Article

Design and Development of Dragon Fruit (*Hylocereus polyrhizus*) Peel Extract-Based Freshness Indicators for Avocado (*Persea americana* Mill.) Smart Packaging

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Abstract

Avocado (*Persea americana* Mill.) is classified as a climacteric fruit, which experience a surge in respiration rate after harvest. Therefore, consumers usually need to be cautious when selecting avocados to ensure they obtain fruits with an acceptable level of freshness. However, the actions taken by consumers further exacerbate the damage to avocados, such as bruising caused by pressing the fruit to assess its ripeness. One approach to minimize such damage is the use *Persea americana* of indicator labels to assess the fruit quality. Freshness indicators can be made from various natural and synthetic materials. One natural dye that can be used is dragon fruit peel, which contains high levels of anthocyanin compounds that serve as natural colorants. This study aims to determine the optimal treatment for indicator labels production and color changes of indicator labels during avocado storage. The research was conducted in two stages: stage I to determine the optimal pH of dragon fruit extract and stage II to assess the quality changes of avocado and the color changes of the indicator label. The best treatment for producing smart packaging indicator labels was at pH 7 with a soaking time of 5 hours. These labels can indicate changes in avocado quality during storage through color variation. A purplish-red color indicates that the fruit is still unripe, which then changes to pink when the fruit ripens. The indicator label turns to shades of pink and yellow as the ripening progresses, and eventually develops black spots, indicating that the fruit has deteriorated.

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1. Introduction

Avocados are fruits that are highly susceptible to physical, chemical, and biological damage, resulting in a relatively short shelf life (1). Additionally, avocados are classified as climacteric fruits, which experience a surge in respiration rate after harvest. Therefore, consumers usually need to be cautious when selecting avocados to ensure they obtain fruits with an acceptable level of freshness (2). However, the actions taken by consumers further exacerbate the damage to avocados, such as bruising caused by pressing the fruit to assess its ripeness. One approach to minimize such damage is the use of smart packaging (3).

Smart packaging refers to packaging equipped with indicators that function to monitor quality deterioration during storage (4). Freshness indicators can be made from various natural and synthetic materials. One natural dye that can be utilized is dragon fruit peel, which contains high levels of anthocyanin compounds that serve as natural colorants (5). Anthocyanins are amphoteric compounds capable of reacting with both acids and bases. In an acidic medium, anthocyanins produce a red color and change to purple or blue as the

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medium becomes alkaline (6). Environmental conditions influence this color change and depend on the functional groups bonded to the basic structure of the compound (7).

Extensive research has been conducted on smart packaging. For instance, Azrita (8), developed a packaging design using ammonium molybdate and potassium permanganate color indicators to detect the avocado ripeness. Muhammad (9) investigated smart packaging that utilized natural indicators extracted from red cabbage. Widiastutik (10) explored the use of red spinach leaf extract as a natural indicator solution. However, the use of dragon fruit peel extract as an indicator has not been widely studied. Therefore, this research aims to develop a simple, inexpensive, and readily available indicator that can be applied to avocados.

2. Materials and Methods

2.1. Materials and Tools

The tools and materials used in this study included an Erlenmeyer flask, dropper pipette, hot plate, pH meter, knife, basin, mortar and pestle, stirring rod, analytical balance, funnel, Buchner funnel, blender, centrifuge, flask, bulb, temperature and humidity thermometer, volumetric pipette, vacuum pump, acid cabinet, beaker, digital microscope, stand and clamp, burette, thermometer, glass beaker, test tube, refractometer, refrigerator, penetrometer, hair dryer, and colorimeter. The materials used were avocado fruits, dragon fruit peels, 0.1 N NaOH solution, 1 M NaOH solution, 1 M HCl solution, pH 7 phosphate buffer solution, 1% starch indicator, 0.1 N standard iodine solution, Whatman No. 1 filter paper, 95% ethanol, phenolphthalein indicator, distilled water, polyethylene plastic, aluminum foil, tissue, Styrofoam containers, plaster, paper, and labels.

2.2. Methods

2.2.1. Stage one

Preliminary research was conducted to determine the pH of the indicator solution and the optimal immersion time.

2.2.1.1. Extraction of Dragon Fruit Peel Using the Maceration Method

A total of 500 g of dragon fruit peel was blended and macerated with 160 ml of 95% ethanol–distilled water (7:3). The pH mixture was adjusted to 2.0 using 1 M HCl. The sample was then stored for 24 hours at 4°C in a refrigerator. Afterward, the macerated solution was centrifuged at 5000 rpm for 20 minutes. The dragon fruit peel extract was adjusted to different basic pH levels (7, 9, and 11) using 1 M NaOH (11).

2.2.1.2. Fabrication of Indicator Label

Filter paper was cut into 2 × 4 cm pieces and soaked in 20 mL of dragon fruit peel extract indicator solution at a temperature of 28 ± 2°C for 5, 10, and 15 hours. The Whatman No. 1 filter papers were then dried using an electric dryer or a hair dryer for approximately 2 minutes at a temperature range of 20–40°C until completely dry (9).

2.2.2. Stage two

This study was conducted to determine the optimal storage period for avocado fruit indicator labels. The storage treatment (A) was carried out at room temperature (28 ± 2°C) with a relative humidity of 73.2% for 9 days. Avocado quality analysis was performed every 3 days until the samples showed signs of deterioration.

2.2.2.1. Vitamin C

Vitamin C analysis was carried out by dissolving 5 grams of the sample in 100 mL of distilled water up to the mark on a volumetric flask. Then, 25 mL of the sample filtrate was taken, 2–3 drops of starch indicator were added, and the solution was titrated with 0.1 N standard iodine solution until a dark blue color appeared. The vitamin C content was calculated using the following formula (12):

$$\text{Vitamin C} = \frac{\text{ml Iod } \times 0.88 \times \text{FP}}{(\text{B} \times 1000)} \times 100\% \quad (1)$$

ml Iod = Volume of iod used during titration
Fp = Dilution or dilution factor
B = Sample mass (g)

2.2.2.2. Total Soluble Solid

The prism refractometer was cleaned with distilled water, and 2-3 drops of avocado pulp were placed on the lens. The total sugar content or total dissolved solids was then measured digitally and expressed in °Brix (13).

2.2.2.3. Total Acid

Titratable acidity was determined by diluting 5 g of sample with 100 mL distilled water. The mixture was then filtered through filter paper. A 25 mL of the filtrate was taken, and phenolphthalein (pp) indicator was added. The sample was titrated with 0.1 N NaOH to the endpoint (persistent pink color appeared). The total titratable acidity was calculated using the following formula (14):

$$\text{Total Acid} = \frac{ml\ NaOH \times N \times Fp \times Mr\ NaOH}{weight\ of\ sample} \times 100\% \quad (2)$$

Information:
Ml NaOH = Volume of NaOH used during titration
N = Normality of NaOH (0.1 N)
Fp = Dilution or dilution factor
Mr NaOH = Molar mass of NaOH

2.2.2.4. Fruit Firmness

Firmness testing was carried out using a hand-held digital penetrometer. The probe needle was inserted into three parts of the fruit: the base, middle, and tip. The value was displayed on the digital penetrometer and expressed in Newtons (N) (15).

2.2.2.5. Color Analyses of Indicator Label

Color measurements of the smart indicator labels were analyzed using a colorimeter (AMT-506). Color quantification was performed by placing the colorimeter sensor directly on the smart indicator label. The device displayed the L*, a*, and b* values on the screen. To determine the overall color change of the indicator label during storage, the hue value (h°) was calculated. using the following formula (16):

$$^{o}\text{Hue} = \tan\left(\frac{\bar{x}\,b*}{\bar{x}\,a*}\right) \times 180/\text{PI}() \quad (2)$$

Information:

$\bar{x}$ b* : Average b* value

$\bar{x}$ a* : Average a* value

180 : *Degrees Arch tangent*

PI () : Pi = 3.14

3. Results and Discussion

Preliminary research was conducted to determine the optimal pH of the indicator solution and the ideal immersion time for the indicator label used to monitor avocado quality. The selection of the most suitable color indicator was based on visually observable color changes in the indicator label during storage. Figure 1 presents the color change results of smart indicator labels prepared with indicator solutions at different pH levels.

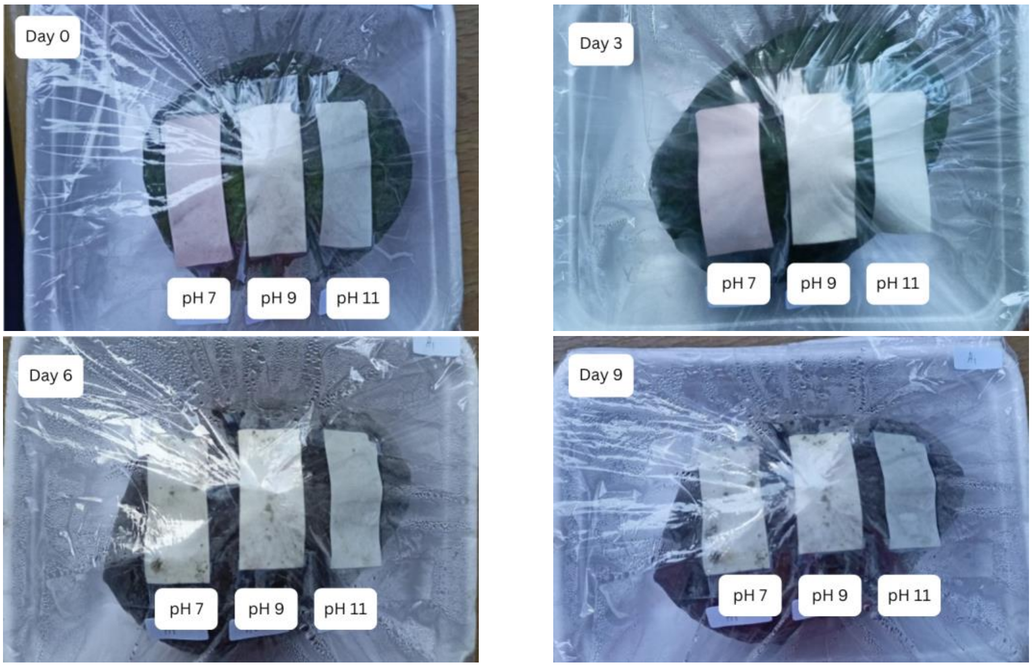

Figure 1. Color changes of indicator labels prepared from dragon fruit peel extract at different pH values (pH 7–11) during storage at room temperature (28 ± 2°C).

The color changes of the indicator label can be seen in Figure 1. Among the tested treatments, the indicator with the most significant color change response after storage is A1, which is purple-red on day 0, pink and yellow on day 9, and develops black spots by day 9. Based on these observations, the dragon fruit peel extract solution at pH 7 (A1) was the optimal indicator solution, as it exhibits a higher sensitivity level compared to other extract solutions, indicated by distinct color changes and a pH range similar to that of avocados during storage. Furthermore, a soaking time of 5 hours was found to be optimal, as it resulted in the strongest color binding compared to soaking times of 15 and 30 hours. The best treatment from the preliminary study was subsequently applied in the main experiment for developing the smart packaging indicator for avocados.

3.1. Total Acid

Total acidity reflects the total amount of acids present in a substance and is closely related to pH, as an increase in total acidity corresponds to a decrease in pH, indicating the substance's acidic properties (17). The analysis of variance results show that storage duration (sig .000) and the interaction between storage duration and storage type (sig. .000) have a significant effect, while storage type (sig .426) showed no significant effect at the 5% level ($p>0.05$) on the total acidity of avocados. The relationship between storage type and storage duration on the total acidity of avocados is presented in Figure 2.

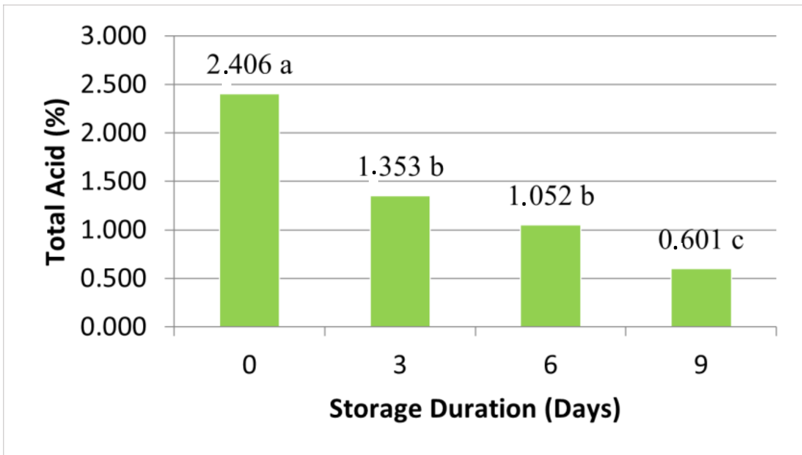

Figure 2. The effect of storage duration on total acid of avocado; values followed by different letters indicate significantly different results ($p< .05$).

Figure 2 shows that storage duration significantly affected the total acidity of avocados. Duncan's multiple range test for the storage duration factor shows that avocados stored at room temperature exhibited a gradual decrease in total acidity period, from day 0 to day 9. The high total acidity at the beginning of storage was due to the formation of organic acids. The acid content was higher in unripe fruits compared to ripe fruits, which are more abundant in young fruits and those approaching ripeness, compared to fully ripe fruits (18). The decrease in total acidity of avocados during storage was due to the utilization of organic acids as substrates in the fruit's respiration process, which provides energy for metabolic activities (19). Total acid in fruit tends to decrease after the fruit ripening phase, as the higher sucrose content increases sugar proportion, leading to water loss from cells and plasmolysis. The water loss also carries away organic acids from the fruit tissue (20).

3.2. Vitamin C

Vitamin C, or ascorbic acid, is highly susceptible to degradation due to oxidation under alkaline conditions, high temperatures, and exposure to sunlight or trace metals (21). The analysis of variance results showed that storage duration (sig .009) significantly affects the pH value of avocado at the 5% level ($p<.05$). meanwhile, the storage type (sig .862) and the interaction between storage duration and storage type (sig .120) had no significant effect ($p > .05$) on the vitamin C content of avocados.

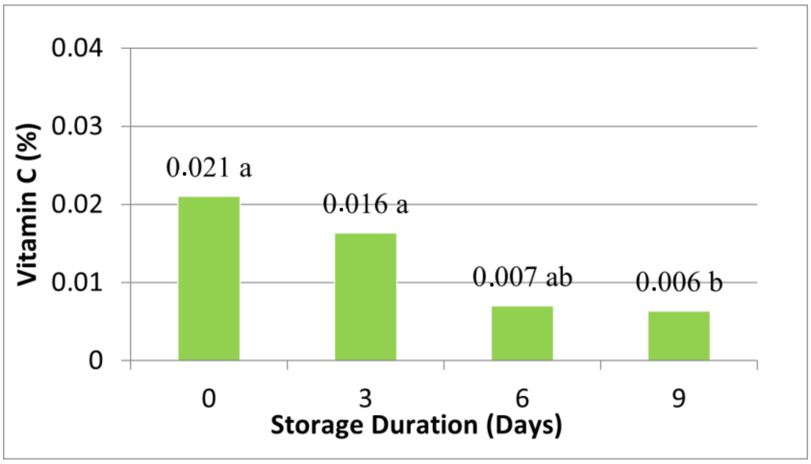

Figure 3. The effect of storage duration on vitamin C of avocados; values followed by different letters indicate significantly different results ($p < .05$).

Duncan's multiple range test for the storage duration factor indicated that vitamin C levels on days 0, 3, and 6 were not significantly different from one another, whereas these days differed significantly from day 9. Vitamin C content tended to decrease with longer storage duration, as prolonged storage accelerates respiration, which consumes organic acids that serve as energy reserves in the fruit (22). Vitamin C levels will continue to fall until they are damaged. This diminution is due to the process of vitamin C respiration and oxidation into L-dehydroascorbic acid, which is then converted into L-diketogulonic acid, a compound that lacks vitamin C activity. Vitamin C storage at ambient temperature declines rapidly because external variables such as heat and oxygen cannot be managed to ensure that the fruit ripening process continues smoothly (23).

3.3. Total Soluble Solids

Total soluble solids (TSS) in a food product serve as an indicator of fruit quality, particularly sweetness, since sugar constitutes a major portion of dissolved solids (15). The analysis of variance (ANOVA) results indicated that storage type (sig .02) significantly affects the total soluble solids of avocado at the 5% level ($p < .05$). Meanwhile, the storage duration (sig .448) and the interaction between storage duration and storage type (sig .94) had no significant effect ($p > .05$).

The effect of storage duration on the total dissolved solids of avocados can be seen in Figure 4. Avocados stored at room temperature exhibited an increase in TDS during storage, reaching the highest value on day 6, with an average of 6.30 °Brix. The total soluble solids increase was attributed to a rise in reducing sugar content, likely resulting from the enzymatic hydrolysis of starch into simple sugars (glucose and fructose) by amylase, phosphorylase, and invertase present in the fruit (24). Sugar content generally increased with storage duration, but it declined toward the end of the storage period due to reduced respiration and the depletion of starch as a substrate for metabolic processes (25). The total dissolved solids (TDS) of avocados before storage were 5.60 °Brix and generally increased over the storage period. This increase was attributed to the hydrolysis of starch into sucrose, glucose, and fructose, with the rate of hydrolysis exceeding the rate of glucose conversion into CO_2, H_2O, and energy, leading to the accumulation of glucose in the fruit tissue. However, by day 9, TDS decreased. This decline is thought to result from continued respiration, during which reducing sugars are broken down into pyruvic acid and subsequently metabolized to CO_2 and H_2O (26) (27).

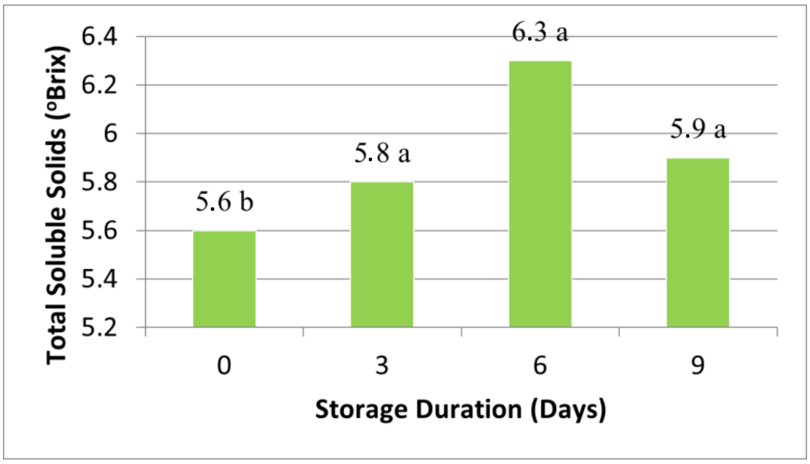

Figure 4. The effect of storage duration on total soluble solids of avocados; values followed by different letters indicate significantly different results (p< .05).

3.4. Fruit Firmness

The firmness or texture of agricultural products varies depending on the commodity and the material's physical and chemical properties. Texture is an important parameter for assessing fruit quality (15). The analysis of variance indicated that storage duration (sig .000), storage type (sig .030), and the interaction between storage duration and storage type (sig .033) significantly affected the hardness of avocados at the 5% level ($p < .05$).

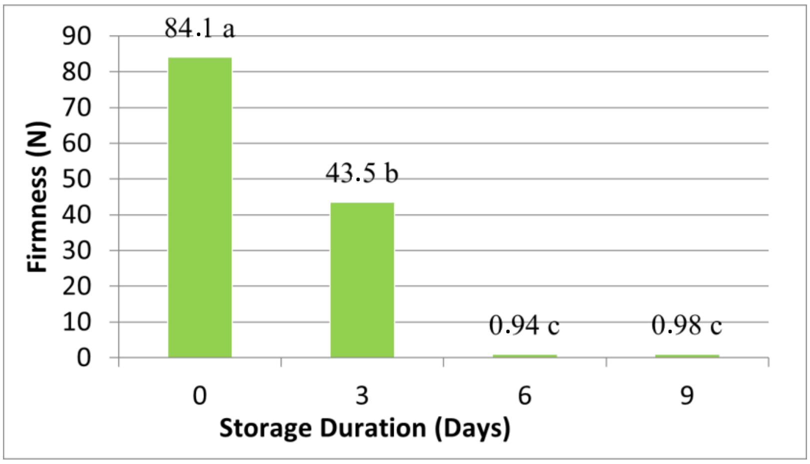

Figure 5. The effect of storage duration on firmness of avocados; values followed by different letters indicate significantly different results (p<0.05).

The effect of storage duration on avocado firmness can be seen in Figure 5. Fruit hardness tends to decrease with longer duration. The ripening process of fruit is associated with a reduction in hardness due to the degradation of pectin into protopectin, which reduces cell wall turgor pressure and results in softer fruit. This is also caused by the pectin methylesterase enzyme, which degrades cellulose and hemicellulose along with an increase in the respiration rate towards the climacteric peak (28). Avocado firmness can further decrease due to skin tissue damage, leading to high transpiration rates, wrinkling, and softening of the flesh (29). Room temperature can accelerate metabolic processes, affecting respiration, ripening, senescence, texture, and color. Enzymatic activity, particularly from pectinase and cellulase, contributes to the breakdown of protopectin, while higher temperatures enhance transpiration and respiration rates, promoting faster fruit softening (30).

3.5. Measurement of the indicator label

The color change of the indicator was assessed using the hue value, which represents the color angle and identifies the dominant color on the indicator label. The hue value provides a means to monitor the overall color change of the indicator label during storage. Based on Figure 6, the hue value of the smart indicator label increased during storage until the fruit reached optimal ripeness and decreased thereafter. On day 0, the hue value was 43.51, increasing to 49.40 on day 3 and 55.18 on day 6, before decreasing to 41.35 on day 9. Three phases of color change were observed on the smart indicator label: Phase I, purplish-red, indicating unripe or young avocados; Phase II, pink, indicating optimal ripeness; and Phase III, a gradation of pink and yellow, indicating the onset of fruit deterioration. The color change of the indicator label is closely associated with the release of volatile acids, such as acetic acid, from avocados during storage, which interact directly with the label (31). The purplish-red color on day 0 corresponds to young, unripe fruit characterized by a light green color, firm texture, and lack of aroma. The transition to pink on day 3 indicates optimal ripeness, during which fruit hardness decreases due to the conversion of insoluble protopectin into water-soluble pectin (32). The aroma of avocados changes during ripening due to the formation of aliphatic alcohol esters and short-chain fatty acids, which are responsible for the characteristic fruit aroma produced at the onset of the climacteric phase (33). On day 6, the indicator label changed from pink to a pink-yellow gradient with the appearance of black spots, indicating the beginning of fruit deterioration. At this stage, the fruit texture softened, and the skin color turned brownish. By day 9, the indicator label remained pink with yellow, but the number of black spots increased, reflecting further decay. The skin color changed to brownish-black due to chlorophyll degradation into chlorophyllide mediated by chlorophyllase activity (34). Fruit texture became softer and more watery as a result of hydrolysis of cell wall components during ripening, allowing cell contents to soften and absorb water from surrounding tissues (35). Additionally, the fruit aroma became pungent or “rotten” due to the formation of esters and the loss of previously volatile compounds (36).

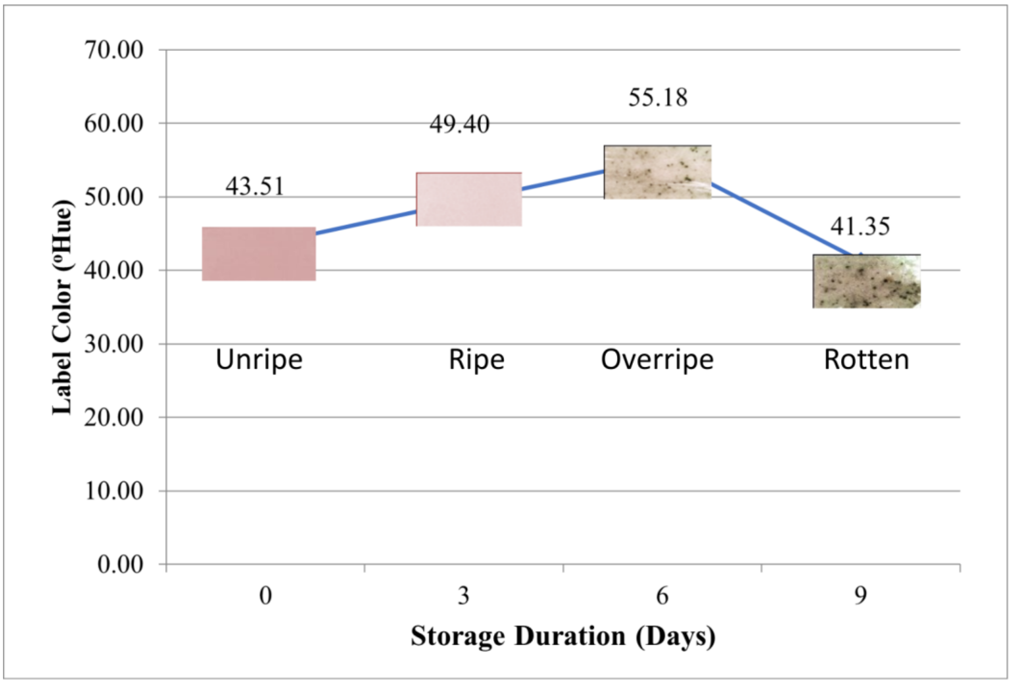

Figure 6. Color change profile of avocado freshness indicators based on hue values.

4. Conclusions

The best treatment for producing smart packaging indicator labels was at pH 7 with a soaking time of 5 hours. These labels can indicate changes in avocado quality during storage through color variation. A purplish-red color indicates that the fruit is still unripe, which then changes to pink when the fruit ripens. As ripening progresses, the indicator label turns to shades of pink and yellow and eventually develops black spots, indicating that the fruit has deteriorated.

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Author Contributions

Y. conceived and designed the experiments; Y. performed the experiments; Y. analyzed the data; Y. wrote the paper; Y. monitored the planning and execution of the study

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Institutional Review Board Statement

Not applicable.

Data Availability Statement

Available data are presented in the manuscript.

Conflicts of Interest

The author declares no conflict of interest.

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