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Research Article

Effect of Coating and Coated Paperboard Packaging on the Quality of Grapes and Apple during Storage

Soriful Islam,[1] **Md Shakil**,[2] **Md Sazzat Hossain Sarker**,[1] **Md Faridunnabi Nayem**,[2] **Tanjina Akter**,[2] **Ishmam Haque Sachcha**,[1] **and Sabina Yasmin**[1]

[1]*Department of Food Engineering and Technology, Hajee Mohammad Danesh Science and Technology University, Dinajpur, Bangladesh*
[2]*Department of Technology, Chulalongkorn University, Pathum Wan, Bangkok 10330, Thailand*

Correspondence should be addressed to Sabina Yasmin; sabina.fet@hstu.ac.bd

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Edible coatings and active packaging have become more prevalent in response to changing consumption patterns and market trends to enhance the quality and safety of fresh products. In this work, we investigated the effect of aloe vera gel (AVG) coating and paraffin wax-coated paperboard (PWB) packaging on the postharvest quality attributes of both grapes and apples during storage. The fruits were coated with 50% AVG concentrations, and the inner wall of the corrugated paperboard was coated with paraffin wax emulsion. The grapes and apples were stored for 12 and 35 days, respectively, at ambient conditions ($25 \pm 3^{\circ}C$ and 80–85% relative humidity). The physicochemical properties, microbiological attributes, and decay incidence of the fruits were analyzed at intervals during storage. Both fruits treated with AVG and PWB packaging retained better qualities than the control at the final day of the storage period. Particularly, PWB packaging provided considerably superior quality from the control sample in terms of weight loss (≈54% and 32%), firmness (≈48% and 68%), and color difference (≈30% and 28%) for both grapes and apples. These findings would introduce a novel approach for preserving the quality attributes of both climacteric and nonclimacteric fruits for a prolonged storage period at ambient temperature by PWB packaging and AVG coating.

1. Introduction

Shelf life is considered a significant concern of fresh fruits and vegetables to minimize postharvest losses and maintain acceptability and safety for consumer satisfaction [1]. Packaging is a widely adopted concept to minimize postharvest losses and ensure consumer safety with an increased shelf life of foods. Different packaging materials such as plastic, metal, glass, and paper have been used worldwide based on foods' size, shape, quantity, and chemical interactions. Plastics are considered the prime choice because of their low price, availability, uncomplicated manufacturing process, and handling. However, the attraction has shifted from typical plastic materials to biodegradable packaging and edible coating due to the replacement of chemical uses on food and environmental considerations [2].

The edible film, paper, and paperboard packaging from renewable sources have attracted manufacturers' interest [3]. Paper and paperboards are generally used with other hydrophobic materials (wax and polyethylene) because of their poor moisture, gas, aroma, and grease barrier properties [4]. Several polymeric compounds, such as paraffin wax, milk proteins, celluloses, lipids, starch, zein, and alginate, have been reported to be used to increase the mechanical qualities of papers and paperboards [5]. Paraffin wax, among them, is best suited for moisture and water vapor barriers for fresh fruits and vegetables because of its low polarity behavior [5, 6]. The effectiveness of paraffin wax is increased with the amount applied on paper or paperboard [6].

In addition, edible coatings prepared from plant and animal sources are applied to the exterior portion of food products as a thin layer of eatable material. The coating helps to modify the environment of the fruit's surroundings and

improve the shelf life of fresh fruits by maintaining quality, reducing weight loss, minimizing respiration and oxidation reaction rates, and delaying microbial decay and ripening while storing [7–9]. Several compounds, like milk proteins, celluloses, lipids, starch, zein, alginate, mucilage, and aloe vera gel, have been applied on the surface of fruits as edible coatings [10]. Aloe vera gel (AVG) has recently captivated attention as an edible coating due to its edibility, eco-friendliness, chemical inactivity, and antifungal properties with fruits that alter their flavor or texture [11]. The complex structure of AVG coating also provides excellent protection against moisture loss, browning, texture change, and microbiological proliferation [10, 12]. The AVG coating in various fruits, including pineapple [13], strawberry [14], papaya [15], table grapes [16], hog plum [17], apple [18], jujube [19], and blueberry [20], reduced moisture loss, microbial degradation, softening, and respiration rates and preserved other quality attributes, which could increase the shelf life of the fruits during storage.

To the best of our knowledge, from the literature search, few studies investigated the effect of AVG coating on the postharvest properties of apples and grapes. The grapes, nonclimacteric fruits, experience significant physiological and biochemical reactions in the fresh fruit. These include firmness and water loss, degradation of color, and enhancement of respiration during postharvest handling, resulting in a high rate of fungal decay [21] and poor storability [22]. The AVG coating has been investigated to reduce the rate of these physiological and biochemical reactions. Unal [23] studied the effect of AVG coating (25%) on the postharvest life of table grapes in cold storage conditions (1°C and 90% RH). They reported that postharvest AVG treatments significantly delayed weight loss, maintained visual appearance, and preserved the rachis chlorophyll concentration and antioxidant capacity during storage. Another study by Unal [23] used AVG coating on table grapes at three concentrations and stored them at 1.0 ± 0.5°C. They also found that AVG coating significantly delayed fruit weight loss, changes in soluble solid contents, titratable acidity, and maturity index during storage compared to uncoated grapes [23]. Some studies observed that the application of various combinations of edible coatings, like salicylic acid before harvesting and AVG after harvesting [24], chitosan before harvesting followed by AVG after harvesting [16], and putrescine combined with AVG [25], enhances the postharvest quality of table grapes in cold storage conditions.

Apple is a climacteric fleshy fruit, and ethylene is responsible for most physiological changes during postharvest storage. Following its production, this hormone (ethylene) is recognized by several receptors, which then control downstream ethylene-related genes through a signaling cascade. The ethylene inhibitor named 1-methylcyclopropene (1-MCP) is commonly used to improve the postharvest quality of apples by controlling the ripening process, which helps to extend storage life [26]. Natural coating, such as AVG coating, can reduce fruit metabolite production, which lowers the increase of soluble solids in coated climacteric fruits and delays fruit ripening [27]. Few previous studies investigated the impact of AVG coating on the postharvest quality of apples and fresh-cut apples. Khan [18] reported that AVG coating (20%) on apples exhibited longer shelf life with higher firmness and lower weight loss than uncoated apples in reirrigated conditions. In another study, Ozturk [28] observed that 20% AVG coating on apples improved the postharvest quality with a significant delay in weight loss in cold storage (2°C and 90 ± 5% RH) and at 20°C [28]. Quality changes of AVG-coated fresh-cut apple slices were investigated by Song [29]. They revealed that the AVG coating demonstrated a delay in browning and reduced weight loss and softness compared to uncoated slices. The AVG coating also effectively decreased aerobic bacteria, yeast, and mold populations.

However, no previous research investigated the effect of AVG coating or paraffin wax-coated paperboard packaging on the postharvest qualities of apples and grapes stored in an ambient condition. Apples and grapes have distinct postharvest physiology and storage characteristics due to their different ripening patterns. Apples are climacteric, whereas grapes are nonclimacteric. Therefore, this research aimed to assess the effect of AVG coating and PWB packaging on the physicochemical properties, microbial quality, and decay of apples and grapes, respectively, during ambient storage conditions.

2. Materials and Methods

2.1. Fruit Collection and Preparation. Grapes (Red Globe) and apples (Royal Gala) were collected from a community market in the Dinajpur district, Bangladesh. The fruits were selected based on their uniform size, shape, and maturity and were free from disease and damage. Fruits were transported rapidly in plastic crates to the experimental area under ambient conditions. The fruits were washed using running tap water (1-2 min), wiped with clean tissue paper to absorb the remaining water on the fruits' surface, and dried using a blower at a gentle pace (30 min). After drying, the fruits were considered for aloe vera gel coating and paraffin wax-coated paperboard packaging.

2.2. Preparation of Aloe Vera Gel Coating. Aloe vera gel was extracted from disease and injury-free and fresh (immediately after harvesting) aloe vera leaves uniform in maturity (18th month age of aloe vera leaf), color, and size based on Parven et al. [15] with a little modification. The selected leaves were initially rinsed with free-flowing tap water (1-2 min) to remove dirt, followed by soaking (5 min) in 0.1% sodium hypochlorite. The excess water from the surface of aloe vera leaves was wiped with clean tissue paper, and the gelatinous parenchyma matrix of the leaves was separated by a sharp stainless-steel knife. The colorless hydro parenchyma was homogenized uniformly by an electric kitchen blender (Jaipan, JP-3501, India) for 2 min and filtered through a sterile muslin cloth to separate fibrous fractions and the liquid gel fraction. The isolated gel was diluted at a 1 : 1 (v/v) ratio with distilled water, followed by pasteurization (70°C, 45 min), and cooled to ambient temperature (25 ± 3°C). Finally, citric acid was added to the mixture to maintain its final pH to 4.0.

2.3. Preparation of Paraffin Wax Emulsion and Paperboard Coating. The paraffin wax emulsion was prepared using the Liu et al. [30] method with minor alterations. For melting, paraffin wax (20 g) was placed in a 250 mL glass beaker in a thermostatic water bath at 80–85°C. Then, 3 g of emulsifier (Span-80, pharmaceutical grade) was added to the completely melted paraffin wax. After that, around 30% of the solid content in the mixture was adjusted by gradually adding deionized water with continuous agitation. The resultant mixture was homogenized twice at high pressure (400 bar) and quickly cooled to room temperature to obtain the paraffin wax emulsion.

The inner wall of the corrugated paperboard ($9'' \times 6'' \times 6''$, 3 mm thickness, single wall) was covered manually (using hand brush) with a layer of paraffin wax emulsion at a thickness of approximately 1 mm. After the completion of coating, the paraffin wax-coated paperboard (PWB) was dried at ambient condition for 24 h.

2.4. Experimental Design and Treatments. The research was carried out using a completely randomized design (CRD) model with three different treatments: control (uncoated fruits), AVG coating, and PWB packaging. Chrysargyris et al. [31] method was followed for the coating of both fruit samples (apples and grapes). Initially, the collected fruit samples were washed in a 0.05% sodium hypochlorite solution (5 minutes), then rewashed with the stream of distilled water, and kept at ambient condition for drying. After that, aloe vera gel was applied evenly on the surface of the fruits by immersing in aloe vera gel for 10 min [17] and kept at ambient condition for 30 minutes. The AVG-coated fruits in the uncoated paperboard box were considered as AVG coating treatment. The fruits without AVG coating in the paraffin wax-coated paperboard box were designated as PWB packaging treatment, and the fruits without coating in the uncoated paperboard box were indicated as control. The experimental design for apple was constructed with three treatments × three repetitions × six fruits per repetition × six sampling intervals (with day 0) with 324 fruits. For grapes, the experimental design was constructed with three treatments × three repetitions × twelve fruits per repetition × five sampling intervals (with day 0) with 540 fruits. Finally, fruits with different treatments were stored at ambient condition (25 ± 3°C and 80–85% relative humidity). For the grapes, sampling was done on 0 (before coating), 3rd, 6th, 9th, and 12th day of the storage period. The apples were analyzed on 0 (before coating), 7th, 15th, 21st, and 35th day of the storage period.

2.5. Physical and Chemical Quality of the Fruits

2.5.1. Total Soluble Solids Content, Titratable Acidity, and pH. The juice was extracted from each fruit after removing the skin and seeds. The total soluble solids (TSS) content of the fruit samples was measured using a hand refractometer (HI 9601). The pH of the fruit samples (fruit juice) was measured using a digital pH meter (HI 2211 pH/ORP meter, China) [32]. Titratable acidity (TA) was estimated by conducting titration reaction of 5 ml of aliquot (5 g extracted juice was diluted to 100 ml) with 0.1 N NaOH at pH 8.1 and phenolphthalein indicator (0.1%). TA was expressed on the equivalency of citric acid percentage.

2.5.2. Weight Loss. The weight of fruit samples was measured using a digital balance (model with accuracy). The percent weight loss of a fruit sample was calculated using the following equation:

$$\text{weight loss } (\%) = \frac{(W_o - W_f) \times 100}{W_o}, \quad (1)$$

where W_o is the initial weight of fruits and W_f is the weight at the sampling day of the fruits.

2.5.3. Fruit Firmness. The firmness of the fruits was represented as the resistance of fruits against the penetration of a narrow diameter rod using a texture analyzer (Probe TA39, TA-MTP). The rod of texture analysis was placed perpendicularly on the sample and kept pressing until a noticeable crack appeared [31]. The same procedure was done three times for each fruit, and the mean value of fruit firmness (kg/cm^2) was reported.

2.5.4. Color Value. The color difference (ΔE) of each fruit sample was determined by a colorimeter (CR400, Konica Minolta) having the Hunter color lab system (coordinate L, a, b). The mean color difference for each fruit was recorded and determined by the following equation:

$$\Delta E = \sqrt{(L* - L_\circ)^2 + (a* - a_\circ)^2 + (b* - b_\circ)^2}, \quad (2)$$

Where, "o" refers to the color reading of the control sample.

2.6. Decay Evaluation. Fruit decay was evaluated individually during the storage period, as mentioned in Chrysargyris et al. [31], on a scale of 1 to 5 (where 1 represents free of dirt and infection; 2 represents trace amount of infection; 3 represents slight infection; 4 represents infection at moderate level; and 5 represents severe infection). Three different fruits per treatment and storage time were used to conduct the decay analysis.

2.7. Microbial Analysis. Microbial analysis was done by following the total plate count (pour plate) method [10]. Initially, a 10 g sample was mixed in 90 mL of sterile peptone and homogenized in a stomacher (MIX 2, AES Laboratoire, Combourg, France). The homogenized sample was serially diluted, and 1 mL from each dilution was transferred to the liquid agar plate and allowed to solidify at ambient temperature. The solidified agar plates were kept in an incubator for 24 h at a temperature of 37°C. After incubation, Colony Counter (Stuart Scientific, UK) was used to count the colonies of each plate. The agar plate having 30–300 colonies was selected, and colony-forming units (CFUs) were calculated by the following equation:

$$\frac{\text{CFU}}{g} = \frac{(\text{number of colonies} \times \text{dilution factor})}{\text{volume of culture plate}}. \quad (3)$$

The grapes were sampled for microbial analysis on 0 (before coating), 6th, and 12th day of the storage. However, the apples were tested on 0 (before coating), 21st, and 35th day of storage.

2.8. Statistical Analysis. A completely randomized design (CRD) was used. One-way analysis of variance (ANOVA) of all the experimental data was performed by SPSS (IBM SPSS Statistic 22) software with a significant mean difference at $P \leq 0.05$. All the results were presented as mean ± standard deviation (SD).

3. Result and Discussion

3.1. Total Soluble Solids. The amount of total soluble solids (TSS) in a fruit directly influences its taste when consumed. The TSS content in fruits elevates when the maturation progresses due to the hydrolysis of polysaccharides that are not dissolved in simple sugars [33]. Furthermore, the senescence process and the rapid metabolism of fruits can also cause this increment of TSS. Coating on fruits may decrease the respiration rate that lowers fruit metabolites and thus may result in a slower rate of increase in the soluble solids content of coated fruits [34]. Barakat et al. [35] reported that the rise in TSS content in climacteric fruits during storage is common, attributed to the gradual increase of free sugars in the fruits. Rodriguez et al. [36] also stated that an increase in TSS during the storage period may result from pectin breakdown and the conversion of carbohydrates into simple sugars during storage because of the metabolic activities of the tissues. In another study, Shahkoomahally and Ramezanian [37] also observed the increasing trend of TSS in fruits, probably due to the significant loss of water and weight throughout storage. Our current investigation of fruit TSS has revealed a similar phenomenon.

For grapes, we found that the TSS of grapes significantly increased in all treatments over the storage time, as summarized in Table 1. At the end of 12 days of storage, the control grapes had a high value of TSS content (20.90°Brix), followed by the AVG coating (20.53°Brix) and the PWB packaging treatment (19.0°Brix). This may be due to the higher senescence process and the rapid metabolism of fruits [34]. However, the PWB packaging treatment maintained a lower TSS in grapes from the third day of storage. It continued until the last day of observation, where the AVG coating treatment exhibited consistent patterns with the control. The finding of AVG coating in our current study is supported by Nia et al. [16], who reported that AVG coating (33%) on table grapes exhibited comparable TSS to uncoated grapes. These authors solely observed the effect of AVG coating and did not consider the PWB packaging.

In the case of apples, an increment in the TSS content was also observed in all treatments over the storage time, as summarized in Table 2. However, compared to the control, both AVG coating and PWB packaging maintained a significantly lower TSS level from the first seven days of storage to the completion of the storage period (35 days). The addition of a paraffin-wax layer on the inner surface wall of the paper-box and/or the presence of gel barriers surrounding the fruit may have modified the environment by decreasing oxygen level and/or elevating CO_2 levels, thereby inhibiting ethylene generation [15]. This may result in a delayed ripening process and the rapid increment of fruit-soluble solids. Our results align with the study of Ali et al. [38], who investigated the effect of apple AVG coating. During storage, they noticed that the AVG coating maintains the TSS of fruits due to slower respiration and ethylene production. Ozturk et al. [28] also reported that AVG coating effectively delayed the TSS increase in Piraziz apple during cold storage.

3.2. Titratable Acidity (TA) and pH. Titratable acidity (TA) and pH are two critical variables for determining fruit freshness, and they are closely related since pH is characterized by acid compounds. In this study, the TA content of the grapes and apples decreased gradually with the increasing storage time of all treatments, as summarized in Tables 1 and 2, respectively. A decreasing trend in TA, along with storage time, has also been stated for grapes [16], apples [18], and persimmon [39]. The decrease of TA with increasing TSS during storage was observed due to the hydrolysis of the polysaccharides undissolved in simple sugars with the maturation of the fruits [33]. Moreover, a decrease in the TA content may also be initiated by high metabolic activities in fruit cells, such as ethylene production and respiration rate, utilizing numerous organic acids, etc. [40]. Our study recorded the highest TA of grapes in PWB-packed grapes on the final day of storage, around 65% higher than uncoated grapes. The PWB packaging could change the internal microenvironment of a fruit, slowing down respiration and delaying the loss of TA. On the other hand, AVG coating on grapes did not significantly affect the lagging loss of TA compared to control fruit. However, the effectiveness of AVG coating in delaying the reduction in TA throughout the storage has been reported for grapes [10, 16] and blueberries [41]. In the case of apple, TA reduction was lowered by AVG coating and PWB packaging compared to uncoated throughout the storage. Our findings are in line with earlier studies that found reduced TA in AVG-coated apples [18], papaya [15, 27], and persimmon [39]. This substantial reduction of TA in uncoated apples suggests that they may ripen faster than coated fruits.

We also observed an upward trend of pH in grapes and apples with increasing storage time. A rise in pH in treatments during postharvest storage with time might be related to biochemical changes in fruit, including the breakdown of organic acids, starches, and pectin to free acids and simple development [16]. In contrast, we found that the coating treatments lower the increase of pH of fruits compared to uncoated ones. At the final day of storage, PWB-packed grapes and apples exhibited the lowest pH levels, with reductions of approximately 13% and 9%, respectively, compared to the control. Like this study, a similar trend has

Table 1: TSS, TA, and pH of AVG- and PWB-coated grapes.

Parameter	Treatment	Storage (day)				
		0	3	6	9	12
TSS (°Brix)	Control	13.53 ± 0.31^{Ae}	15.2 ± 0.36^{Ad}	17.43 ± 0.25^{Ac}	18.83 ± 0.40^{Ab}	20.90 ± 0.36^{Aa}
	AVG-coated grapes	13.63 ± 0.15^{Ae}	14.97 ± 0.25^{Ad}	17.13 ± 0.25^{Ac}	18.80 ± 0.40^{Ab}	20.53 ± 1.12^{Aa}
	PWB-coated grapes	13.53 ± 0.60^{Ae}	14.67 ± 0.15^{Bd}	15.93 ± 0.35^{Bc}	17.30 ± 0.30^{Bb}	19.00 ± 0.44^{Ba}
TA (%)	Control	0.88 ± 0.04^{Aa}	0.77 ± 0.05^{Ab}	0.56 ± 0.04^{Bc}	0.38 ± 0.04^{Bd}	0.28 ± 0.04^{Be}
	AVG-coated grapes	0.88 ± 0.04^{Aa}	0.67 ± 0.04^{Bb}	0.55 ± 0.07^{Bc}	0.47 ± 0.05^{Ac}	0.33 ± 0.05^{Bd}
	PWB-coated grapes	0.89 ± 0.05^{Aa}	0.81 ± 0.03^{Ab}	0.69 ± 0.03^{Ac}	0.48 ± 0.04^{Ad}	0.46 ± 0.03^{Ad}
pH	Control	3.56 ± 0.05^{Ae}	3.75 ± 0.05^{Ad}	3.94 ± 0.04^{Ac}	4.27 ± 0.05^{Ab}	4.36 ± 0.04^{Aa}
	AVG-coated grapes	3.58 ± 0.08^{Ad}	3.77 ± 0.05^{Ac}	3.87 ± 0.06^{Abc}	3.92 ± 0.04^{Bab}	3.99 ± 0.06^{Ba}
	PWB-coated grapes	3.53 ± 0.47^{Ad}	3.63 ± 0.04^{Bbc}	3.70 ± 0.03^{Bb}	3.73 ± 0.03^{Cab}	3.80 ± 0.06^{Ca}

Note. The data are presented as mean ± SD. Values with different superscript lowercase letters within a row and uppercase letters within a column are statistically significant from each other ($P < 0.05$).

Table 2: TSS, TA, and pH of AVG- and PWB-coated apples.

Parameter	Treatment	Storage (day)					
		0	7	15	21	28	35
TSS (°Brix)	Control	13.00 ± 0.70^{Ae}	14.73 ± 0.35^{Ad}	15.56 ± 0.31^{Ad}	16.95 ± 0.21^{Ac}	17.90 ± 0.30^{Ab}	19.90 ± 0.70^{Aa}
	AVG-coated apples	13.17 ± 0.35^{Ae}	14.23 ± 0.25^{ABd}	14.77 ± 0.35^{Bd}	15.90 ± 0.20^{Bc}	16.93 ± 0.45^{Bb}	18.300 ± 0.20^{Ba}
	PWB-coated apples	13.22 ± 0.27^{Af}	14.01 ± 0.19^{Be}	14.44 ± 0.15^{Bd}	15.13 ± 0.25^{Cc}	15.87 ± 0.15^{Cb}	16.33 ± 0.15^{Ca}
TA (%)	Control	0.46 ± 0.05^{Aa}	0.31 ± 0.02^{Ab}	0.21 ± 0.03^{Cc}	0.16 ± 0.02^{Bd}	0.11 ± 0.02^{Be}	0.10 ± 0.12^{Be}
	AVG-coated apples	0.47 ± 0.06^{Aa}	0.37 ± 0.05^{Ab}	0.27 ± 0.02^{Ac}	0.19 ± 0.03^{Bd}	0.15 ± 0.03^{Ad}	0.13 ± 0.02^{Ad}
	PWB-coated apples	0.46 ± 0.04^{Aa}	0.35 ± 0.03^{Ab}	0.28 ± 0.01^{Ac}	0.28 ± 0.015^{Ac}	0.17 ± 0.02^{Ad}	0.15 ± 0.02^{Ad}
pH	Control	4.20 ± 0.10^{Af}	4.42 ± 0.07^{Ae}	4.52 ± 0.04^{Ad}	4.67 ± 0.05^{Ac}	4.80 ± 0.03^{Ab}	4.94 ± 0.03^{Aa}
	AVG-coated apples	4.21 ± 0.03^{Ae}	4.34 ± 0.05^{ABd}	4.44 ± 0.07^{ABc}	4.54 ± 0.06^{Bb}	4.58 ± 0.03^{Bb}	4.71 ± 0.02^{Ba}
	PWB-coated apples	4.18 ± 0.51^{Ae}	4.30 ± 0.03^{Bd}	4.38 ± 0.01^{Bc}	4.40 ± 0.01^{Cc}	4.45 ± 0.015^{Cb}	4.51 ± 0.03^{Ca}

Note. The data are presented as mean ± SD. Values with different superscript lowercase letters within a row and uppercase letters within a column are statistically significant from each other ($P < 0.05$).

also been reported for AVG-coated grapes [16] and apples [38]. This slows down the pH change of fruits upon coating application and may lead to delays in ripening and deterioration.

3.3. Weight Loss. During postharvest storage, water loss is the most unwanted physiological process in horticultural products. Fruit water loss causes economic concerns because it degrades both the structural quality and visual attractiveness of the fruit [39]. The loss of water, along with some other soluble substrates from fruits and vegetables, can easily occur by transpiration through the peel, which is responsible for the weight loss of fruits and vegetables during postharvest storage. Moreover, the weight loss may also be initiated by respiration, which causes the fruit to lose one carbon atom per cycle in the form of CO_2 [15]. Like earlier studies [15, 20], in our study, weight loss for grapes and apples for all treatments increased gradually over the storage period, as shown in Figures 1(a) and 1(b), respectively. Weight loss of grapes (Figure 1(a)) was higher in the control sample (8.37%) and lower in the PWB-packed sample (3.87%) at the last day of storage. The application of AVG coating on grapes also effectively delayed the weight loss of fruits. As shown in Figure 1(b), uncoated apples (control) experienced a significantly higher weight loss of about 17% on the last day of storage. Both AVG coating and PWB packaging of apples significantly reduced the water loss to the control. In our study, the decline in weight loss of fruits was likely because of the AVG coating and PWB packaging, which acted as a semipermeable barrier against oxygen, carbon dioxide, and water vapor, thereby minimizing respiration rate and water loss [41]. In addition, it was also reported that fresh fruits and vegetables are susceptible to weight loss during storage because of the vapor pressure gradient between the fruit tissue and the surrounding atmosphere. This vapor pressure gradient is influenced by various factors including light exposure, temperature, ripeness, and the occurrence of oxidation during storage [15]. This gradient can initiate the senescence of fruits by accelerating different metabolic reactions, such as ethylene production [42]. Our findings were in agreement with the previous studies where AVG coating was also found to be effective in minimizing the weight loss of grapes [10, 16], blueberry [41], apple [18], persimmon [39], and papaya [15, 27].

3.4. Fruit Firmness. In our study, the firmness of grapes and apples decreased with increasing storage time in both control and coated samples, as shown in Figures 2(a) and 2(b). Fruits start getting softer and losing their firmness because of the biochemical changes in cell wall fractions. In general, these biochemical changes are the results of hydrolytic reactions of cell-wall polymers such as cellulose,

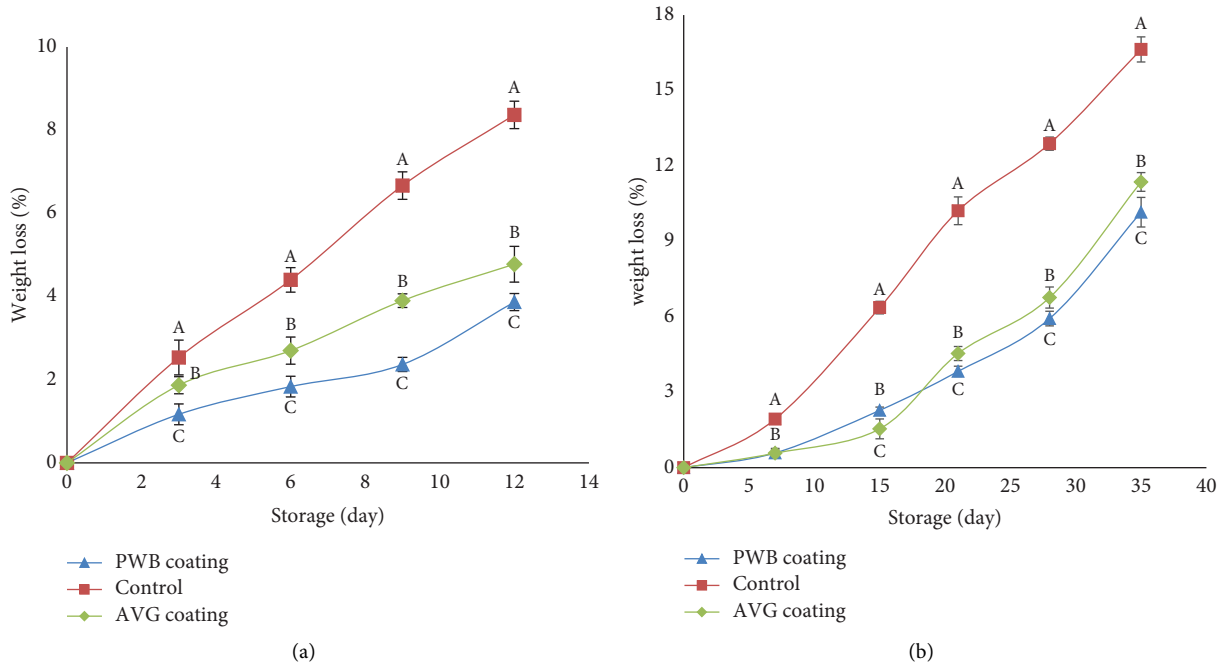

Figure 1: (a) Percentage of weight loss in grapes throughout storage. Different letters indicate a significant difference among all treatments on the specified storage day ($P < 0.05$). (b) Percentage of weight loss in apples throughout storage. Different letters indicate a significant difference among all treatments on the specified storage day ($P < 0.05$).

hemicelluloses, and pectin, among others [43], and the simultaneous drop of turgor pressure inside the cell [44] as maturation progresses. The softening of fruit during the ripening stage is closely proportional to the deterioration rate of pectin compounds via the enzymatic reaction of pectin methylesterase (PME) and polygalacturonase (PG). Previous studies also reported a loss of firmness in apples [29], grapes [10], and jujube [19] proportional to the storage time.

Coating treatments have been reported in the literature to maintain the firmness of fruits. The firmness retention in coated grapes was notably superior to that in uncoated grapes. Specifically, the firmness of PWB-packed grapes and AVG-coated grapes was approximately 50% and 35% higher, respectively, compared to uncoated grapes after a 12-day storage period. In the case of apples, a similar change was noticed throughout the storage. The PWB-packed apples were significantly ($P < 0.05$) higher in firmness (4.63 kg/cm^2) compared to AVG-coated (4.09 kg/cm^2) and control (2.76 kg/cm^2) at the final day of storage. The AVG coating or PWB packaging could hold the firmness of fruit flesh during storage by regulating the actions of the fruit enzymes, such as polygalacturonase, pectin methylesterase, and galactosidase [10, 45]. In addition, the coating on the fruit surface provides a barrier against the diffusion of water to prevent dehydration, which leads to the minimization of firmness loss [46]. The positive effect of AVG coating on maintaining firmness has been reported for grapes [10], apples [18, 29], and blueberries [41]. In contrast, AVG coating (30%) on jujube fruits [19] and AVG coating (33%) on grapes [16] did not show any positive effect on the fruit flesh firmness during postharvest storage.

3.5. Color Value. The color of the fruit is one of the most important consumer requirements for fruit acceptance. As depicted in Figures 3(a) and 3(b), the color difference (ΔE) increased in all treatments throughout the storage period. However, both coating applications showed less color difference (ΔE) in the grapes and apples compared to uncoated samples during storage. After harvesting, fruits undergo color changes as a spontaneous transformation of chlorophyll into various pigments, synthesizing carotenoids and anthocyanins [47]. In addition, the cell wall degradation of fruits during ripening and storage aids in changes of color and firmness by the activity of hydrolytic enzymes [48]. However, both PWB packaging and AVG coating act as a barrier and alter gas permeability, which may increase internal CO_2 levels. The alteration of CO_2 level changes the external and internal color of fruits and also delays the synthesis of carotenoids, degradation of chlorophyll, alteration of anthocyanin, and total phenolic contents [33, 49]. In another study, Valverde et al. [10] also reported a similar result with AVG-coated table grapes.

3.6. Decay Evaluation. The visual decay incidence of the control sample, treated grapes, and apples is shown in Tables 3 and 4, respectively. Initially, no sign of decay was observed in all treatments of grapes and apples until 3 days and 12 days of storage, respectively. Infection of fruits was increased after three days of storage for grapes and fifteen days for apples, with the growth of soft rot spots and shrinkage up to the last day of storage. Nevertheless, fruit coating demonstrated reduced decay compared to uncoated fruits, with the PWB packaging treatment for grapes and

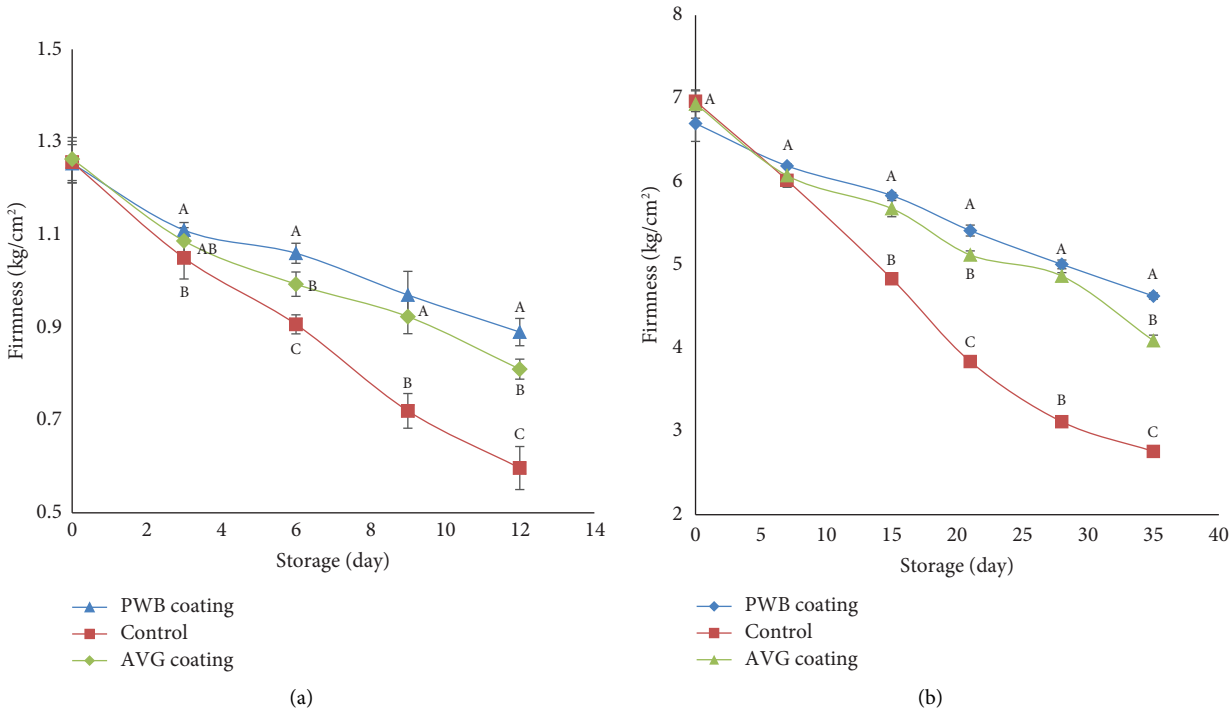

Figure 2: (a) Firmness of grapes throughout the storage. Different letters indicate a significant difference among all treatments on the specified storage day ($P < 0.05$). (b) Firmness of apple throughout the storage. Different letters indicate a significant difference among all treatments on the specified storage day ($P < 0.05$).

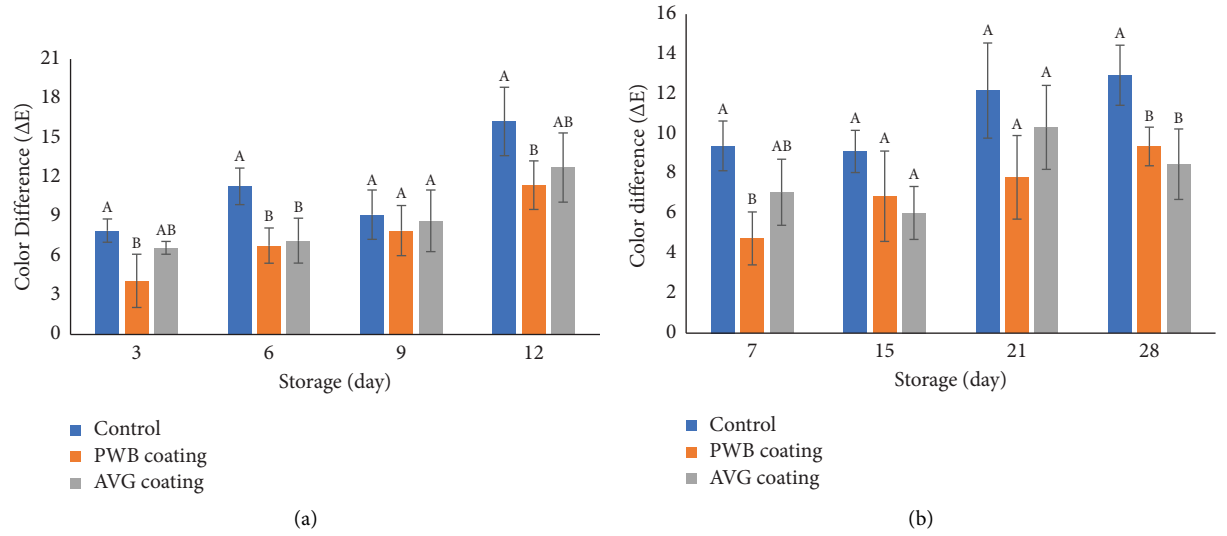

Figure 3: (a) Color difference (ΔE) of grapes during storage. Data are presented as mean ± SD. (b) Color difference (ΔE) of apple during storage. Data are represented as mean ± SD.

Table 3: Decay incidence of grapes during storage.

Fruit	Treatment	Storage (day)				
		0	3	6	9	12
Grapes	Control	1 ± 0.00^{Ad}	1 ± 0.00^{Ad}	1.97 ± 0.06^{Ac}	2.5 ± 0.10^{Ab}	3.00 ± 0.15^{Aa}
	PWB-coated grapes	1 ± 0.00^{Ab}	1 ± 0.00^{Ab}	1.07 ± 0.012^{Cb}	2.03 ± 0.06^{Ba}	2.07 ± 0.06^{Ca}
	AVG-coated grapes	1 ± 0.00^{Ad}	1 ± 0.00^{Ad}	1.43 ± 0.06^{Bc}	2.20 ± 0.10^{Bb}	2.5 ± 0.10^{Ba}

Note. The data are presented as mean ± SD. Values with different superscript lowercase letters within a row and uppercase letters within a column are statistically significant from each other ($P < 0.05$).

Table 4: Decay incidence of apples during storage.

Fruit	Treatment	Storage (day)					
		0	7	15	21	28	35
Apples	Control	1 ± 0.00^{Ae}	1 ± 0.00^{Ae}	1.53 ± 0.15^{Ad}	4.1 ± 0.20^{Ac}	4.5 ± 0.10^{Ab}	5.00 ± 0.08^{Aa}
	PWB-coated apples	1 ± 0.00^{Ae}	1 ± 0.00^{Ae}	1.00 ± 0.10^{Bd}	2.23 ± 0.06^{Cc}	2.48 ± 0.06^{Cb}	3.07 ± 0.12^{Ca}
	AVG-coated apples	1 ± 0.00^{Ad}	1 ± 0.00^{Ad}	1.00 ± 0.10^{Bd}	2.73 ± 0.12^{Bc}	3.27 ± 0.12^{Bb}	4.10 ± 0.10^{Ba}

Note. The data are presented as mean ± SD. Values with different superscript lowercase letters within a row and uppercase letters within a column are statistically significant from each other ($P < 0.05$).

Table 5: Microbial evaluation (CFU/g) of grapes during storage.

Fruit	Treatment	Storage (day)		
		0	6	12
Grapes	Control	$1.5 \times 10^3 \pm 0.10^{Ac}$	$1.4 \times 10^5 \pm 0.08^{Ab}$	$1.3 \times 10^7 \pm 0.13^{Aa}$
	PWB-coated grapes	$1.5 \times 10^3 \pm 0.10^{Ac}$	$2.1 \times 10^3 \pm 0.14^{Cb}$	$1.2 \times 10^5 \pm 0.15^{Ca}$
	AVG-coated grapes	$1.5 \times 10^3 \pm 0.10^{Ac}$	$3.6 \times 10^4 \pm 0.07^{Bb}$	$1.4 \times 10^6 \pm 0.11^{Ba}$

Note. The data are presented as mean ± SD. Values with different superscript lowercase letters within a row and uppercase letters within a column are statistically significant from each other ($P < 0.05$).

Table 6: Microbial evaluation (CFU/g) of apples during storage.

Fruit	Treatment	Storage (day)		
		0	21	35
Apples	Control	$3.0 \times 10^2 \pm 0.9^{Ac}$	$1.2 \times 10^6 \pm 0.16^{Ab}$	$1.5 \times 10^7 \pm 0.14^{Aa}$
	PWB-coated apples	$3.0 \times 10^2 \pm 0.9^{Ac}$	$6.3 \times 10^4 \pm 0.19^{Cb}$	$1.2 \times 10^5 \pm 0.17^{Ca}$
	AVG-coated apples	$3.0 \times 10^2 \pm 0.9^{Ac}$	$1.3 \times 10^5 \pm 0.18^{Bb}$	$1.8 \times 10^5 \pm 0.11^{Ba}$

Note. The data are presented as mean ± SD. Values with different superscript lowercase letters within a row and uppercase letters within a column are statistically significant from each other ($P < 0.05$).

apples showing a lower infection score than the AVG coating treatment and the control. This phenomenon of AVG coating aligns with earlier research indicating the application of AVG coating on the minimization of decay incidence in table grapes [16], strawberries [50], and orange fruit [51].

3.7. Microbial Analysis. The edible coating could enhance microbial safety of foods by reducing or preventing microbial infestation. The AVG coating provides better barrier against infestation of Gram-positive than Gram-negative bacteria [52]. Additionally, it aids in minimizing the proliferation of *Rhizopus stolonifer*, *Botrytis cinerea*, and *Penicillium digitatum* [53]. The microbial load of both grapes and apples during storage at ambient temperature is shown in Tables 5 and 6, respectively, where microbial load increased in all treatments with the progression of the storage period. Initially, the microbial load in the grapes and apples was 1.5×103 and 3.0×102 CFU/g, respectively. The growth of microorganisms in both AVG coating and PWB packaging treatments was found to be lower throughout the storage period. Microbial proliferation was the lowest in PWB-treated grapes and apples, followed by AVG-coated grapes and apples and then the control samples at the end of storage. On the last day of storage, the microbial load in control grapes and apples was 1.3×107 and 1.5×107 CFU/g, respectively, whereas, in both PWB-packed grapes and apples, the microbial population was 1.2×105 CFU/g. According to Albanese et al. [54], coatings effectively delay microbial proliferation by forming a barrier layer on the surface of the fruit, which lowers its water activity. AVG gel coating has also been found effective in microbial population minimization when applied on lotus root slices [38], apple slices [29], and grapes [10] during the storage period.

4. Conclusion

The current study evaluated the effectiveness of PWB packaging and the AVG coating on grapes and apples, respectively, and postharvest qualities during storage at ambient conditions. The findings suggest that fruits subjected to both PWB packaging treatment and AVG coating treatment exhibited lower water loss, total soluble solids, color difference, decay incidence, and higher fruit firmness compared to untreated (control) fruits during storage. However, the PWB packaging treatment exhibited a more significant impact on preserving the quality of fruits compared to the AVG coating treatment. The PWB-packed fruits significantly delayed the loss of firmness, microbial proliferation, and decay infection. These findings suggest that PWB packing and AVG coating have the potential to serve as organic and ecofriendly treatments for preserving the quality and extending the postharvest life of both grapes and apples. Future studies should explore the coating attributes of AVG and evaluate the packaging properties of PWB and their effectiveness on the antioxidant characteristics of both coated and uncoated grapes and apples during storage [54].

Data Availability

The data used to support the findings of this study are available on request from the corresponding author.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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