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The effect of different thermal modifications on slowly digestible starch and physicochemical properties of green banana flour (*Musa acuminata colla*)

Yana Cahyana[a,*], Evelyn Wijaya[a], Tien Siti Halimah[a], Herlina Marta[b], Edy Suryadi[c], Dian Kurniati[a]

[a] Laboratory of Food Chemistry, Department of Food Technology, Universitas Padjadjaran, Indonesia
[b] Laboratory of Food Processing Technology, Department of Food Technology, Universitas Padjadjaran, Indonesia
[c] Laboratory of Soil and Water Engineering, Department of Agricultural Engineering and Biosystem, Universitas Padjadjaran, Indonesia

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ABSTRACT

The effect of heat moisture treatment (HMT), annealing (ANN), and dual retrogradation (DR) on functional and pasting properties, digestibility of starch components of banana flour comprising rapidly digestible starch (RDS), slowly digestible starch (SDS) and resistant starch (RS) has been investigated, using native banana flour (NBF) as a control. Crystal type, relative crystallinity and morphological changes were characterised by XRD and SEM. HMT has markedly modified the pasting properties and resulted in the highest SDS content. HMT and ANN increased the relative crystallinity but DR decreased it. HMT and DR altered XRD patterns from B to A and A + B type respectively, while ANN did not change the XRD patterns. The NBF compact granule surface remained unchanged with ANN but changed to a more porous surface with HMT and DR, thereby increasing the digestibility. Crystal type and granule morphology affected the digestibility while relative crystallinity might change the pasting point.

1. Introduction

Banana is a potential source of starch and worth investigating due to its abundance, particularly in tropical countries. Starch in banana pulp constitutes as much as 70–80% on a dry weight basis. This figure is comparable to the starch content of the endosperm of corn grain or white potato pulp (Zhang, Whistler, BeMiller, & Hamaker, 2005).

From the point of view of its application in the food industry, native starch application has been limited due to its poor thermal, shear and acid stability, and also the high rate and extent of retrogradation during storage (Hoover, 2010). In order to enhance such properties, either chemical, physical, or enzymatic modification has been applied. Amongst the modifications commonly applied, physical modification is an interesting approach to ameliorate native starch properties owing to the absence of residues of any chemical reagents.

Physical modifications such as heat moisture treatment (HMT), annealing (ANN) and retrogradation have been commonly used to modify native starch properties. HMT is usually applied to foods with a low moisture content (< 35% w/w) while ANN is applied in samples with a higher water content (> 65% w/w) at which the temperature is set below the onset of gelatinisation but above the glass transition temperature (Tg) (Tester & Debon, 2000). Retrogradation is carried out by storing the gelatinised starch at a low temperature. A number of reports have described the change in functional properties following either HMT, ANN or retrogradation of potato and cassava (Gunaratne & Hoover, 2002; Osundahunsi, Seidu, & Mueller, 2011; Xie, Hu, Jin, Xu, & Chen, 2014). These physical modifications are sometimes referred to as thermal modifications.

An increase in crystallinity and a reduction in swelling volume and solubility of modified starch have been documented following HMT and ANN treatment (Zavareze and Dias, 2011). Apart from functional properties, thermal modification of starch might also alter its digestibility including RDS, SDS and RS (Englyst, Kingman, & Cummings, 1992). RDS leads to a rapid elevation of blood glucose due to the rapid conversion to glucose in the duodenum and proximal regions of the small intestine while SDS is the portion slowly digested which provides sustained glucose release and may be able to reduce postprandial blood glucose level and lower postprandial insulinemia (Cummings, Beatty, Kingman, Bingham, & Englyst, 1996). RS is the remaining fraction that is not digested in the upper gastrointestinal tract but is mainly fermented in the colon. RS of unripe banana flour has been demonstrated to lead to a reduced glycemic response, reduced hunger, increased satiety parameters and insulin sensitivity (Hoffmann Sardá et al., 2016).

Although a number of studies have reported the effect of thermal

* Corresponding author.
E-mail address: y.cahyana@unpad.ac.id (Y. Cahyana).

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modification on functional properties and digestibility of various starches, including wheat starch (Hu, Xie, Jin, Xu, & Chen, 2014), a detailed study comparing different thermal treatment effects on banana flour properties has not been reported despite the fact that certain food applications utilise the flour. Furthermore a number of reviews on different methods of thermal modification of various starch sources have come up with conflicting conclusions of the effects on certain properties leading to a difficulty in choosing an appropriate modification method for banana flour. It was therefore considered important to examine the effects of the three commonly applied thermal modifications i.e HMT, ANN and DR in a simultaneous study. DR was chosen because it led to a pronounced change in properties particularly SDS content compared to single or triple retrogradation (Hu et al., 2014). The treatments applied differed in their severity (moisture content, temperature and gelatinisation degree) which could lead to markedly different changes in granule morphology and molecular structure thereby leading to different changes in digestibility, functional and pasting properties. Another objective of the present study was to determine which factors affect the change of banana flour properties. The pronounced difference in the morphology and starch structure induced by different treatments may provide information to allow us to achieve this objective.

2. Materials and methods

2.1. Materials

The flour used in this study was from unripe green banana (*Musa acuminata colla*, AAA group, Cavendish subgroup), commonly known locally as pisang kapas. Banana at ripening stage 1 (entirely green) was selected for the study due to the highest content of starch compared to the other ripening stages. The fruit was purchased in a local market at Gede Bage (Bandung, Indonesia). Flour production was carried out immediately after the purchase of the fresh samples. A glucose oxidase/peroxidase kit was purchased from Megazyme International Ireland (Bray Business Park, Bray, Co. Wicklow, Ireland). Pancreatin and amyloglucosidase were supplied by Sigma Aldrich. All chemicals used in this work were of analytical grade.

2.2. Banana flour preparation

The method was that of Yangılar (2015) with a slight modification. First of all banana fruit was dipped in water and washed and then the peel was stripped off. The pulp was cut into transverse slices approx. 2 mm thick, followed by dipping the slices of pulp in water for 10 min, draining and drying at 50 °C overnight in an oven (Shel Lab). After that, the pulp slices were milled to produce flour (Fomac miller machine FCT Z-300) and passed through 80 mesh screens. Banana flour was placed in impermeable plastic bags and stored at 25 °C for later analysis. Banana flour production was repeated 3 times in order to allow appropriate statistical analysis.

2.3. Thermal modifications

Thermal modification treatments applied in this study included HMT, ANN and DR. HMT was carried out by adjusting the initial water content of the flour to 30% by the addition of distilled water (Gunaratne & Hoover, 2002). The water was added by spraying it onto the flour homogenously and the mass used was calculated taking into account the initial moisture content of the flour. The flour was then heated at 100 °C for 8 h following conditioning in a refrigerator at 4–5 °C for 24 h. Prior to heating, the moisture content of the flour was determined following conditioning to ensure that had reached the targeted moisture content. Sampling of flour for moisture content measurement was performed in a representative way by taking equilibrated flour from different parts of the container. We managed to attain the targeted moisture content in 24 h. ANN was performed by suspending flour in 70% distilled water (w/w), followed by heating the suspension in a water bath at 55 °C for 12 h (Hormdok & Noomhorm, 2007). It was then centrifuged at 1500*g* for 30 min to precipitate the treated flour. Meanwhile DR was applied to the flour in water suspension (1:5.5 w/v) which was then heated at 100 °C for 30 min followed by storage at 4 °C for 48 h. Heating at 100 °C and storage at 4 °C were repeated twice successively on the same sample (Tian et al., 2013). Flour treated either with HMT, ANN or DR was then oven dried at 50 °C for 24 h and then ground prior to sieving to 80 mesh.

2.4. X-ray diffraction (XRD)

Powder X-ray diffraction analysis of the native and modified flours was carried out on powder using an X-ray diffractometer (PANalytical X'Pert PRO seri PW3040/x0) with Cu Kα value of 1.54 radiation with a 2θ range of 3°–50° using a voltage of 40 kV and filament current 30 mA. Crystallinity was calculated using a Sigma plot programme as reported in the literature (Cheetham & Tao, 1998).

2.5. Granule morphology

Granule morphology was characterised directly from the flour (not isolated starch) by scanning electron microscopy (SEM); using a JEOL JSM-6360 LA at 15 kV. Samples were mounted, and the sample holder was sealed with silver paint and coated with gold/palladium at 8–10 mA for 10–15 min, under low pressure less than 10 torr. Representative digital images of starch granules were obtained at 1000× magnification.

2.6. Functional properties

2.6.1. Colour evaluation

The colour scale for L^*, a^* and b^* of native and modified flour was measured using a Spectrophotometer CM-5 (Konica Minolta Co., Osaka, Japan). Hue was calculated according to equation:

$$\text{HUE} = tan^{-1}\left(\frac{b*}{a*}\right)$$

2.6.2. Swelling volume (SV) and solubility measurement

Swelling volume was determined as follows; 0.35 g (db) of banana flour were suspended in 12.5 mL of water in a centrifuge tube, and mixed for 30 s using a vortex mixer. The samples were then kept in a 92.5 °C water bath for 30 min. Samples were cooled in ice water for 1 min, and centrifuged at 2050*g* for 30 min. The supernatant volume was measured and then dried in a hot air oven to measure the percent solubility (Collado & Corke, 1999).

$$\text{Swelling Volume (ml/g)} = \frac{\text{total volume}-\text{supernatant volume}}{\text{Weight Sample (db)}}$$

$$\text{Solubility (\%)} = \frac{\text{W dried supernatant}}{\text{W sample (db)}} \times 100\%$$

2.6.3. Freeze thaw stability (FTS) measurement

The freeze-thaw stability was determined by the method of Wattanachant, Muhammad, Mat Hashim, and Rahman (2003). An aqueous suspension of flour (5%) was heated at 95 °C for 30 min with constant mild agitation, then cooled to room temperature in a shaking iced water bath. Next, an aliquot of the paste (20 g) was taken and placed in a centrifuge tube and subjected to a freeze thaw cycle by storing at 4 °C for 24 h, then freezing at −15 °C for 48 h, followed by thawing at 25 °C for 3 h. It was then subjected to centrifugation at 2050*g* for 15 min. After centrifugation, the supernatant eliminated from the gel was weighed, and the extent of syneresis was calculated as the