

# pH-sensitive films based on cassava starch and purple yam (*Dioscorea alata* L.) peel anthocyanins: a colorimetric indicator for monitoring pork freshness

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## Abstract

This study was conducted to evaluate the performance of cassava starch film incorporated with purple yam (*Dioscorea alata* L.) peels anthocyanins as an indicator of pork deterioration. Effects of drying temperature (40°C and 50°C) and drying time (24 h and 48 h) on water activity, water vapor permeability, and color parameters of the films were determined using factorial design. Results revealed that the responses do not depend on the drying parameters. The film with the low-level drying parameters (40°C/24 h) was chosen for color stability analysis and application test. The color stability of the film during 31 days of storage (presence and absence of light; under refrigeration and at room temperature) showed greater stability under refrigeration without light exposure. The film was used to monitor pork freshness during storage at room temperature. The film gradually lost color intensity and presented a more grayish ( $C^*_{ab}$  decrease) and darker color ( $L^*$  decrease) during storage. Based on the hue angle values, the film also showed distinct color changes from red to orange as the pH of the pork increases with spoilage. Color differences ( $\Delta E$ ) in the film during storage compared to its initial color were identified. The film was able to detect quality changes in the pork meat by film color changes that are easily distinguishable by the human eye and therefore can be potentially used as intelligent packaging material.

## 1. Introduction

Changes in pH usually coincide with the process of food deterioration. Spoilage of meat products happens when lipids and protein are decomposed by microbial degradation which produces volatile amines (Koshy *et al.*, 2021). As concentrations of these volatile compounds increase, the environment inside the packaged meat gradually becomes alkaline, which colorimetric pH-sensing films can detect (Dong *et al.*, 2020). Colorimetric pH-sensing films monitor changes in packaged product quality based on visual color variation (Luchese *et al.*, 2018).

One natural source of a pH-sensitive dye incorporated in these colorimetric pH-sensing films is anthocyanins. Anthocyanins undergo chemical structure transformation and color change under different pH conditions (Roy and Rhim, 2020).

In the Philippines, the annual production of purple yam (*Dioscorea alata* L.) was around 26000 metric tons in 2000-2005 (Cornago *et al.*, 2011). Anthocyanins can be found in purple yam (Srivichai and Hongsprabhas,

2020), even in the peels. Aquino and Morales (2020) reported that the purple yam peel extract yields high antioxidant activity of 78.84% and contains 155 mg/L cyanidin-3-glucoside. However, peels found in tuber families are rarely consumed or used in the cooking of food and are frequently thrown away (Lau *et al.*, 2021). Hence, in this study, the potential of purple yam peel anthocyanin extract incorporated in cassava starch films was explored for application as pork spoilage indicator.

## 2. Materials and methods

### 2.1 Extraction of anthocyanins from purple yam peels

Anthocyanins were extracted following the procedure described by Aquino and Morales (2020) with modifications. The purple yam peels, weighing 312 g, were macerated using a blender (SMK-707A, American Power) with 750 mL of distilled water. The solution was added with anhydrous citric acid to adjust the pH to 2.0. The mixture was transferred to a beaker. Then, the beaker was covered with aluminum foil to protect the extract from light and refrigerated for 42 h. After this period, the mixture was filtered through a cheesecloth.

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The collected filtrate was then filtered through Whatman paper No. 1 using a vacuum pump. Following vacuum filtration, the collected filtrate was transferred to centrifuge tubes and centrifuged for 10 minutes at 2000 rpm. The supernatant was transferred into a 1 L amber bottle and was stored in the freezer until the preparation of the films.

## 2.2 Preparation of the films

Films were prepared by casting technique, as described by Aquino and Morales (2020). Film-forming solution of cassava starch (5% w/w), glycerol (3% w/w), and purple yam peel anthocyanin extract (10% w/w) was prepared in a beaker and heated up to 70°C in a stirring hot plate (PC-420D, Corning) while being stirred slowly and constantly at 200 rpm. Afterwards, about 40 mL of suspension was put into polystyrene petri dishes (diameter = 85 mm) and dried in a hot air dryer, 50% RH. Drying temperature and drying time were studied using a 2<sup>2</sup> full factorial design. The dried films were stored at 27°C, 44%RH for two days prior to analysis.

## 2.3 Effect of drying temperature and drying time on water activity, water vapor permeability, and color parameters

### 2.3.1 Experimental design

The effect of drying temperature and drying time on water activity, water vapor permeability, and color parameters (L\*, a\*, b\*) of the cassava starch film incorporated with purple yam (*Dioscorea alata* L.) peels anthocyanins was evaluated using a two-factor set at two levels (2<sup>2</sup>) full factorial design. Tests were carried out in triplicate for each combination of factors and levels. As a result, the experimental design layout consisted of twelve (12) runs run in random order. The design layout generated using Minitab 21.4 Software is presented in Table 1.

Table 1. Drying temperature and drying time of the pH indicator films.

Std Order	Run order	Drying temperature [°C]	Drying time [hr]
2	1	50.00	24.00
7	2	40.00	48.00
5	3	40.00	24.00
9	4	40.00	24.00
6	5	50.00	24.00
4	6	50.00	48.00
8	7	50.00	48.00
3	8	40.00	48.00
1	9	40.00	24.00
10	10	50.00	24.00
12	11	50.00	48.00
11	12	40.00	48.00

### 2.3.2 Determination of water activity

The water activity of the film was determined using a water activity meter (Labswift-aw, Novasina, Dakila Trading Corporation, Manila). The film was placed in the sample slot of the water activity meter and values of water activity were obtained in triplicates.

### 2.3.3 Determination of water vapor permeability

Water Vapor Permeability (WVP) of the film was determined following the method of Wang *et al.* (2018) and Yun *et al.* (2019). The film was fixed over a 50 mL centrifuge tube holding 30 g dried silica gel. After that, the centrifuge tube was kept at 27°C in a desiccator with distilled water. For seven days, the centrifuge tube was weighed every 24 h.

Film thickness was measured using a digital calliper (HDCD-28150, Ingeo, Ingeo Tools Co., Limited, China). Measurements were done at three (3) random points, and the mean thickness was used to determine the WVP using equation 1.

$$WVP = \frac{W \times x}{t \times A \times \Delta P} \quad (1)$$

where W represents the increased weight of centrifuge tube (g), x represents the film thickness (m), t represents the duration (s) for the increased weight of centrifuge tube, A represents the permeation area of film sample (m<sup>2</sup>) (5.72555 10<sup>-4</sup> m<sup>2</sup>), and ΔP (3564 Pa at 27°C) represents saturated vapor pressure.

### 2.3.4 Determination of color parameters

The color parameters (L\*, a\*, b\*) were measured at five random positions using a hand-held chromameter (CR-400, Konica Minolta, Konica Minolta Inc., Japan), calibrated using a standard white plate, and the average values were calculated. The measured values corresponded to three determinations: the coordinate L\* is a measure of lightness, with values ranging from 0 (completely black) to 100 (completely white); the chromaticity coordinate a\* can have negative (green) to positive (red) values; and the chromaticity coordinate b\* can have negative (blue) to positive (yellow) values (Luchese *et al.*, 2017).

## 2.4 Color stability analysis

The color stability of the films was assessed as a function of temperature and lighting according to Prietto *et al.* (2017). The film with the low-level drying parameters (40°C/24 h) was stored for 31 days in both room (25±5°C) and refrigerated (4±5°C) temperature storage, with and without light exposure. The film considered with light exposure is not covered with aluminum foil, while the film considered without light

exposure is covered with aluminum foil. Every Monday, Wednesday, and Friday, the color parameters of the film were determined using a hand-held chromameter (CR-400, Konica Minolta, Japan). The hand-held chromameter was calibrated using a standard white plate. Color values of five random points on the surface of each film were measured ( $L^*$  for lightness,  $a^*$  for red/green, and  $b^*$  for yellow/blue). The average of these values was then used to calculate the overall color difference ( $\Delta E$ ).

$$\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad (2)$$

$$\Delta L^* = L^* - L_0$$

$$\Delta a^* = a^* - a_0$$

$$\Delta b^* = b^* - b_0$$

Using equation 2 by Prietto *et al.* (2017), the change in color ( $\Delta E$ ) of the film over storage time was compared to its initial color (Day 0).

where  $\Delta E$  is change in color;  $L^*$ ,  $a^*$  and  $b^*$  are the color attributes of the films; and  $L_0^*$ ,  $a_0^*$  and  $b_0^*$  are the initial color parameters of the film (Day 0).

### 2.5 Application test of film on pork

Application test of the film on pork samples was conducted following Ezati *et al.* (2020) with modifications. About 50 g of pork shoulder sample was contained in a polypropylene container. A 3 cm × 3 cm pH indicator film was placed on the cover of the container. The polypropylene container was stored at 25±5°C. At 0, 24, 48, and 72 h of storage of the pork shoulder sample, the color values ( $L^*$  (lightness),  $a^*$  (red/green) and  $b^*$  (yellow/blue)) of the indicator film were obtained using a hand-held chromameter (CR-400, Konica Minolta, Japan). The hand-held chromameter was calibrated using a standard white plate.

Following the procedure of Dini *et al.* (2019), the  $a^*$  and  $b^*$  values were used to calculate the Hue angle ( $h_{ab}$ ) or color angle and the chroma ( $C^*_{ab}$ ) or color saturation. The  $h_{ab}$  is the angle formed by the hypotenuse and 0° on the  $a^*$  axis. It conveys color tones. For interpretation, the results are presented in degrees and range from 0° to 360°.

Hue angle and chroma are calculated using equations 3 and 4, respectively (Dini *et al.*, 2019).

$$h_{ab} = \tan^{-1} \left( \frac{b^*}{a^*} \right) \quad (3)$$

$$C^*_{ab} = \sqrt{a^{*2} + b^{*2}} \quad (4)$$

On the other hand, the pH of the pork was taken at three random positions using a digital pH meter (YY-1030, Shenzhen Yago Technology Co., Ltd., China). The digital pH meter was calibrated using buffer solutions with pH 4.0, 7.0, and 10.01.

### 2.6 Statistical analysis

Analysis of Variance (ANOVA) was conducted at 5% significance level using Minitab 21.4 Software and followed by Tukey's test for mean comparison. The correlation between pH values and color change ( $\Delta E$ ) of the pH indicator film with the low-level drying parameters (40°C/24 h) was evaluated by Pearson's correlation method. Data are presented as mean±standard deviation.

## 3. Results and discussion

### 3.1 Effect of drying temperature and drying time on water activity, water vapor permeability, and color parameters

#### 3.1.1 Effect on water activity

The films exhibited water activities ranging from 0.420 to 0.442, similar to the results of Aquino and Morales (2020). Results showed that drying time and drying temperature do not significantly affect the water activity of the films ( $p > 0.05$ ). The water activity of the films depends more on the internal matrix of the biopolymeric film. The hydrophilic nature of starch, glycerol, and anthocyanins due to the presence of hydroxyl groups allows the film to hold moisture (Alves *et al.*, 2007; Yu *et al.*, 2009; Shuzhen *et al.*, 2018; Teng *et al.*, 2020). The water activities of starch edible films with different plasticizers exhibit values close to 0.6 and above 0.6 (Radev and Pashova, 2015).

#### 3.1.2 Effect on water vapor permeability

The film water vapor permeability ranges from 6.255 to 7.413  $10^{-10}$  g m<sup>-1</sup> s<sup>-1</sup> Pa<sup>-1</sup>. Results showed that the water vapor permeability of the films does not depend on the drying process ( $p > 0.05$ ). This result is consistent with the findings of Oliveira *et al.* (2018) and Nury *et al.* (2023). The water vapor permeability parameter depends more on the internal matrix of the biopolymeric film, especially with the added plasticizer. Water vapor is transferred between the hydrophilic layers of the material, there is a higher incidence in materials with a stronger hydrophilic load (Oliveira *et al.*, 2018). Such as with the result of Nury *et al.* (2023), in which amaranth flour film containing sorbitol as the plasticizer has better water vapor permeability properties compared with those of the films containing glycerol, since sorbitol is less hygroscopic. The barrier ability of anthocyanin-based films has been linked to the development of a compact internal microstructure network and the reduction in the availability of hydrophilic groups of the films by means of strong interactions between molecules, particularly hydrogen bonds between anthocyanins and polymers (Zhao *et al.*, 2022).

### 3.1.3 Effect on color parameters

The color values of the films were between 34.92 to 37.07 for L\*, 21.39 to 23.11 for a\*, and 1.30 to 2.87 for b\*. The films showed no significant differences ( $p > 0.05$ ) in terms of color values (L\*, a\*, b\*) regardless of drying time and drying temperature. The color parameters of the film depend more on the amount of anthocyanin extract added to a biopolymeric film. According to Aquino and Morales (2020) and Yun *et al.* (2019), the higher amount of extract gives lower L\* values indicating that the extract gave a darker color to the films. Further, Yun *et al.* (2019) also reported that cassava starch-bayberry extract films showed higher a\* values as anthocyanin-rich bayberry extract content increased. With this, the color difference ( $\Delta E$ ) of the cassava starch-bayberry extract films significantly increased as the bayberry extract content increases.

### 3.2 Color stability analysis

If the use of the film in determining the freshness of meat products is based on color variations, then assessing its capacity to maintain that color till the end of its shelf life is necessary to provide consumers with reliable visual feedback.

Since there is no significant difference in the water activity, water vapor permeability, and color parameters for each combination of factors and levels, the film with the low-level drying parameters (dried at 40°C for 24 h), presenting more economical production, was subjected to color stability analysis as a function of lighting and temperature storage conditions.

Table 2 shows that the presence of light and the ambient temperature during storage influenced the color of the films. Most of the changes were observed at room temperature in the presence of light followed by room temperature without light exposure. When maintained in refrigerated conditions, the films displayed greater color stability. The results of higher stability at refrigerated temperature are in accordance with the findings of Prietto *et al.* (2017). Furthermore, all the films showed an increase in b\* value with increasing storage duration, indicating an increase in yellowness. This behavior is consistent with the results found by Maciel *et al.* (2012) and Zhang *et al.* (2019), in which the color variation was associated with anthocyanin structure changes.

Temperature influences the stability of anthocyanin molecular structures, therefore as the temperature increases, these compounds degrade. As the temperature increased, the pyrylium ring of anthocyanins opened, forming a chalcone structure that resulted in yellow pigmentation (Zhang *et al.*, 2019). On the other hand, anthocyanins could change with light, speeding up their breakdown (Enaru *et al.*, 2021). The results of higher anthocyanin destruction in the presence of light agree with the findings of Bakhshayes *et al.* (2006).

Figure 1 shows the plot between the storage time of the films and their color variation ( $\Delta E$ ) with respect to their initial color (Day 0). The color change is only visible to the human eye when the  $\Delta E$  value is greater than 5 (Tassanawat *et al.*, 2007). The films containing purple yam peel anthocyanins would be suitable for refrigerated foods in the absence or presence of light, as the  $\Delta E$  was less than 5 and remained stable over 31 days

Table 2. Color change of the films stored at varying light and temperature storage conditions for 31 days.

Storage time (Day)	Color change ( $\Delta E$ )			
	REA	REP	ROA	ROP
0	0	0	0	0
3	0.33±0.01 <sup>ab</sup>	0.46±0.15 <sup>bb</sup>	1.14±0.06 <sup>gA</sup>	1.50±0.41 <sup>cA</sup>
6	0.27±0.05 <sup>ac</sup>	0.51±0.09 <sup>bc</sup>	1.57±0.17 <sup>fB</sup>	2.13±0.31 <sup>abcA</sup>
8	0.34±0.11 <sup>ab</sup>	0.40±0.20 <sup>bb</sup>	1.76±0.18 <sup>fA</sup>	2.07±0.44 <sup>bcA</sup>
10	0.27±0.03 <sup>ab</sup>	0.35±0.20 <sup>bb</sup>	1.81±0.18 <sup>efA</sup>	2.18±0.43 <sup>abcA</sup>
13	0.26±0.11 <sup>ab</sup>	0.52±0.26 <sup>bb</sup>	2.17±0.15 <sup>deA</sup>	2.45±0.34 <sup>abcA</sup>
15	0.36±0.09 <sup>ab</sup>	0.41±0.17 <sup>bb</sup>	2.30±0.17 <sup>cdA</sup>	2.46±0.38 <sup>abcA</sup>
20	0.21±0.07 <sup>ab</sup>	0.48±0.08 <sup>bb</sup>	2.49±0.17 <sup>abcA</sup>	2.57±0.36 <sup>abcA</sup>
22	0.38±0.04 <sup>ab</sup>	0.40±0.13 <sup>bb</sup>	2.40±0.16 <sup>abcdA</sup>	2.45±0.29 <sup>abcA</sup>
24	0.22±0.05 <sup>ab</sup>	0.29±0.03 <sup>bb</sup>	2.77±0.03 <sup>abA</sup>	2.98±0.27 <sup>abA</sup>
27	0.28±0.08 <sup>ac</sup>	1.31±0.14 <sup>ab</sup>	2.96±0.06 <sup>abA</sup>	3.11±0.34 <sup>abA</sup>
29	0.30±0.11 <sup>ab</sup>	0.58±0.23 <sup>bb</sup>	2.73±0.10 <sup>abA</sup>	2.89±0.23 <sup>abA</sup>
31	0.30±0.08 <sup>ab</sup>	0.70±0.16 <sup>bb</sup>	2.89±0.01 <sup>abA</sup>	2.96±0.25 <sup>abA</sup>

Values are presented as mean±SD of triplicate. Values with different lowercase superscripts in the same column are statistically significantly different ( $p < 0.05$ ). Values with different uppercase superscripts in the same row are statistically significantly different ( $p < 0.05$ ). REA: under refrigeration with absence of light, REP: under refrigeration with presence of light, ROA: at room temperature with absence of light, ROP: at room temperature with presence of light.

(Figure 1, Plot REA and REP).

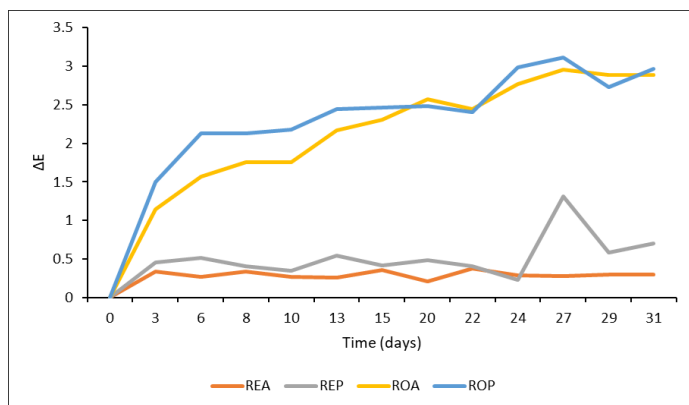


Figure 1. Color change of the film with drying temperature/time of 40°C/24 hrs during storage under refrigeration without an incidence of light (REA), under refrigeration with incidence of light (REP), at room temperature without an incidence of light (ROA), and at room temperature with incidence of light (ROP), compared to the film at initial time. Results are the means of three determinations.

### 3.3 Application of the film for the freshness of pork

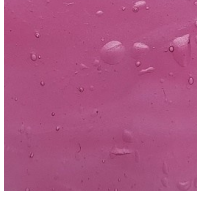
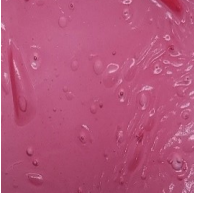
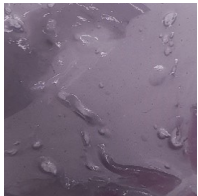

Foods undergo microbial breakdown during storage, producing volatile chemicals that contain  $(\text{CH}_3)_3\text{N}$  (trimethylamine),  $(\text{CH}_3)_2\text{NH}$  (dimethylamine), and  $\text{NH}_3$  (ammonia). These compounds' quantities progressively

rise in the headspace of an enclosed food package, raising the pH over time. The headspace provides information on its freshness (Zhang *et al.*, 2014). Pork is considered fresh when its pH falls between 5.18 and 6.12, sub-fresh when it falls between 6.13 and 6.16, and spoiled when it rises over 6.17, according to a study by Huang and Liu (2010). The performance of the film for monitoring pork freshness was studied by fitting it into a polypropylene container stored at  $25\pm 5^\circ\text{C}$  and evaluating the color change at various time intervals.

As shown in Table 3, the pH of fresh pork was 5.72 in the beginning (0 h). After being stored for 24 h, the pH value rose to 6.25, which is at the spoilage point. The pH value of the pork samples continuously increased until the end of the storage period where it had a pH value of 7.12. This is in line with other studies by Liu *et al.* (2018) and Yun *et al.* (2019), which reported that the pH value increased from 5.8 to 7.6 as the storage time of chicken and pork increased.

Table 3 also shows that as the pH of the pork samples changed; the color values of the pH indicator films changed accordingly. At the start (0 h), the films displayed a stronger intensity in color. After being stored, the films gradually lost color intensity and

Table 3. Chroma, lightness, and hue angle of the films monitoring the pork samples stored at  $25\pm 5^\circ\text{C}$  for 72 h.

Storage time (h)	pH of the pork samples	$C^*_{ab}$	$L^*$	$h_{ab}$ ( $^\circ$ )	Film
0	$5.72\pm 0.20^d$	$27.74\pm 2.79^a$	$62.77\pm 3.18^a$	$4.77\pm 1.66^d$	
24	$6.25\pm 0.30^c$	$24.22\pm 3.70^a$	$58.03\pm 3.29^{ab}$	$10.97\pm 5.75^c$	
48	$6.76\pm 0.19^b$	$11.79\pm 3.59^b$	$55.36\pm 1.78^{bc}$	$354.32\pm 3.47^b$	
72	$7.12\pm 0.06^a$	$5.46\pm 1.03^b$	$48.98\pm 2.89^c$	$49.37\pm 5.79^a$	

Values are presented as mean $\pm$ SD of triplicate. Values with different lowercase superscripts in the same column are statistically significantly different ( $p < 0.05$ ). Hue angle: Red ( $0^\circ \geq h_{ab} < 44^\circ$ ); Orange ( $44^\circ \geq h_{ab} < 60^\circ$ ); Yellow ( $60^\circ \geq h_{ab} < 120^\circ$ ); Green ( $120^\circ \geq h_{ab} < 180^\circ$ ); Cyan ( $180^\circ \geq h_{ab} < 240^\circ$ ); Blue ( $240^\circ \geq h_{ab} < 300^\circ$ ); Magenta ( $300^\circ \geq h_{ab} < 360^\circ$ ). Film photos are cropped to 1:1.

presented a more grayish color ( $C^*_{ab}$  decrease). This is similar to the findings of Golasz *et al.* (2013), where the anthocyanin films became achromatic. The  $L^*$  values of the films decrease during storage, showing a darker color. Significant differences ( $p < 0.05$ ) in each storage time were observed in hue angle ( $h_{ab}$ ), showing that the films changed from red hue ( $h_{ab} = 4.77^\circ$  at 0 h;  $h_{ab} = 10.97^\circ$  at 24 h), to a magenta hue ( $h_{ab} = 354.32^\circ$  at 48 h), and to an orange hue ( $h_{ab} = 49.37^\circ$  at 72 h).

The changes in the anthocyanin structure could have caused the changes in the chroma ( $C^*_{ab}$ ), lightness ( $L^*$ ), and hue angle ( $h_{ab}$ ) of the films. In acidic conditions, anthocyanins appear red and exist as flavylium cations (oxonium-charged oxygen) (Mattioli *et al.*, 2020). When pH increases, kinetic and thermodynamic competition between the hydration reaction of flavylium ion occurs, resulting in the formation of colorless carbinol pseudo base, which can undergo ring opening to produce yellow retro-chalcone structures. This reaction can be followed by more bluish anionic quinonoidal species with further deprotonation (Golasz *et al.*, 2013; Khoo *et al.*, 2017). The decrease in color intensity and lightness might result from the predominant forms that do not reflect red-colored pigments (Golasz *et al.*, 2013).

Pearson's correlation was used to analyze the association between the color difference ( $\Delta E$ ) of the pH indicator films during storage with the film at 0 h and the pH of pork samples. A high correlation coefficient ( $R$ ) of 0.99 was observed between them. As shown in Figure 2, it is evident that throughout the storage period, the pH of pork samples and the value of  $\Delta E$  continuously increased.

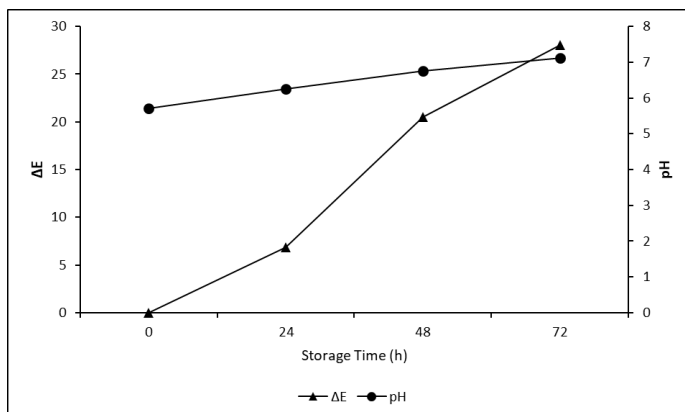


Figure 2. The color change of the films, against the film at 0 h, during the storage of pork samples at room temperature for 72 h and the change in pH of the pork samples.

While the results had shown a correlation between the film color and pork spoilage, it is important to determine whether the consumers would be able to recognize these variations in color, especially if commercial application of the film is sought after. One useful indicator to assess the capacity of the human eye

to detect color differences without the use of a sensory panel is color difference ( $\Delta E$ ). The color change or color difference can be easily distinguishable to the human eye when the  $\Delta E$  value is greater than 5 while values above 12 indicate absolute color differences that even untrained panelists can notice (Tassanawat *et al.*, 2007). Based on the  $\Delta E$  values found in this study, as shown in Figure 3, the consumers would most likely be able to detect the color changes of the film during storage if a color scale were attached to the packaging of the product. Similar to the findings of Zhang *et al.* (2014), Koshy *et al.* (2021), and Zhang *et al.* (2019), distinctive and noticeable color changes in the film occur within 48 h, suggesting that the process of pork spoilage has begun.

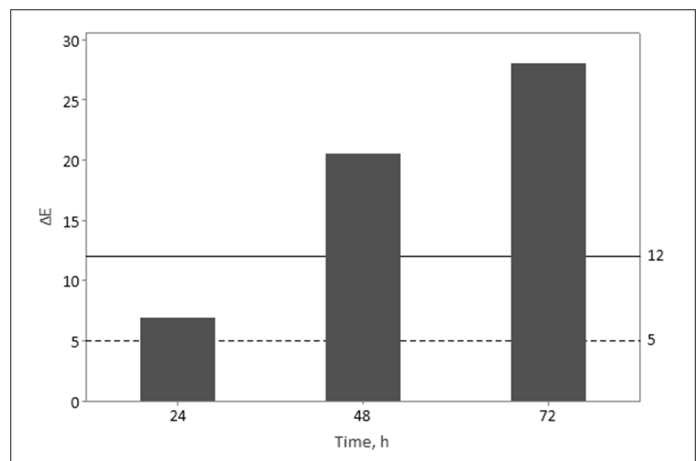


Figure 3. Color difference between the pH indicator films during pork samples storage and films at 0 h.  $\Delta E > 5.0$  = easily distinguishable, dashed line;  $\Delta E > 12.0$  = absolute color difference, straight line.

Due to the spoilage of pork samples, which increased the pH value to 7.12, the films in this study showed distinct color changes from red to orange. The color of the films was initially red, when pork was fresh, with a pH value of 5.72. The films showed visible color changes after 24 h at pH value of 6.25, although the hue remains red. Thereafter, the color of the films continued to drastically change from red to magenta to orange when the pH in pork samples approached 7.12 after 72 h. Therefore, the developed cassava starch film with purple yam peel anthocyanins was able to detect quality changes in the pork meat during storage at room temperature through film color changes that are easily distinguishable by the human eye.

#### 4. Conclusion

In conclusion, cassava starch film with anthocyanins from purple yam peels has the potential to be a pH indicator that can detect quality changes in pork meat as it is stable and sensitive to pH changes.

For the improvement of the study, it is recommended to determine the appropriate content of anthocyanins favorable to its practical application for real-time

monitoring of pork freshness. Although the color difference ( $\Delta E$ ) after 24 h was around 6.0, which is greater than 5.0 and is considered easily distinguishable to the human eye. It would be favorable if the color difference ( $\Delta E$ ) would have a value greater than 12.0 so that there would be absolute color differences that even untrained panelists can notice. Especially, based on the results, the onset of spoilage occurred after 24 h of storage. It is also recommended to further analyze its mechanical properties, other gas barrier properties aside from water vapor permeability, and morphological properties.

### Conflict of interest

The authors declare no conflict of interest.

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