolic processes of ripening. This phenomenon has been observed in various fruits, including citrus [34], and tomato [35].

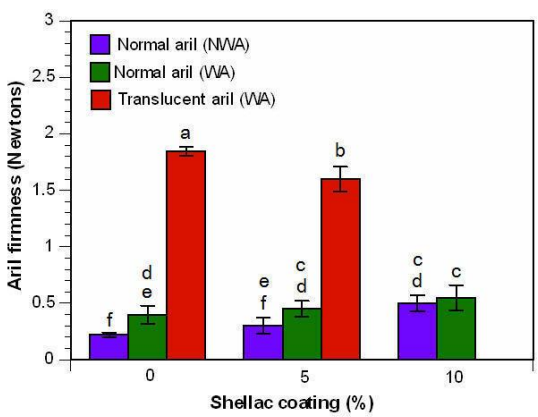
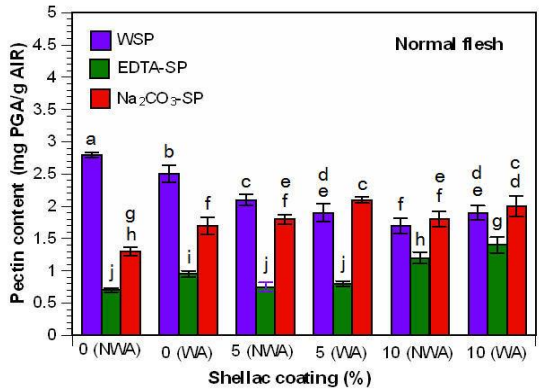


Figure 4: Aril firmness of normal and translucent aril of ripe mangosteen. NWA = non–watered and WA = watered. Vertical bars represent the mean ± SD. The different letters on the bars indicate significant differences at *p*–value < *0.05* according to DMRT.



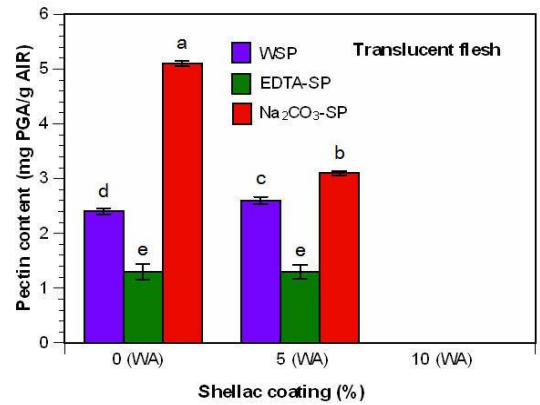


Figure 5: Pectin content in mangosteen aril. NWA = non-watered and WA = watered. Vertical bars represent the mean ± SD. The different letters on the bars indicate significant differences at *p*–value < *0.05* according to DMRT.

3.4 *Pectin content*

Pectin is a critical compound in plant cell walls, particularly within the middle lamella, where it reinforces cell–to–cell adhesion. As the fruit ripens, the middle lamella slowly loses its structure, which makes the tissue softer. Unripe mangosteen aril is predominantly composed of insoluble pectin, which is enzymatically converted into more soluble forms by pectic enzymes such as pectin methylesterase (PME) and polygalacturonase (PG) during ripening. In this study, water–soluble pectin (WSP) contained a high proportion of soluble carbohydrates, including mono– and oligosaccharide residues. EDTA–soluble pectin (EDTA–SP) contains deprotonated carboxyl (COO^-) pectin, which is loosely bound to the cell wall via Ca^{2+}. Finally, Na_2CO_3–soluble pectin (Na_2CO_3–SP) is pectin bound via ester linkages. The present results

indicate that normal ripe aril of uncoated fruit was characterized by high WSP, low EDTA–SP, and moderate Na_2CO_3–SP levels. Normal ripe aril of 10% shellac–coated fruits retained higher levels of EDTA–SP and Na_2CO_3–SP, suggesting delayed pectin solubilization (Figure 5). The sequential extraction method of pectin involves the use of specific solvents to isolate distinct pectin pools in a specific order: water–soluble pectin, ionically bound pectin (calcium pectates), and covalently bound pectin. Therefore, the sum of the extracted fractions does not represent the total pectin content of the tissue at any single point in time, but rather the distribution of pectin among these different pools.

The pectin profile in translucent flesh was mostly the same as in normal aril, with the exception of a slightly higher Na_2CO_3–SP content (Figure 5). However, previous research on pectic enzyme activity revealed that the softening patterns of normal and translucent flesh were comparable [24], [36]. These findings suggest that pectin structures in translucent flesh may interact with other compounds via ester bonding, potentially contributing to altered firmness and texture. The differences observed between the normal and translucent fruit reflect the physiological changes occurring in the cell wall, where pectins are being transformed from one form to another (e.g., from soluble to ionically or covalently bound forms). These transformations, rather than loss of material during extraction, account for the differing amounts in each fraction between treatments.

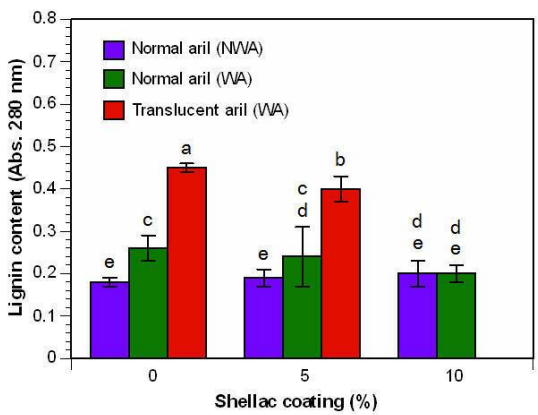


Figure 6: Lignin content in normal and translucent aril of mangosteen. NWA = non–watered and WA = watered. Vertical bars represent the mean ± SD. The different letters on the bars indicate significant differences at *p*–value < *0.05* according to DMRT.

3.5 *Lignin content*

Lignin, a secondary metabolite, was detected in both normal and translucent flesh, with notably higher accumulation in translucent flesh (Figure 6). Many secondary metabolites are synthesized in plants under some stress conditions, such as low temperature [37], irradiation [38], water flooding [39], and mechanical wounding [40]. Anatomically, lignin is a major component of plant fibers and plays a protective role by regulating gas movement through the cell wall. It is commonly found in aerenchyma cells formed under flooding conditions [39]. In mangosteen, capillary water accumulation in pericarp lenticels is associated with elevated lignin deposition in the aril [7]. Supporting this observation, scanning electron micrographs of translucent flesh revealed extensive coverage by white stripe layers (identified as lignin), with a smooth surface and minimal open-air pores [8].

Generally, the fruit peel structure consists of stomata and lenticels, both covered by a cuticle (natural wax). This cuticular layer acts as a semi–permeable barrier, regulating gas and water exchange between the fruit and the surrounding atmosphere. For on–tree mature green mangosteen fruits, prolonged exposure to rainwater, specifically soaking for more than two hours, was found to induce abnormal aril ripening and TFD development after harvest [41]. According to the present results, higher pericarp water content in non–coated controls (Figure 3) resulted in a threefold increase in translucent flesh incidence (Table 1). Exogenous water from rainfall or water treatments penetrates the pericarp through lenticels via capillary action (Figure 7). This capillary water likely obstructed the movement and exchange of gases (O_2 and CO_2), creating cellular hypoxic conditions characterized by reduced internal oxygen and elevated CO_2 levels. Under hypoxia, the tricarboxylic acid (TCA) cycle is suppressed, leading to energy depletion in living cells. To compensate, plants activate alternative metabolic pathways such as fermentation and the pentose phosphate pathway to generate intermediate substrates and regenerate NAD^+ for glycolysis (Figure 7). Under hypoxia, alcohol dehydrogenase (ADH) activity is triggered, resulting in the production of ethanol and the oxidation of NAD^+ in the final step of fermentation [42]. However, excessive ethanol accumulation exacerbates cellular damage. Key intermediates, such as erytose–4–P from the pentose phosphate pathway and phosphoenolpyruvate (PEP) from glycolysis, serve as

precursors for shikimate biosynthesis, which subsequently yields chorismate. Chorismate is further converted into phenyl compounds via the phenylpropanoid pathway, ultimately producing phenolic acids and monolignols [43]. Monolignols are polymerized into lignin by peroxidase (POD). Lignin binds to pectin through ester linkage, and both are eluted by Na_2CO_3 extraction buffer. This biochemical remodeling contributed to the formation of translucent and firm flesh tissues.

The elevated Na_2CO_3–SP in translucent flesh (Figure 5) suggests a predominance of ester–bound pectic compounds. During ripening, the hydrolysis of middle lamella pectin in mangosteen aril is predominantly facilitated by pectate lyase (PL) rather than polygalacturonase (PG) [24]. This pattern indicates that hydrolyzed pectin in the middle lamella binds to intermediate substances derived from the shikimate pathway, forming new structures [38]. Figure 6 provides supporting evidence of elevated lignin levels in translucent flesh. Normally, lignin is synthesized through polymerization of monolignol derivatives from the phenylpropanoid pathway [43]. Therefore, lignin may bind to hydrolyzed pectin structures through ester linkages, similar to the formation of lignified aerenchyma in plant roots under waterlogged conditions [39]. This change in cell wall structure likely results in increased firmness and the characteristic translucency observed in affected mangosteen aril.

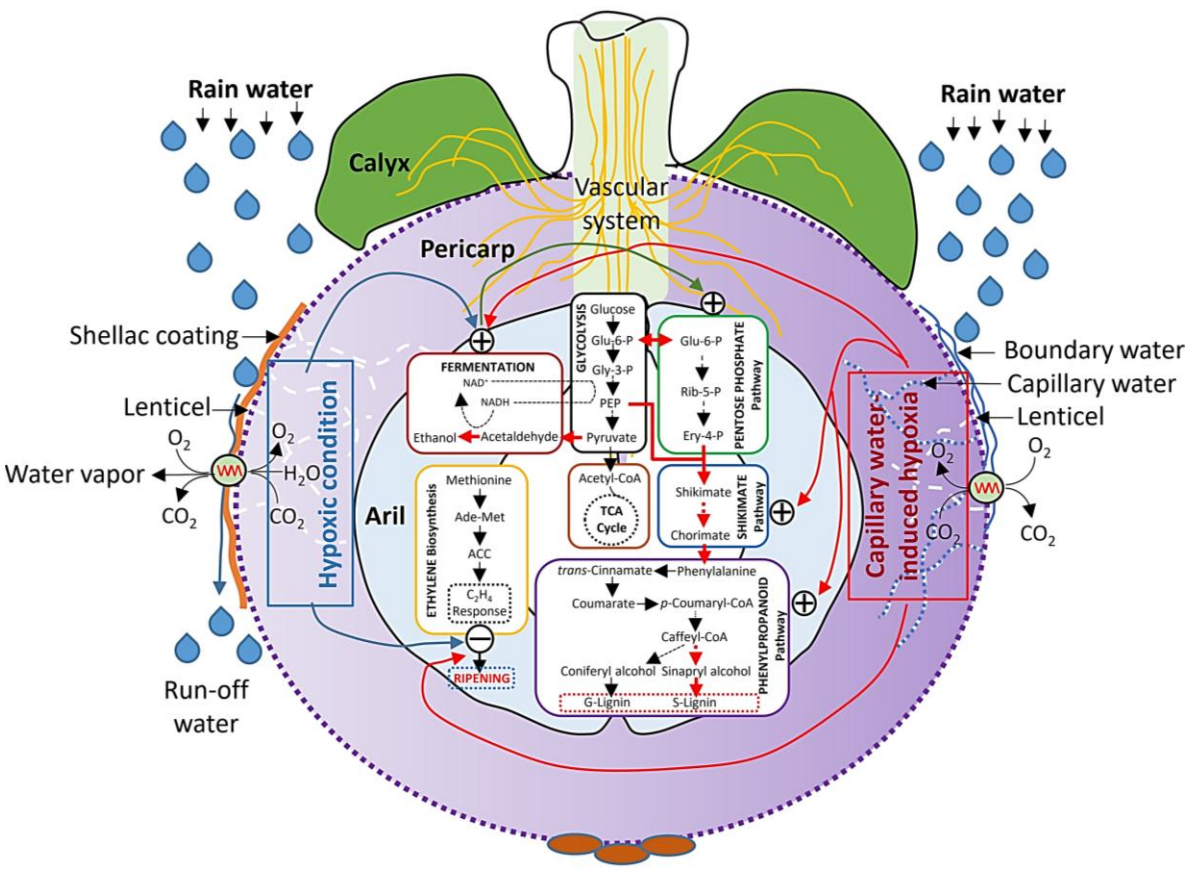


Figure 7: Putative pathway of capillary water inducing translucent flesh disorder in the mangosteen aril.

4 Conclusions

Water infiltration into the mangosteen pericarp, a known concern during rainy seasons, was correlated with significant changes in cell wall composition, specifically reduced water–soluble pectin and elevated Na_2CO_3–soluble pectin fractions. These compositional changes correlated with increased incidence of translucent flesh disorder. This study demonstrated that preharvest application of 10% shellac coating effectively delayed ripening and mitigated TFD incidence in mangosteen fruits, most likely through creating a physical barrier to water penetration into the pericarp. An additional benefit was the extension of the fruit's postharvest shelf life by approximately one week. Based on these findings, two practical strategies emerge for growers. First, where possible, cultural practices that shift fruit maturation to avoid peak rainy seasons could significantly reduce the risk of these water–induced physiological disorders. Second, the application of a water–protective coating, such as the shellac–based one, presents a viable method to protect fruit during periods of heavy rainfall.

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Author Contributions

P.L.: Methodology, experiments, data curation, statistical analysis, writing an original draft; S.N.: Conceptualization, investigation, methodology, research design, interpretation, writing an original draft and reviewing; K.B.: Investigation, methodology, interpretation, writing an original draft, and reviewing; S.R.: Methodology and interpretation; W.A.: Methodology and interpretation; C.W.: Interpretation, writing an original draft, and reviewing. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

Declaration of generative AI and AI-assisted technologies in the writing process

The authors utilized the QuillBot tool to enhance the language and readability of the manuscript.

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