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The study of edible film production from unriped banana flour and riped banana puree

Jirukkakul, N.

Department of Agro Industry, Faculty of Applied Science and Engineering, Khon Kaen University, Nong Khai Campus, Nong Khai 43000, Thailand

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Abstract

The edible film made from banana flour and banana puree *(Musa* AAA) were estimated the mechanical properties, water vapor permeability (WVP), color and solubility. The potassium metabisulfite (KMS) and ascorbic acid were used as the browning prevention chemicals. The banana flour film had 3x2 factorials experiment design (Flour 3% and 5%, glycerol 1% and 2% and 2 chemicals KMS and ascorbic acid). The results showed that the film made from banana flour was higher tensile strength (TS), elongation (E), water vapor permeability (WVP) and L value than the film made from banana puree. The KMS affected high L value and low b value in the both of banana flour film and banana puree film. The suitable treatment of banana film was the film made from banana flour which treated with KMS and composed of 5% banana flour and 2% glycerol. The obtained film would be applicable for food packaging to protect foods.

Introduction

Banana (genus *Musa*, family Musaceae) is a climatic fruit representing a major staple. It is cultivated in approximately 120-130 countries primarily located in tropical and subtropical regions (Bello-Perez *et al.*, 2005). World production of banana was estimated at 103 million tons in 2004, according to the Food and Agriculture Organization statistical database. In the same year, Thailand produced a 5^{th} of Asia's banana production (Zhang *et al.*, 2005). Most dessert banana cultivars in the world are classified under the AAA group, including almost all the cultivars sold in the export market. In Thailand, Banana cv. *Musa* (AAA group), or "Kluai Hom Thong," was the most exported banana in 2010 at a value of 1,318 million THB (Centre for Agricultural Information Office of Agricultural Economics, 2011). Bananas are consumed as fresh products; however, due to their seasonality and their commercialization in various regions of the world, they are also found in the market as frozen pulps, snacks and powders (flours).

Riped banana is an excellent and worthwhile food because its pulp is sugar rich and easily digested, and its content in potassium and magnesium is helpful for muscle contraction control. Banana puree is one of the first solid foods given to infants. With its high carbohydrate content, it is a stable calorie resource. Research on banana puree products that have been published include studies on the rheological behavior and chemical characteristics of banana mayonnaises (Izidoro *et al.*, 2008), the sensory properties of low fat set yoghurt with probiotic cultured banana puree (Srisuvor *et al.*, 2013), banana juice processing (Sim and Bates, 1994; Calligaris *et al.*, 2012) and banana jam and beer (Aurore *et al.*, 2009).

Unriped banana contains large amounts of starch, cellulose, hemicellulose and lignin in its pulp. Therefore, economic strategies to increase utilization of banana include banana flour production. Banana flour can be incorporated into innovative products, such as increased nutrient value snacks (Wang *et al.*, 2012), slowly digestible cookies (Agama-Acevedo *et al.*, 2012), gluten free pasta (Zandonadi *et al.*, 2012), indigestible carbohydrate of pasta (Ovando-Martinez *et al.*, 2009), yellow alkaline noodles (Choo and Aziz, 2010: Saifullah *et al.*, 2009) and high dietary fiber bread (Ho *et al.*, 2013). Moreover, banana flour is significant for its capacity to produce an edible film.

Pelissari *et al.* (2013a) studied the optimized conditions of the banana film production process. The result showed that film displays higher opacity, lower solubility in water, better WVP and flexibility and more excellent mechanical strength and rigidity than other biodegradable films. Pelissari *et al.* (2013b) compared film made by different varieties of banana films and found that the cultivar Terra *(Musa paradisiaca)* exhibits excellent features for the preparation of biodegradable films. Banana film

*Corresponding author.
Email: *artnaruk@hotmail.com*

made from banana starch was found to have a high tensile strength value (25 MPa) (Romero-Bastida *et al.*, 2005). Modifying banana starch by oxidation and acetylation affects the properties of the film. Oxidation induced increasing of solubility and WVP of the film whereas acetylation affected those values in the opposite way. Tensile strength increased and elongation reduced when the oxidation level is increased (Zamudio-Flores *et al*., 2009). Banana flour film can be applied to packaging which depend on its ability to seal (Sothornvit and Pitak, 2007). The composite film from banana flour and chitosan exhibits great water permeability. With the integration of chitosan's antimicrobial property and banana flour's ability to seal, Film of these properties were benefit for produce sealed edible bag for preserving fresh cut vegetables (Pitak and Rakshit, 2011).

The banana *Musa* AAA, which is the most consumed, has not yet been researched for its edible film, so it was selected for this study. Film production from both riped (puree) and unriped (flour) banana was investigated and physical properties of the resulting films were studied, including color, appearance, moisture content, tensile strength, elongation, water vapor permeability and solubility.

Materials and Methods

Materials

Raw banana and riped banana cv. Kluai Hom Thong were purchased from a local market in Nong Khai Province, Thailand. The raw banana had green peel at the 5th stage of ripening and was selected to produce banana flour. The riped banana had yellow peel at the 7th stage of ripening and was selected to produce banana puree. Both the flour and puree acted as raw materials for film formation. Food grade of ascorbic acid, potassium metabisulfite (KMS) and glycerol were provided by Ajax Finechem Pty Ltd, New Zealand.

Banana flour and banana puree production

The green bananas were washed, steam blanched for 11 min, peeled, sliced at the average thickness of 5 cm and soaked in solution either 470 mg ascorbic acid/kg banana or 100 mg KMS/kg banana for 30 min to prevent browning reaction (Galeazzi and Sgarbieri, 1981). The banana pieces were dried at 55°C for 12 h. The dried chips were then milled and ground using a hammer mill. The obtained flour was 6-7% moisture content. The color and viscosity of the banana flour were determined.

Riped bananas were washed, steam blanched for 11 min, peeled and blended. Either 470 mg ascorbic acid/kg banana or 100 mg KMS/kg banana were added to the puree and mixed in for 2 min to prevent browning reaction. The color and viscosity of the puree were determined.

Film preparation

The banana flour solution (3% and 5% w/w) was heated to 85°C for 10 min. Glycerol (1% and 2% w/w) was added to the solution and stirred. Fifty millimeter each solution (flour and puree solutions) was poured into a smooth superlene plate with a 15 cm internal diameter. The solutions in the casting plates were dried at 60°C for 12 h. The dried films were peeled at ambient temperature and kept in a plastic bag.

Flour and puree characteristics

The color of the banana flour and banana puree was measured using a HunterLab Spectrocolorimeter (Model TC-P III A, Tokyo Denshoku Co., Ltd., Japan). The 10-20 g of samples were prepared, put into a clean Petri dish and covered. The CIELab system was used in reporting the L^*, a^*, b^* values of samples.

The Rapid Visco Analyzer was used to characterize the banana flour. The 3.24 g of accurately weighed banana flour was added to 25 ml distilled water to prepare a suspension. The banana flour solution was kept at 50°C for 1 min and then heated up to 95°C and held for 3.2 min. It was then cooled to 50°C and a final isothermal step was taken at 50°C. The resulting RVA curve was expressed in Rapid Visco Units (RVU). The viscosity at 200 rpm was used to determine the viscosity of the banana puree. The viscosity in units of centipoise was obtained at the same temperature.

Thickness of banana films

Film thickness was measured with an accuracy of 0.01 mm using a Dial Thickness Gauge at three random positions of the film sample. The average values from each sample were then used in calculating water vapor permeability and mechanical properties.

Tensile strength (TS) and elongation (E) of banana films

Tensile strength (TS) and elongation (E) values of the films were determined using a texture analyzer and the standard testing method ASTM D882 (1997). Films were cut in 1x12 cm^2. Initial gauge separation and crosshead speed were fixed at 50 mm and 50 mm/min, respectively. Tensile strength was calculated as follows:

$$\frac{F_{max}}{A}$$

Where,
F_{max} is the maximum force (N) and
A is the cross section area of the film (m^2).
The elongation at break was calculated from the ratio of increase in length and expressed as a percentage.

Water vapor permeability (WVP) of the banana films

Water vapor permeability (WVP) tests were performed using the gravimetric modified cup method based on ASTM E96 (ASTM, 2000) and using a specially designed permeation cell, which was maintained at 24°C. The test cups were filled with 30 ml distilled water to achieve 100% relative humidity on one side of the film. The film (diameter = 6 cm) was placed on the cup and was sealed with a sealant ring. The sample cups were weighed and kept in a chamber. Silica gels were used to control the relative humidity on the other side of the film. The temperature and relative humidity were measured at 24°C and 75%, respectively. The sample cups were weighed every 1 h for 8 h. An accurate weight loss (g) versus time (h) was plotted to obtain a straight line of linear regression with r greater than 0.99. The WVP testing was replicated 3 times, and the WVP was calculated as follows:

$$WVP = \frac{\Delta Wx}{A\Delta t(p_2 - p_1)}$$

Where,
Δw is the accurate weight loss (g)
Δt is the time for weight change (day),
A is the area of the exposed film (m^2),
x is the film thickness (mm),
p_2 -p_1 is the vapor pressure differential across the film (kPa)

Color of the banana films

The color of the banana flour film was measured with the HunterLab Spectrocolorimeter (Model TC-P III A, Tokyo Denshoku Co., Ltd., Japan). The sample was put into the test cell and covered. The color was measured using the CIELab system and L^*, a^*, b^* values were reported for each of the samples.

Solubility of the banana films

Solubility (S) tests were performed in boiling water. Films were cut into 1.5×1.5 cm^2 pieces and weighed (A). Distilled water (50 ml) was heated to 100°C on a hot plate, then accurately weighted films were soaked for 4 min (Perez-Gago and Krochta, 2001). The samples were filtrated to keep the residual films, which were dried in the hot air oven at 70°C for 24 h to keep the weight constant. The final films were then weighed again (B). The % solubility (%S) tests were calculated with 3 replications. The percentage solubility in each case was calculated as follows:

$$\%S = \frac{(A - B) \times 100}{A}$$

Results and Discussion

Banana flour characteristics

The L values of the banana flour treated with KMS and ascorbic acid were 66.52 and 67.43, respectively. The b values of them were expressed at 7.74 and 11.97, respectively (Table 1). The banana flour treated with KMS showed lower b value than that treated with ascorbic acid, because KMS was more effective in preventing browning reaction than ascorbic acid. Sims and Bates (1994) reported that Polyphenoloxidase (PPO) was made completely inactive by the sulfite and heating treatments.

Table 1. The properties of banana flour (wet basis)

Banana flour	% Moisture content	L value	a value	b value
Treated with KMS	7.01±0.37^a	66.52±0.13^b	0.82±0.04^a	7.74±0.20^b
Treated with ascorbic acid	5.23±0.48^b	67.43±0.24^a	0.81±0.04^a	11.97±0.15^a

The superscripts indicate the difference of statistical analysis between samples ($p \leq 0.05$).
Data are mean of triplicates.

The RVA curve of the banana flour showed a resistance in mechanical force. Viscosity profiles showed high concentrations due to a slight increase in viscosity during cooking and then breakdown. At high viscosity, swollen granules occupy most of the space and cannot move off from each other. As a result, the higher concentrations of banana flour underwent distinct setbacks (retrogradation) during cooling. The RVA properties of banana flour are shown in Table 2. Banana granules treated with ascorbic acid had the highest peak viscosity, trough viscosity, breakdown viscosity, final viscosity and setback viscosity. It could be implied from this that these samples had the highest water-binding potential. Banana flour treated with KMS had the highest resistance to heating, shear-thinning, as revealed by its breakdown viscosity. These results are similar to results from Daramola and Osanyinlusi (2006), which report a setback viscosity of 70 RVU and from Nimsung *et al.* (2005), which report a peak viscosity and final viscosity of 243-432 RVU and 280-542 RVU, respectively. Moreover, the peak viscosity and breakdown viscosity of banana starch

Table 2. The RVA properties of banana flour (wet basis)

Banana flour	Peak viscosity (RVU)	Trough (RVU)	Breakdown viscosity (RVU)	Final viscosity (RVU)	Setback viscosity (RVU)	Peak time (min)	Pasting (°C)
Treated with KMS	152.08±8.34[b]	139.9433±6.89[b]	12.14±2.21[b]	190.67±10.52[b]	50.72±4.08[b]	6.58±5.53[a]	50.23±0.19[a]
Treated with ascorbic acid	227.22±17.32[a]	191.39±13.02[a]	35.83±4.98[a]	265±21.08[a]	73.61±8.07[a]	5.53±0.23[a]	51.03±0.80[a]

The superscripts indicate the difference of statistical analysis between samples ($p \leq 0.05$).
Data are mean of triplicates.

has been found to be similar to corn starch (Torre-Gutierrez *et al*., 2008).

Banana puree characteristics

The characteristics of the banana puree included viscosity and color (Table 3). The banana puree treated with KMS showed higher viscosity than that treated with ascorbic acid, whereas the color (L^*, a^*, b^*) was not different. The viscosity identified in this experiment was higher than previously investigated banana juice with the value of 0.09 Pa.s (Calligaris *et al*., 2012) since the banana juice was diluted with water in a 1:1 ratio, It also showed a higher L value and lower b value than the banana puree from this experiment.

Table 3. The viscosity and color of banana puree

Banana puree	Viscosity (Pa.s)	L* value	a* value	b* value
Treated with KMS	3.71±0.49[a]	68.33±2.54[a]	4.54±0.98[a]	36.95±2.87[a]
Treated with ascorbic acid	1.76±0.25[b]	66.55±3.41[a]	4.56±0.71[a]	35.95±1.43[a]

The letters indicate the difference of statistical analysis between samples ($p \leq 0.05$).
Data are mean of triplicates.

Tensile strength (TS) and elongation (E) of the banana films

Food products require high TS and E of packaging material for protection during transportation and sale. Generally, natural materials are weaker than synthetic materials, but they are environmentally friendly. For example, Sothornvit and Pitak (2007) showed that polysaccharide films alone are weaker and less flexible than polysaccharide films enhanced with plasticizer. The addition of plasticizers decrease the power of intermolecular forces and polymer chain cohesiveness (Cheng *et al.*, 2006). The KMS and ascorbic acid used to treat the banana flour did not affect the film's TS and E. The higher banana flour content in film caused high TS (Table 4). The results were similar to previously investigated banana/chitosan films with 0.5% glycerol (Pitak and Rakshit, 2011) and banana films tested by Sothornvit and Pitak, 2007. TS and E increased with the addition of banana flour, attributed to the water's response to the higher hydrogen bonds between starch chains. These bonds contribute to cohesiveness in the film (Turhan and Sahbaz, 2004). The protein and lipids in banana flour appeared to have a plasticizer effect, which reduced the mechanical resistance and increased the flexibility of the films (Pelissari *et al*., 2013a).

Water vapor permeability (WVP) of the banana films

WVP is important for food packaging because the deterioration of foods depends on water content transferring from the product's surroundings to the interior products. WVP of the films increased with banana flour content. WVP was only 1.38-2.04 and 5.64 g.mm/m^2.day.kPa for banana flour films and banana puree films, respectively (Table 4 and Table 5). Tapia-Blacido *et al*. (2005) concluded that banana flour films have a more complex composition, not only because of amylose and amylopectin fractions, but also because fat and protein molecules behave as plasticizers. This may explain the greater water barrier of cellulose- and methylcellulose-based films. The puree films had higher WVP than the flour films because the sugar in riped bananas behaves as a plasticizer. Plasticizers and fat increase WVP of films as the small hydrophobic molecules get inserted between close polymer chains. The intermolecular attractions decrease and increasing molecular

Table 4. The properties of banana films from banana flour treated with KMS or ascorbic acid

Film flour: glycerol	TS (MPa)	E (%)	WVP (g.mm/m^2.day.kPa)	L* value	a* value	b* value	Solubility (%)
KMS 3:1	1.65±0.03^{bc}	21.26±3.28^{a}	1.38±0.06^{c}	90.88±0.52^{a}	0.44±0.05^{d}	7.26±0.17^{f}	23.35±0.60^{c}
KMS 3:2	0.73±0.18^{cd}	14.50±5.44^{b}	1.92±0.20^{ab}	90.46±0.33^{ab}	0.55±0.03^{c}	8.37±0.15^{e}	30.89±1.51^{a}
KMS 5:1	2.34±0.50^{a}	12.99±4.00^{b}	2.01±0.09^{a}	87.87±0.34^{d}	0.98±0.09^{a}	11.15±0.38^{c}	14.75±0.37^{e}
KMS 5:2	1.99±0.13^{a}	25.15±4.37^{a}	1.96±0.08^{a}	89.25±0.24^{c}	0.52±0.05^{cd}	11.86±0.34^{b}	25.30±0.53^{b}
Ascorbic â 3:1	2.07±0.04^{b}	27.72±0.86^{a}	1.45±0.08^{c}	90.39±0.07^{b}	0.27±0.03^{e}	10.90±0.07^{c}	20.67±0.61^{d}
Ascorbic â 3:2	0.82±0.25^{d}	12.09±5.67^{b}	1.47±0.03^{c}	90.15±0.23^{b}	0.52±0.04^{cd}	10.15±0.08^{d}	25.93±2.23^{b}
Ascorbic â 5:1	2.28±0.34^{a}	25.98±1.33^{a}	1.76±0.06^{b}	89.51±0.09^{c}	0.49±0.04^{cd}	11.73±0.16^{b}	12.72±0.38^{f}
Ascorbic â 5:2	2.20±0.30^{a}	24.73±1.59^{a}	2.04±0.06^{a}	87.82±0.24^{d}	0.71±0.07^{b}	14.24±0.31^{a}	20.83±1.18^{d}

The superscripts indicate the difference of statistical analysis between samples ($p \leq 0.05$).

Table 5. The properties of banana films from banana puree treated with KMS or ascorbic acid

Film	TS (MPa)	E (%)	WVP (g.mm/m^2.day.kPa)	L* value	a* value	b* value	Solubility (%)
Treated with KMS	1.45±0.05^{b}	17.73±0.50^{a}	5.64±0.13^{a}	49.07±0.80^{a}	0.44±0.05^{d}	6.00±0.24^{b}	40.73±1.86^{a}
Treated with Ascorbic acid	2.02±0.25^{a}	17.73±1.97^{b}	5.64±0.31^{a}	49.09±0.61^{a}	0.55±0.03^{c}	7.62±0.53^{a}	37.68±2.35^{b}

The superscripts indicate the difference of statistical analysis between samples ($p \leq 0.05$).
Data are mean of triplicates

mobility allows water migration (Rodriguez *et al.*, 2006). Some researchers have previously reported similar WVP values for banana films (Pelissari *et al.*, 2013a and Pelissari *et al.*, 2013b).

Color of the banana films

The color of the banana films was yellowish, classified as a red-yellow color. The banana flour films had higher L values but lower a and b values than banana puree films due to the color of the raw flour and puree materials (Table 4 and Table 5). The L values were similar to plantain banana films (Pelissari *et al.*, 2013b), while the b values were similar to oxidized banana starch films (Garcia-Tejeda *et al.*, 2013). It seems that a Maillard reaction effect caused the decrease in lightness of the puree films (Garcia-Tejeda *et al.*, 2013). The addition of a glycerol affected the L value of the films. Films tended to become more transparent. The banana flour content caused the film to have low transparency and to become more yellowish.

Solubility of the banana films

Solubility is an important property for biodegradable and edible film applications. The desired value for the solubility of films will depend on their application. Soluble film packaging is convenient to use in ready-to-eat products, as they melt in boiling water or in the consumer's mouth. Moreover, they can easily be used as fertilizer without adding to pollution. Thus, solubility is an important characteristic for understanding a product's degradable properties. The solubility of banana flour films and banana puree films were in the ranges of 12.72-25.93% and 63.84-65.38%, respectively (Table 4 and Table 5). Solubility increased as glycerol content increased. Glycerol causes film extensibility because it inserts between polysaccharide chains, so it impacts water absorption. The solubility of the banana flour films was high and was reduced when glycerol and banana flour content increased. Amylose-amylose, amylopectin-amylopectin and amylose-amylopectin interactions take place during drying of the films, which reduces the amount of hydrophilic groups available for interaction with water (Pelissari *et al.*, 2013b). The sugar content of the banana puree acts as a soluble solid. Thus, the banana puree films had higher solubility than the banana flour films. These results correspond with those from previous studies of banana flour films and banana starch films (Pelissari *et al.*, 2013b).

Conclusions

The KMS and ascorbic acid were not affect to the mechanical properties of banana flour film. The KMS caused film lighter and less yellowness than ascorbic acid because KMS affected on inactive of polyphenol oxidase enzyme. Moreover, the solubility of film which treated with KMS was higher than film which treated with ascorbic acid. TS, E and WVP of banana flour film were higher than banana puree film because the hydrogen bonds between starch chains increased with banana flour content. Film production from both banana puree and banana flour would be applicable for coating on food materials or would be produce to food packaging.

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