The quality improvement of yam flour (Dioscorea alata) through the fermentation process

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Abstract. Yam (Dioscorea alata) is a local tuber used as a substitute for wheat flour and a source of non-rice carbohydrates. The processing into flour expands the diversification of yam's product. However, the flour produced does not resemble wheat flour, so the processing needs to be modified. This study compared several properties of modified yam flour with four treatments. The four treatments were fermentation for 12 hours with Bi-Mocaf starter, fermentation for 18 hours with tape yeast, fermentation for 72 hours with pure water and without fermentation treatment. This study found: yam flour had an average moisture and ash content of 19% and 9.00%. The fermentation with tape yeast produced the highest yield (20.40%). The highest amylose content (7.23%), protein (4.25%), viscosity (3.65 cp), carbohydrate (74.20%), and energy (319.81 kcal) were produced by fermentation in 12 hours with the Bi-Mocaf fermentor. Without fermentation, treatment formed the highest dietary fiber (18.27%) and fat content (0.780%). The processing into flour is expected to expand product diversification and increase the added value of yam tubers.

1. Introduction

Yam tuber (Dioscorea alata) is one of the local Indonesian tubers used as an alternative food source, can be used as a functional food and food diversification. Water yam contains high carbohydrates (around 77.95 - 82.88%) and protein (7.4%) but low sugar content [1–3]. Moreover, it also contains several bioactive components, such as water-soluble polysaccharides (WSP), diosgenin, alkaloids, saponins, tannins, flavonoids, phenols, glycosides, steroids, and dioscorin [4, 5]. As a food ingredient, yam utilization is still limited, mostly traditional food, such as steamed tubers, fried tubers, and chips [1, 6, 7]. We can do the prospect of yam as a functional food and food diversification by making flour that has a good antioxidant capacity, thereby expanding its use in producing various modern processed products [1, 6, 8–10]. Geared flour processing can replace or substitute wheat flour. Processed into flour can expand product diversification (flexibility of use), extend shelf life, facilitate storage and distribution, and increase yam tuber's added value [4]. Product diversification from yam flour includes white bread [11], sweet bread [12], dry noodles [13], noodles [9], salted noodles [14], cakes [15], edible paper [16], snack bars [17], muffins [18], cookies [19], and other products. However, generally, products made from yam flour have some disadvantages compared to wheat flour products. This is because some of the properties of yam flour have not approached the properties of wheat flour, so it is necessary to modify the flour processing process so that substituting yam flour with wheat flour can
increase. We can use several methods to modify the processing process for tuber flour. These methods include blanching and soaking of sodium bisulfite solution [20], partial pre-gelatinization [21], and fermentation [5, 22–24]. This modification process has been used for the process of making mocaf (modified cassava flour) [22] and Dioscorea hispida flour [25]. The fermentation process of Dioscorea hispida flour reduces the content of carbohydrates, lipids, proteins, fiber, and ash. The puffiness and solubility of fermented flour are under the original flour. Simultaneously, the fermented flour amyllose content is greater than the original flour [26]. Several modifications to the process can be adopted for the manufacture of modified yam flour. This study aims to determine the physical and chemical characteristics of yam flour, processed by several fermentation methods.

2. Material and Methods

2.1. Material
The research was carried out in the post-harvest laboratory of the Yogyakarta Assessment Institute of Agriculture Technology (AIAT). The main ingredient of this research was yam tubers obtained from Gunungkidul district, Yogyakarta Special Region. Additional ingredients used were yeast tape, Bi-Mocaf starter, water, and other materials used for physical and chemical analysis of yam flour.

2.2. Methods
The research was conducted using experimental laboratory methods. The experimental design used was a completely randomized design with four flour processing treatments (three fermentation treatments and one control) and five replications. The four treatments are fermentation for three days with water solution based on the method of [18], fermentation for 18 hours using 0.5% tape yeast solution based on the method of [19], and fermentation for 12 hours with Bi-Mocaf starter based on the [17] method and without the fermentation process.

2.2.1. Yam flour production
2.2.1.1. Yam flour production by fermentation treatment for 72 hours with water solution based on [18] method. The yam tubers (10 kg) were washed with clean water to remove dirt, sand, and unwanted particles. The skin of the yam tubers was peeled, the tubers then washed thoroughly using clean water. Yam tubers were reduced in size into chips using a three-purpose tool (1-2 mm thickness). The purpose of size reduction is to speed up the drying time. The chips were fermented by soaking in water for 72 hours (the volume of water used is twice with the yam chip weight). During the fermentation process, every 24 hours, the soaking water was replaced with new water to prevent a bad smell. After 72 hours, the chips were drained and pressed using a hydraulic press to reduce the water content, then dried in a cabinet dryer at 60 °C for 24 hours followed by milling using a hammer mill, and resulting yam flour was sieved.

2.2.1.2. Yam flour production by fermentation treatment for 18 hours with 0.5% yeast tape solution based on [19] method. The yam tubers (10 kg) were washed with clean water to remove dirt, sand, and unwanted particles. The skin of the yam tubers was peeled, the tubers then washed thoroughly using clean water. Yam tubers were reduced in size into chips using a three-purpose tool (1-2 mm thickness). The purpose of size reduction is to speed up the drying time. The chips were fermented by soaking in 0.5% yeast tape solution for 18 hours. The solution used is twice the weight of the yam tuber chip. After 18 hours, the chips were drained and pressed using a hydraulic press to reduce the water content, then dried in a cabinet dryer at 60 °C for 24 hours followed by milling using a hammer mill, and resulting yam flour was sieved.

2.2.1.3. Yam flour production by fermentation treatment for 12 hours with 0.1% Bi-Mocaf solution based on [17] method. The yam tubers (10 kg) were washed with clean water to remove dirt, sand, and unwanted particles. The skin of the yam tubers was peeled, the tubers then washed thoroughly using
clean water. Yam tubers were reduced in size into chips using a three-purpose tool (1-2 mm thickness). The purpose of size reduction is to speed up the drying time. The chips were fermented in soaking in 0.1% Bi-Mocaf solution for 12 hours. The solution used is twice the weight of the yam tuber chip. After 12 hours, the chips were drained and pressed using a hydraulic press to reduce the water content, then dried in a cabinet dryer at 60 °C for 24 hours, followed by milling using a hammer mill, and resulting yam flour was sieved.

2.3. Analysis

2.3.1. Physical and chemical analysis. Yam flour analysis of physical and chemical characteristics includes yield [20], moisture content [21], ash content [21], protein content [21], fiber content [21], fat content [21], carbohydrate content [21], energy [21] viscosity, and amylose [22]. This analysis is based on several standards on wheat flour INS No. 3751:200 [27]

2.3.2. Statistical analysis. All tests were performed in triplicate and analyzed by Kruskal Wallis analysis to determine whether there were significant differences between treatments. This analysis was carried out with the Statistical Package for Social Science (SPSS) version 23 software. If the value of A. Sig <0.05, there is a significant difference between treatments, but if the value is A. sig. > P-value (0.05), then there is no significant difference between treatments.

3. Results and Discussion

3.1. Yield

The yield of yam flour produced from the four processing treatments was 17, 33 to 20.40 (Table 1).

| Fermentation treatments                              | Yield (%) |
|------------------------------------------------------|-----------|
| Fermentation for 12 hours with 0.1% Bi-Mocaf starter solution (m/v) | 17.33     |
| Fermentation for 18 hours with 0.5% tape yeast solution (m/v)     | 20.40     |
| Fermentation for 72 hours with pure water             | 19.64     |
| Without fermentation                                   | 20.15     |

The results of statistical analysis with the Kruskal Wallis analysis showed that the yield of the treatment was not significantly different because of the value of A. Sig (0.16) > P-value (0.05). However, fermentation for 12 hours with 0.5% tape yeast solution produced the highest yield (20.40%). But compared with the results of research [23], the yield of yam flour produced by this study is lower than other treatments. These differences may be due to different cultivars, cultivation techniques, soil types, climate, and cultivation methods.

3.2. Moisture Content

The four flour treatments’ moisture content was within 12%, while the moisture content of fresh yam was around 77% (Table 2). There was a decrease in the moisture content of about 65% during producing yam tubers into flour.
Table 2. The moisture content of fresh and flour yam

| Fermentation treatments | Water content (%) |
|-------------------------|-------------------|
| Fresh yam               | 77.003            |
| Fermentation for 12 hours with 0.1% Bi-Mocaf starter solution (m/v) | 12.167 |
| Fermentation for 18 hours with 0.5% tape yeast solution (m/v) | 12.373 |
| Fermentation for 72 hours with pure water | 12.397 |
| Without fermentation | 12.237            |

When yam flour is compared with the Indonesian National Standard (INS) for wheat flour quality, the four flours are produced to meet the standard (INS 3751-2009). The maximum moisture content of wheat flour is 14.5% [27,28]. The moisture content of yam flour below 13% ensures a relatively long shelf life without rotting and proliferation of pathogenic microbes if stored at relatively low humidity levels [25]. When analysed statistically with the Kruskal Wallis test, there was no significant difference in water content between the four treatments because the value of A. sig (0.926) > P value (0.05).

3.3. Ash content

Its ash content can indicate the mineral content of a material. Ash content value depends on the type of material and method of ashing. Total ash's value can be used as a nutritional parameter of foodstuffs [26] and [27]. The ash content of yam flour is presented in Table 3.

Table 3. Ash content of fresh and flour yam

| Fermentation treatments | Ash content (%) |
|-------------------------|------------------|
| Fresh yam               | 6.173            |
| Fermentation for 12 hours with 0.1% Bi-Mocaf starter solution (m/v) | 9.880 |
| Fermentation for 18 hours with 0.5% tape yeast solution (m/v) | 9.900 |
| Fermentation for 72 hours with pure water | 10.277 |
| Without fermentation | 8.787             |

The ash content of fresh yam tubers was 6.17%. After being processed into flour, the ash content increases from 8.78 to 10.28%. The increase in ash content is because much water content comes from the yam tubers [28]. Statistically, with Kruskal Wallis analyses, there were significant differences between treatments (A.sig value (0.024) < P value (0.05).

3.4. Protein content

Protein is an excellent source of amino acids that contains the elements carbon, hydrogen, oxygen, and nitrogen, which serve as bodybuilding and regulatory substances [29]. The processing of flour causes an increase in yam tuber protein content. The protein content of fresh yam tubers was 1.1%, increasing from 3.0% to 3.2%. In this study, yam flour protein levels are similar to those reported by [25], i.e., 2.7 to 4.3%. The highest protein content of yam flour was produced by fermentation treatment with 0.1% Bi-Mocaf starter solution. The protein content of fresh yam tubers and flour is presented in Table 4.

Table 4. The protein content of fresh and flour yam

| Fermentation treatments | Protein content (%) |
|-------------------------|---------------------|
| Fresh yam               | 1.100               |
| Fermentation for 12 hours with 0.1% Bi-Mocaf starter solution (m/v) | 3.206 |
| Fermentation for 18 hours with 0.5% tape yeast solution (m/v) | 3.185 |
| Fermentation for 72 hours with pure water | 3.032 |
| Without fermentation | 2.253               |
The flour produced through the fermentation process makes higher protein content than without fermentation. This is due to the limited source of nitrogen used by microorganisms in yam tubers. This is in line with those reported by [30] and [31], explaining that in the fermentation process in tuber flour production, microbes hydrolyze complex proteins into free amino acids or simpler peptides through the activity of proteolytic enzymes. This is in line with research [32], which explains the increase in protein content because, during fermentation, the lactic acid bacteria isolates produce peptidoglycan in their cell walls. This peptidoglycan is composed of glycoprotein and lipoprotein components. This protein component is contained and analyzed in fermented yam flour. Statistically, with Kruskal Wallis analysis, there was a significant difference between treatments (A.sig value 0.016 < P-value).

### 3.5. Dietary fiber content

Dietary fiber has beneficial functional effects on the human body, consisting of soluble dietary fiber and insoluble dietary fiber. The dietary fiber content of fresh yam tubers and flour were presented in Table 5.

| Fermentation treatments                                      | Dietary fiber content (%) | Table 5. The dietary fiber content of fresh and flour yam |
|-------------------------------------------------------------|---------------------------|----------------------------------------------------------|
| Fresh yam                                                    | 5,875                     |                                                          |
| Fermentation for 12 hours with 0.1% Bi-Mocaf starter solution (m/v) | 16,202                    |                                                          |
| Fermentation for 18 hours with 0.5% tape yeast solution (m/v) | 14,916                    |                                                          |
| Fermentation for 72 hours with pure water                   | 13,968                    |                                                          |
| Without fermentation.                                        | 18,272                    |                                                          |

The content of dietary fiber increases after the yam tubers are processed into flour. The initial dietary fiber content was 5.88% (fresh yam tubers), which increased from 13.97 to 18.27% (yam flour). Yam flour without fermentation produces the highest dietary fiber levels because lactic acid bacteria do not degrade fiber. Statistically, with Kruskal Wallis analysis, there was a significant difference in dietary fiber content between treatments because of the A.sig value (0.016 < P-value (0.05).

### 3.6. Fat content

Fresh yam fat content is around 1.9%; after being processed into flour, the fat content decreases 0.35 to 0.78%. These data are in agreement with other studies were reported by [33], which is above 0.3%, and higher than reported by [34], which is 0.1 to 0.2%, and [25], which is 1%. Types of varieties, cultivation methods, climate, soil types, and processing methods could also be responsible for these differences. Statistically analyzes with Kruskal Wallis, there was a significant difference between treatments (A.sig value 0.016 < P value (0.05). The fat content of fresh tubers and yam flour is presented in Table 6.

| Fermentation treatments                                      | Fat content (%) | Table 6. The fat content of fresh and flour yam |
|-------------------------------------------------------------|----------------|------------------------------------------------|
| Fresh yam                                                    | 1,940          |                                                |
| Fermentation for 12 hours with 0.1% Bi-Mocaf starter solution (m/v) | 0,551          |                                                |
| Fermentation for 18 hours with 0.5% tape yeast solution (m/v) | 0,407          |                                                |
| Fermentation for 72 hours with pure water                   | 0,350          |                                                |
| Without fermentation.                                        | 0,780          |                                                |
3.7. Viscosity and amylose content

Processing of yam tubers into flour can increase the amylose content, from 3.12% (fresh yam) to 7.22 to 13.63% (yam flour). Research [29] reported an increase in amylose levels in yam flour manufacturing due to the longer fermentation time or the optimal fermentation process. During fermentation, lactic acid bacteria (Lactobacillus Plantarum) produce pullulanase enzymes that can break 1,6-glycosidic bonds, or amylopectin branch have straight amylose chains. The longer the fermentation time, the higher the Lactobacillus Plantarum growth, the higher the enzyme produced, which increases the amylose level. In fermentation with a longer time, namely 72 hours, there was a decrease in amylose levels. This is because some of the amyloses formed degraded by the α-amylose enzyme produced by Lactobacillus Plantarum. Small compounds formed, namely oligosaccharides, simple sugars, and maltose. These simple sugars are then broken down as an energy source and produced lactic acid. Fermentation techniques using lactic acid bacteria (LAB) produce amylase, and pullulanase enzymes can break α-1, 6 glycosidic (amylopectin) bonds randomly on the inside, so that a straight-chain glucose polymer is created, which is a polysaccharide with a smaller degree of polymerization [30, 31]. According to [32], amylase and pullulanase activity increased along with the length of fermentation time. Viscosity reflects starch/flour's ability to bind water and is often used as an index to evaluate the thickening power. Viscosity changes (based on rheological principles) are usually used to determine the wheat flour pasting properties [33]. Starch has a higher viscosity than flour because its main viscosity is produced by starch [34]. The higher the breakdown in viscosity, the lower ability of the flour to withstand shear stress and heating during cooking [35]. Flour exhibits high gelatinization temperature but low enthalpy, affecting non-starch components in flour, such as proteins and lipids [33, 36]. The longer fermentation time causes an increase in the viscosity of fermented taro flour. The increased viscosity of fermented yam flour because there is a yam cell wall breakdown, resulting in amylose and amylopectin easily coming out of the starch granules—highest viscosity produced by Bi-mocaf fermentation (3,650 cp). Fermentation with water for 72 hours cannot increase viscosity. Statistically, there is a significant difference in amylose content (A. sig value = 0.016) and viscosity (A. sig value = 0.017) between treatments because A. sig value < P value (0.05).

| Fermentation treatments                               | Viscosity (cp) | Amylose content (%) |
|-------------------------------------------------------|----------------|---------------------|
| Fresh yam                                             | 4,400          | 3,125               |
| Fermentation for 12 hours with 0.1% Bi-Mocaf starter solution (m/v) | 3,650          | 13,642              |
| Fermentation for 18 hours with 0.5% tape yeast solution (m/v) | 2,650          | 12,271              |
| Fermentation for 72 hours with pure water             | 2,350          | 11,161              |
| Without fermentation.                                 | 2,550          | 7,226               |

3.8. Carbohydrate and energy

The fermentation process can increase energy and carbohydrate content. Initially, the carbohydrate content of fresh yam tubers was 13,738% to ± 74% (yam flour). Fermentation with 0.1% Bi-mocaf starter solution produces the highest levels of carbohydrates and energy. The carbohydrate content of yam flour is high, from 73.94% to 74.19%, which agrees with [33] research (73.27% to 75.50%). Higher carbohydrate content was reported by [25], i.e., 79.7 to 82.2%. According to [33], the carbohydrate content of yam tubers is relatively higher than other tubers. Carbohydrates contribute to protein and fat metabolism as energy reserves and supply energy to muscle, blood, and brain cells. The carbohydrate and energy levels of the four yam flour were significantly different between treatments because the A.sig value (0.016) < P value (0.05).
Table 8. Carbohydrate content and energy of fresh and flour yam

| Fermentation treatments                                      | Carbohydrate content (%) | Energy (k.kal) |
|-------------------------------------------------------------|--------------------------|---------------|
| Fresh yam                                                   | 13,783                   | 76,992        |
| Fermentation for 12 hours with 0.1% Bi-Mocaf starter solution (m/v) | 74,197                   | 314,568       |
| Fermentation for 18 hours with 0.5% tape yeast solution (m/v) | 74,135                   | 312,943       |
| Fermentation for 72 hours with pure water                   | 73,945                   | 311,056       |
| Without fermentation.                                       | 73,944                   | 319,806       |

4. Conclusion

The fermentation process can improve yam flour quality (high carbohydrate, amylose, protein, and energy content, but low ash content). Fermentation with 0.1% Bi-mocaf starter solution produces the best flour characteristics with 12.167% water content; 9.880% ash content; 3.206% protein content; 16.202% dietary fiber content; 0.551% fat content; 3.650 cp viscosity; 13.642% amylose content; 74.197% carbohydrate content, and 314.568 k.cal energy.

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