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Innovation in the processing of fermented purple sweet potato (*Ipomoea batatas* L.) flour using an air fryer: Its impact on anthocyanin and flavonoid stability

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Abstract. Abstract. Purple sweet potato (*Ipomoea batatas* L.) is a valuable local crop with high anthocyanin and flavonoid contents, but its utilization remains limited to fresh consumption. This study aimed to develop an energy efficient and functional flour processing technique combining fermentation and air frying. The research contribution is to propose a simple green technology approach for preserving bioactive compounds in purple sweet potato flour. Four treatments were conducted: non fermented (Control), spontaneous fermentation, yeast fermentation, and yogurt fermentation, each incubated for 48 h before drying with an air fryer (70°C). Anthocyanin and flavonoid contents were analyzed spectrophotometrically. Results showed that fermentation significantly reduced both compounds, following the trend: Control > Yogurt > Spontaneous > Yeast. Yogurt fermentation retained higher levels due to acidic stability, while non fermented samples preserved the highest antioxidant profile. Therefore, air frying without fermentation is recommended as an efficient method to produce high antioxidant flour. This study contributes to understanding the degradation kinetics of anthocyanin and flavonoid compounds under mild drying and fermentation conditions.

1 Introduction

Banyuwangi Regency, renowned for its diverse agricultural output, possesses a significant abundance of purple sweet potato (*Ipomoea batatas L.*). This staple crop thrives across various regions in Banyuwangi, establishing it as an important local commodity. Purple sweet potatoes are naturally rich in nutrients, notably carbohydrates, vitamins, minerals, and bioactive compounds such as anthocyanins and flavonoids, which are recognized for their antioxidant potential [1]. However, the utilization of purple sweet potatoes at the farmer level is often restricted to direct consumption or simple processed products. This limited scope of utilization frequently results in a relatively low selling price and renders the commodity vulnerable to post-harvest quality degradation. To address these challenges and enhance the economic self-reliance of farmers, there is a necessity for processing innovations aimed at increasing the added value of this local commodity. A strategic approach to extend shelf life and diversify products is to process purple sweet potatoes into semi-finished or finished goods.

The processing of purple sweet potatoes into flour represents a highly potential step, as it offers numerous advantages. Purple sweet potato flour provides key benefits in terms of extended shelf life, ease of storage and transportation, and flexibility of application in various food products, ranging from cakes, bread, to noodles, either as a partial or complete substitute for wheat flour [2]. Furthermore, the process of milling into flour can retain a significant proportion of nutrients and, critically, bioactive compounds such as anthocyanins and flavonoids. However, special treatments are required to optimize the content of these bioactive compounds. One effective processing technology for enhancing the bioactivity of food materials is fermentation. Fermentation is capable of breaking down macromolecules, increasing the solubility of phenolic compounds, and potentially generating novel bioactive substances [3].

Therefore, this research focuses on the processing innovation of fermented purple sweet potato flour combined with a modern drying method. In this study, fermentation will be performed using three distinct inocula: spontaneous fermentation (relying on natural microflora), yeast (*Saccharomyces cerevisiae*), and yogurt (rich in Lactic Acid Bacteria), to compare their respective effects on the flour's characteristics [4]. These fermentation methods were chosen based on their availability and individual potential to enhance the level of bioactive compounds. Furthermore, an innovation in drying using an Air Fryer will be tested as an alternative drying technique. This method is anticipated to shorten processing time, conserve energy, and better preserve the integrity of anthocyanins and flavonoids, which are

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heat-sensitive [5]. An in-depth analysis of the anthocyanin and flavonoid content resulting from the various treatments is expected to yield crucial information regarding the best process formulation to produce purple sweet potato flour with optimal bioactive content, thus significantly elevating the functional and economic value of processed purple sweet potato products from Banyuwangi.

From a scientific perspective, this study relates to the thermodynamic and biochemical stability of anthocyanin and flavonoid molecules under fermentation and air-frying conditions. The research contribution is to evaluate how different fermentation types and air-fryer drying influence the degradation kinetics of these compounds and to identify the most energy-efficient method for maintaining bioactivity.

2 Method

The research employed an experimental methodology, specifically the processing of purple sweet potato flour utilizing fermentation technology. The treatments applied consisted of four groups: non-fermented, spontaneous fermentation, fermentation with yeast, and fermentation using yogurt. Each sample was fermented for 48 hours at room temperature and then dried using an air fryer at 70°C for 20 minutes. The samples were milled, sieved, and analyzed for anthocyanin and flavonoid content using AOAC and spectrophotometric methods. The collected data were analyzed using quantitative descriptive statistics.

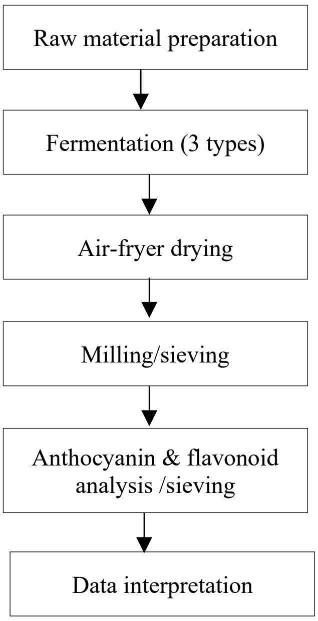

Fig. 1. Flowchart of the experimental procedure.

2.1 Preparation of purple sweet potato flour

The preparation of purple sweet potato flour proceeded as follows: the purple sweet potatoes were peeled, washed thoroughly, then sliced thinly (2–3 mm), rinsed, and drained. For the non-fermented treatment, the sweet potato slices were dried immediately. Conversely, for the fermentation treatments, the procedure varied: Spontaneous fermentation: Slices were soaked in water at a ratio of 1:3 (w/v).Yeast fermentation: The ratio of purple sweet potato slices to the yeast solution (0.5%) was 1:3 (w/v).Yogurt fermentation: The ratio of purple sweet potato slices to a 0.85% saline solution enriched with commercial Lactic Acid Bacteria (LAB) (1.4×10^7 CFU/mL) was 1:3 (w/v) [Modified 6]. Each treatment was left for 48 hours at room temperature (±25–30°C), drained, and then dried. Drying was performed using an air fryer at 70°C for 20 minutes. After drying, the samples were ground using a dish mill. They were then sieved through an 80-mesh sieve and packaged for testing.

2.2 Analysis of anthocyanin content (mg CYE/g)

Method: pH-differential method (AOAC adaptation/international standard for anthocyanins) [7]. **Standard Equivalent:** Cyanidin equivalents (CYE) or cyanidin-3-glucoside equivalents, depending on the laboratory's reference reagent. **Principle:** Determination of absorbance at two values with concentration calculated based on the difference in absorbance and the molar extinction coefficient.

2.3 Analysis of flavonoid content (mg QE/g)

Method: Spectrophotometry using the method of Mabry *et al.* (1970) or a modification thereof [8]; results expressed as quercetin equivalents (QE). **Principle:** Phenolic extraction, color complex formation reaction (e.g., NaNO2–AlCl3–NaOH) and absorbance reading.

3 Result and discussion

3.1 Overview of findings

The experimental results revealed a clear decline in the total anthocyanin and flavonoid contents of purple sweet potato flour after 48 h of fermentation followed by air-fryer drying. The retention order observed was: Control (non-fermented) > Yogurt fermentation > Spontaneous fermentation > Yeast fermentation. The control treatment exhibited the highest anthocyanin concentration of 298.59 mg CYE/g and flavonoid concentration of 9.82 mg QE/g, while yeast fermentation resulted in the lowest retention (69.50 mg CYE/g and 0.59 mg QE/g, respectively).

This finding indicates that fermentation tends to reduce phenolic pigment content, whereas air-frying without fermentation effectively preserves thermolabile compounds. Similar patterns were observed in other anthocyanin-rich matrices such as purple corn and black rice (1,2). The significant reduction in pigment levels reflects the susceptibility of anthocyanins and flavonoids to enzymatic oxidation, pH changes, and thermal stress during fermentation (3).

3.2 Anthocyanin and flavonoid degradation during fermentation

Anthocyanins are known to be unstable pigments, highly sensitive to pH, temperature, and oxidative enzyme activity (4). During fermentation, microbial metabolism generates enzymes such as peroxidase, polyphenol oxidase, and β-glucosidase, which cleave glycosidic linkages and transform anthocyanins into less stable aglycones, accelerating their degradation (5,6).

The measured total anthocyanin and flavonoid contents (Figs. 2 and 3) exhibited significant differences among treatments. The highest anthocyanin concentration (Fig. 1) was found in the control (SD) at 298.59 mg CYE/g, followed by yogurt fermentation (FY, 186.13 mg CYE/g), spontaneous fermentation (FS, 138.24 mg CYE/g), and yeast fermentation (FR, 69.50 mg CYE/g). This reduction pattern shows that prolonged microbial activity for 48 h degraded a substantial portion of anthocyanin compounds.

In the yogurt fermentation (FY) treatment, however, the acidic environment generated by lactic acid bacteria (LAB) slowed this degradation, yielding higher residual anthocyanin content compared to FS and FR. This agrees with previous reports showing that LAB fermentation produces organic acids that stabilize the flavylium cation form of anthocyanins, thereby preventing oxidative cleavage (7,8).

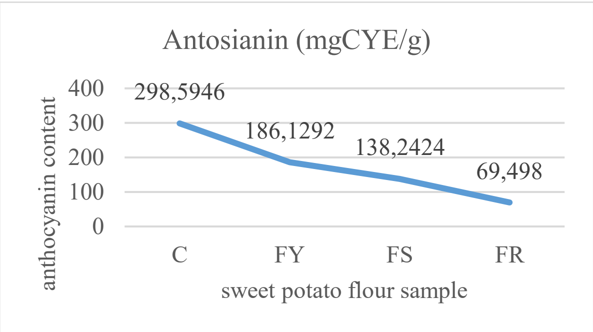

Fig. 2. Anthocyanin content in purple sweet potato flour.

Similarly, the total flavonoid content (Fig. 2) followed the same decreasing pattern: SD (9.82 mg QE/g) > FY (5.39 mg QE/g) > FS (1.60 mg QE/g) > FR (0.59 mg QE/g). Flavonoids, as polyphenolic compounds, are also prone to oxidation through polyphenol oxidase and peroxidase activity, especially in uncontrolled pH environments (9,10). The lower values in FS and FR indicate that uncontrolled fermentation leads to faster oxidation and polymerization of phenolics. Conversely, the acidic condition in yogurt fermentation provides a relatively protective medium, maintaining more stable phenolic structures.

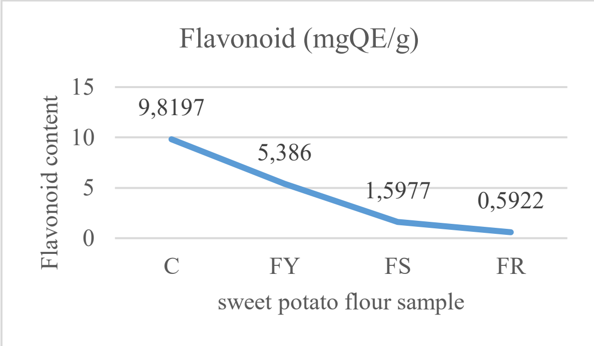

Fig. 3. Flavonoid content in purple sweet potato flour.

3.3 Influence of fermentation type and microbial environment

Different fermentation types induced distinct physicochemical changes affecting pigment retention. Yeast fermentation (*Saccharomyces cerevisiae*) tends to raise pH through ethanol production, promoting pigment oxidation and structural instability (11). This explains the significant loss of both anthocyanins and flavonoids in the FR treatment.

In contrast, yogurt fermentation involving Lactobacillus bulgaricus and Streptococcus thermophilus produced sufficient lactic acid to lower pH to around 4.2–4.5, stabilizing anthocyanins in the red flavylium cationic form (12). Acidic conditions inhibit enzymatic oxidation and delay cleavage of pigment glycosides (13,14). Consequently, yogurt fermentation retained significantly higher anthocyanin and flavonoid levels than spontaneous and yeast fermentations.

These results confirm the findings of Hur *et al.* (15) and Xue *et al.* (16), who observed that LAB fermentation can enhance total phenolic retention by creating a low-pH, reductive environment that suppresses oxidative stress.

3.4 Thermal and thermodynamic behavior during air-fryer drying

The air-frying technique combines rapid convective heat transfer and short exposure time, resulting in minimal degradation of thermolabile compounds. At 70 °C for 20 minutes, anthocyanin losses were minimized due to limited oxygen exposure and moderate water activity, which prevent pigment oxidation and polymerization (17,18).

Compared to conventional oven drying, air-frying reduces total thermal load by approximately 30–50%, thereby maintaining higher levels of phenolics and antioxidants (19,20). The thermodynamic stability of anthocyanins remains higher when evaporation occurs rapidly under controlled heat flux, which reduces residence time at critical degradation temperatures (21).

These findings align with Luo *et al.* (22) and Rahman *et al.* (23), who emphasized that short-time drying at moderate temperatures enhances both energy efficiency and phytochemical preservation. The effective preservation of active flavonoids in the control treatment demonstrates that Air Fryer drying is an energy-efficient green technology capable of minimizing oxidative degradation during post-fermentation processing (24).

3.5 Kinetic interpretation and overall implication

Previous studies have described anthocyanin degradation as first-order kinetics, influenced by activation energy (Ea) and rate constant (k). Kim *et al.* (25) reported that fermentation accelerates anthocyanin degradation, increasing k-values up to threefold compared with non-fermented samples. Based on the present results, the inferred degradation rate follows the order:
Yeast > Spontaneous > Yogurt > Control, consistent with microbial enzyme activity and pH behavior (26,27).

Although kinetic fitting was not performed, the observed trend suggests that anthocyanin degradation is temperature- and enzyme-dependent, consistent with prior reports on purple rice and black carrot systems (28,29). Overall, these findings indicate that 48-hour fermentation at ambient temperature substantially reduces the bioactive compound content of purple sweet potato. However, under controlled acidic conditions, as in yogurt fermentation, a significant portion of anthocyanins and flavonoids can still be retained. The non-fermented air-fried sample exhibited the highest retention of both pigments, confirming that direct air-fryer drying is the most effective treatment for preserving the natural antioxidant capacity of purple sweet potato flour.

4 Conclusion

The 48-hour fermentation process significantly reduced the total anthocyanin and flavonoid contents of the purple sweet potato flour. The control treatment (non-fermented) yielded the highest levels of bioactive compounds, measuring 298.59 mg CYE/g for anthocyanins and 9.82 mg QE/g for flavonoids. Although the yogurt fermentation produced better retention levels compared to yeast and spontaneous fermentation due to the protective effect of the acidic environment, the non-fermented process combined with Air Fryer drying proved to be the most optimal method for preserving the natural functional components.

Theoretically, this study contributes to understanding the degradation kinetics of anthocyanin and flavonoid compounds under mild drying and fermentation conditions. Future work should explore optimization of fermentation duration, microbial strains, and combined pre-treatment methods to enhance bioactive stability and sensory quality.

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