Biological modification of functional properties of orange-fleshed sweet potato flour by spontaneous fermentation and its possible utilization

Neti Yuliana[1*], *Dewi* Sartika[1], *Azhari* Rangga[1], *Mia* Oktasari[1], and *Edo* Jatmiko[2]

[1]Department of Agro-industrial Product Technology, Faculty of Agriculture, University of Lampung, Sumantri Brojonegoro # 1 Bandar Lampung, Indonesia
[2]SMKN 1 Ketapang, Lintas Timur Parit # 8, Berundung, Kec. Ketapang, Lampung Selatan, Lampung, 35592, Indonesia.

Abstract. This study evaluated some functional properties of the orange-fleshed sweet potato flour modified by spontaneous fermentation at different times. This information can further be used to assess its potential application in food processing. Under anaerobic conditions, the peeled slices of orange-fleshed sweet potatoes were fermented at 30°±2°C spontaneously. Samples were taken at 0, 24, 48, and 72 hours and processed into flour. Observations were performed on the pH, residual starch yield, water retention, expansion rate, solubility, and sensory evaluation of the color. Starch granules were observed on samples of 48 h and 72 h using a scanning electron microscope (SEM). Results showed that the properties of the flours were modified by fermentation time. There were linear decreases of pH from 4.87 to 4.16, residual starch yield from 62.12% to 47.88% (db), and color score from 3.6-3.7 (brownish yellow) to 1.6-1.7 (yellowish white). A quadratic decrease in solubility at both 85ºC and 90ºC from 16.92% to 16.74% and 13.07% to 12.45%, respectively, was observed. However, a quadratic increase was found in water retention from 2.55 to 2.72 and linear expansion rate from 13.54 to 16.59. Starch granules changed with fermentation time. With these functional properties, the orange-fleshed fermented sweet potato flour can be applied as raw material for producing baking products with a distinct acidic taste.

1 Introduction

The main ingredient in the production of many foods is flour. Sweet potatoes (*Ipomoea batatas* L.) have starch as their primary constituent, making them an essential raw material in flour production. Using sweet potato flours (SPF) as a substitute for or mixed with other flours has recently garnered significant interest. According to Dereje et al. [1], the processing method influences the physicochemical and functional properties of SPF, and these properties determine the suitable application of SPF.

Biological modification, such as fermentation, is often applied during flour processing to improve the native SPF, especially on white-fleshed sweet potatoes (SP). According to previous research, fermentation time provides a greater extent of flour modification [2-5]. The enzymes and organic acid microorganisms produced during fermentation might alter the starch granules, thus affecting SPF's physicochemical properties. Furthermore, fermentation caused a decrease in the pH and solubility, an increase in swelling power, and changes in the pasting properties [1-2], [6-8] that fermentation increased the expansion rate and water retention of white-fleshed SPF. Although there is much research on fermented SPF, there are few studies on the functional properties of orange-fleshed SPF with fermentation modification. Amajor et al. [6] focused on the chemical property changes of fermented orange-fleshed SPF, while Haruna et al. [9] studied the functional properties of orange-fleshed SPF as affected by heat treatment methods, not by fermentation.

Different types of cultivars have distinct morphologies of starch granules [10]. Hence, the colored SP may exhibit different properties of starch granules. Genotypic backgrounds may have different amylose contents in different SP varieties [11]. The amylose content and amylose to amylopectin ratio are important factors affecting the starch structure and properties [9]. Starch's physicochemical and structural properties from orange-fleshed SP show differences from typical white-fleshed SP [12]. Most studies have concentrated on the functional properties of fermented white-fleshed SPF. However, this study evaluated the functional properties of the orange-fleshed SPF affected by spontaneous fermentation at different times. This information can further be used to assess its potential application in food processing. Moreover, spontaneous fermentation may provide a simple technique to encourage SPF production at the household level.

*Corresponding author: neti.yuliana@fp.unila.ac.id

2. Methodology

2.1 Fermentation of sweet potatoes

The washed and peeled SP were sliced and divided into three representative lots. Each lot was placed into a fermenter containing a boiled solution of 1% sugar and 3% salt. These lots were held at 30°±2°C in anaerobic conditions to maintain the fermenting process. Samples were withdrawn at 0, 24, 48, and 72 hours.

2.2 Production of sweet potato flour

The fermented SP slices were washed, drained, and dried in a blower oven (British foyer, Peabody Holmes, UK) at 60°C for 24-30 hours until the water content was at ± 6-8 %. The dried slices were milled using a grinder (Retsch GmbH, laboratory grinder, Germany) and sieved through an 80-mesh sieve. The flours were packed in containers with tight plastic lids for later evaluation. Observations were done to determine pH, starch yield, water retention, expansion rate, solubility, and sensory evaluation of the color. Starch granules were observed on 48 h and 72 h samples using a scanning electron microscope (SEM).

2.3 Determination of solubility

The solubility was determined using the method previously used by Deng et al. [13] with a slight modification of the dispersion ratio. The flour sample (0.1 g) was dispersed in 12.5 mL of distilled water in centrifuge tubes, heated in a water bath for 30 min to 85ºC, and centrifuged (Beckman GP, UK) at 3500 rpm for 15 min. The supernatants were collected and dried at 105ºC to constant weight. The solubility was calculated as a percentage of dried supernatant weight compared to dried flour (0.1 g).

2.4. Determination of water retention

Water retention was determined as described by Liao et al. [14]. A suspension of 1 g flour (dry basis) in 20 mL distilled water was agitated for 20 min, centrifuged at 4,500 rpm for 10 min, drained, and weighed. Water retention was determined as the ratio of the precipitate weight to the dry flour weight.

2.5 Determination of expansion rate

The expansion rate was determined as described by [14]. Flour dispersion at 0.5 g/100 g was prepared by mixing SP flour with distilled water. The dispersion was moderately stirred for one hour at room temperature and heated to 85ºC in a water bath for 30 min. The hot paste was cooled at room temperature in an iced water bath and centrifuged at 2,300 rpm for 30 min. The expansion rate was determined as the ratio of sediment weight to dry starch weight.

2.6 Morphology of starch granule

The morphology of starch granules was evaluated using a FEI Scanning Electron Microscope (SEM) (Inspect S50, FEI Company, United States) integrated with EDAX AMETEK (Energy Dispersive X-ray Spectroscopy (EDS) System, EDAX, United States. The selected SP sample powder was placed on to a double-sided carbon-taped holder and then coated with

The micrographs were obtained with an accelerating voltage of 10.00 kV with a magnification of 1000×.

2.7 Determination of residual starch

The orange-fleshed SP starch extraction process was carried out in the following manner. The clean SP was grated, squeezed, and extracted with distilled water as much as four times the crushed sweet potato volume. The supernatant was then precipitated for 12 hours to obtain SP starch. The wet starch was then dried in a cabinet for 12 hours at 60ºC to achieve 5-8% moisture content. The dry SP starch was then weighed.

2.8 Color evaluation by sensory analysis

The sample of the fermented SPF was subjected to color evaluation using a scoring test. A panel of 20 students evaluated the samples by comparing the color of fermented SPF with the control (unfermented SPF).

2.9. Data analysis

Data were analyzed using Excel to assess the trend line and determine the effect of fermentation time

3. Results and Discussion

3.1 The pH and residual starch

Fermentation time significantly affected the pH and residual starch yield of SPF. Figure 1 shows a linear decreasing pattern of pH from 4.87 to 4.16 and residual starch from 62.12 to 47.88% (db) during fermentation with different rates. Previous studies showed that natural SP fermentation bacteria were lactic acid bacteria [2, 3]. Yuliana et al. [5] also reported that the lactic acid bacteria were isolated from SP. The pH decrease in this study indicated that lactic acid bacteria activity produced organic acids, thus lowering the pH of SPF. The pH range (4.14-5.97) in this study is comparable with the pH of fermented SPF (4.17-6.26) reported by previous studies [2, 15-16]. The potential application of this fermented flour is to be incorporated into baked products with distinctive flavor and acidic properties. Moreover, using acidic flour effectively prolongs the shelf life of bread.

During fermentation, the dominant organism, lactic acid bacteria, may convert free sugars to lactic acid, produce amylolytic enzymes, and degrade starch granules. Thus, the residual starch content slightly decreased along with the fermentation time from 62.12% to 47.88% (db). This result is still comparative with the total starch content reported by [17-19], which varies between 57% to 90%, 55.76% to 83.65%, and 36.6% to 75.0%, respectively. By this value, the fermented orange SPF is an excellent energy source.

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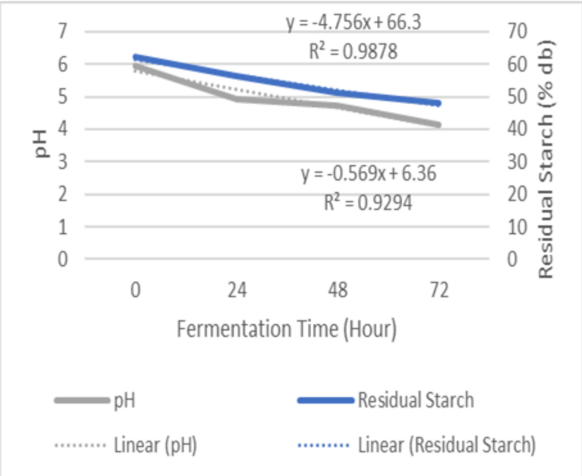


Fig. 1. Spontaneous fermentation at different times affected the pH and residual starch (%) of sweet potato flour.

3.2 Solubility

Fermentation time was observed to make a difference in the solubility of orange SPF, as shown in Figure 2. The solubility at 85◦C and 90◦C decreased from 16.92% to 16.74% and 13.07% to 12.45%, respectively, with a quadratic patent. A slight difference between solubility at 85 and 90◦C was observed, where the solubility at 90◦C was higher than that at 85◦C. This result is in line with most studies that found the solubility of SPF increased as the temperature increased [1, 19-20]. The solubility of orange-fleshed SPF decreased to a certain point and then increased. A slight increase in solubility after 48 hours might be attributed to the expansion of the surface area of the granules as a result of microbial fermentation.

Expanding the granules' surface area facilitates hydrolysis in the amorphous part, causing more starch chains to be broken down, thus increasing solubility [21]. The high solubility of SPF would be due to the high soluble sugar content and leaching of amylose from the starch [22, 23]. Solubility is the ability of solids to dissolve or disperse in an aqueous solution, mostly water [11]. It reflects the degree of dissolution during the starch swelling procedure [1]. Therefore, the higher the solubility value, the more amylose is dissolved in the granules. Solubility of this SPF ranged from 13.07%-12.45% to 16.74%-16.92%. This range showed higher solubility than those reported by previous authors [15, 24]. The flour's high solubility would be beneficial for bakery and confectionery production. However, high solubility causes a decrease in the viscosity stability to heat, which can be caused by amylose leaching. Thus, the middle-range solubility of the flour must be considered.

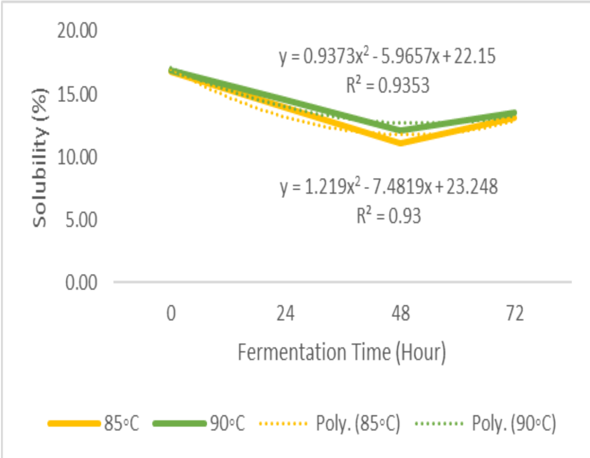


Fig. 2. The solubility of sweet potato flour affected by spontaneous fermentation at different times

3.3 Water retention and expansion rate

The results showed that the water retention and expansion rate of fermented orange-fleshed SPF was significantly affected by fermentation time. The water retention and expansion rate increased quadratically with fermentation time (Figure 3). The increase in water retention due to fermentation treatment conforms to earlier reports for fermented white-fleshed SP [25].

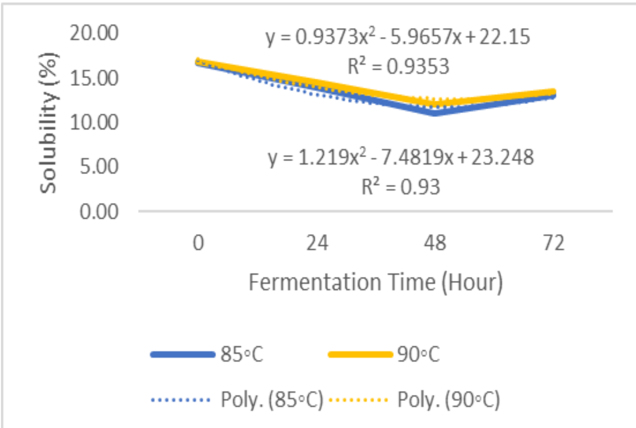


Fig. 3. Water retention and expansion rate of sweet potato flour affected by spontaneous fermentation at different times

The flour's increased water retention (2.55-2.72) and expansion rate (13.54-16.59) can be attributed to the hydration and swelling of SP starch granules in excess water. Most studies reported that starch granules' degradation during fermentation leads to a lesser structural rigidity, shorter starch chain, and easier water absorption. When the granule is heated, it will quickly swell as the hydrogen bonds are weakened [26], causing easier water absorption by degraded granule starch, more manageable swelling, and increasing the expansion rate. However, this expansion rate decreased after 48 hours of fermentation, presumably because the structural rigidity was too weak to resist granule development.

3.4 The color of fermented sweet potato flour

The length of fermentation affected the color score of orange-fleshed SPF, which linearly decreased, as shown in Figure 4.

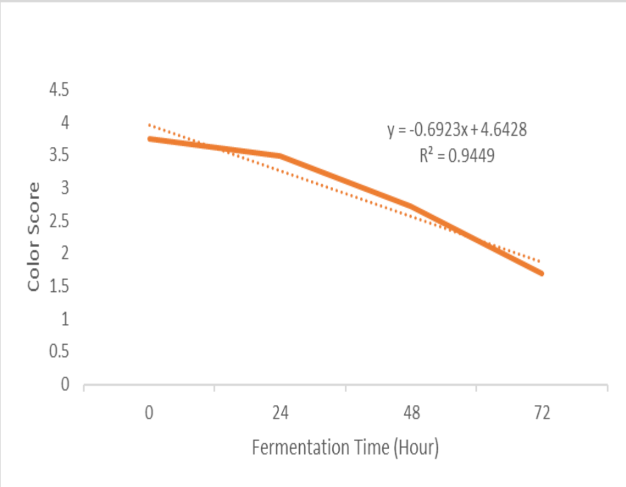


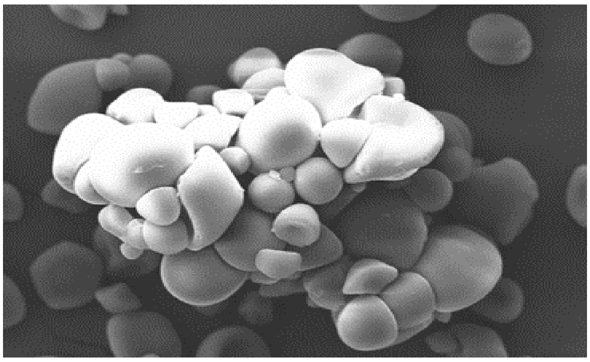
Fig. 4. The color score of sweet potato flour as affected by spontaneous fermentation at different times. Range of the score: 1 (cream white) to 5 (yellow)

Pigment β-Carotene, the primary carotenoid in all raw potatoes [27], contributes to the orange-fleshed color of the sweet potatoes. As the fermentation progressed up to 72 hours, the color score of sweet potato flour decreased from 3.6-3.8 (brownish yellow) to 1.6-1.7 (yellowish white). The fading color could be attributed to lesser retention of carotenoids as affected by organic acid production during fermentation. The presence of lactic acid in the fermentation medium may affect the carotenoid of sweet potatoes. As reported in a few studies, carotenoids are sensitive to environmental factors, including acidic conditions [7, 28]. In addition, sweet potato slices were dehydrated before milling. A pronounced decline was observed in total carotenoids after heating [29].

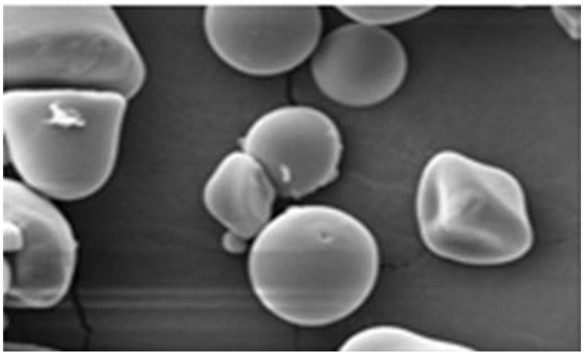
Moreover, oven-drying can leach up these pigments due to the thermochemical reaction [30]. Conversely, a decrease in sugar and protein content occurred during fermentation, reducing the browning process during oven-drying [31]. All of these caused the color of fermented SPF to be lighter the longer the fermentation time was. The color of 72-hour-fermented SPF was yellowish-white, close to the color of wheat flour.

3.5 Morphology of orange sweet potato flour

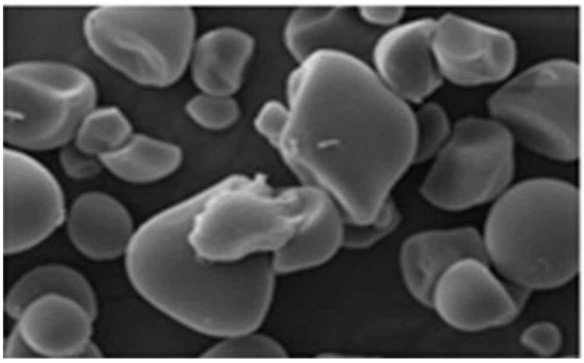
Figure 5 shows the SEM morphology of orange-fleshed sweet potato starch granules extracted from spontaneously fermented orange-fleshed SPF. At 48h and 72 h of fermentation, the starch granules looked small and hollow, indicating starch degradation due to lactic acid bacteria activity during fermentation time.



24 h



48 h



72 h

Fig. 5. SEM micrographs of fermented, orange-fleshed sweet potato starch samples with 1000x magnification.

4. Conclusions

Modification by spontaneous fermentation from h0 to h72 significantly affected orang-fleshed sweet potato flour characteristics. There were linear decreases in pH, residual starch yield, and color score, and quadratic decreases in solubility at 85ºC and 90ºC. Meanwhile, increases were observed in the water retention and expansion rate. Starch granules showed changes with fermentation time. Based on its functional properties, the fermented orange-fleshed sweet potato flour can be applied as an ingredient for baking products with a distinctive acidic taste.

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