Amylograph properties and microstructure of white corn and okara-based composite flour

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Abstract. Okara flour is rich in protein and dietary fiber and could be used to enrich white corn flour to enhance its functionality. This research was designed to investigate the amylograph properties and microstructure of a composite flour made from white corn and okara flours. The composite flour was made using five different ratios of white corn flour:okara flour (100%:0%, 95%:5%, 90%:10%, 85%:15%, and 80%:20%). White corn flour and okara flour were mixed manually and prepared in duplicates. Amylograph properties were observed using a Rapid Visco Analyzer (RVA) and microstructure was observed using Scanning Electron Microscopy (SEM). The composite flour had a pasting temperature range of 78.30°C to 79.90°C, peak viscosity of 126cP to 1977cP, trough viscosity of 1016cP to 1596cP, breakdown viscosity of 245cP to 516cP, final viscosity of 2079cP to 3248cP, and a setback viscosity range of 1063cP to 1652cP. Microstructural analysis clearly showed that white corn and okara flour particles did not break. Composite flours based on the white corn and okara mix used in this research could potentially be developed as raw materials for use in food products with characteristics that are not brittle nor easily broken, including analog rice.

1. Introduction
Over the last few decades, composite flours have received increased attention from researchers and the food industry. Composite flour was initially developed by the Food and Agriculture Organization (FAO) as a substitute for wheat flour to reduce costs, especially in developing countries that depended on imported wheat flour. Usually, local crops were used [1]. Later, composite flours were made not only by mixing local crop flours with wheat flour but also by mixing two or more non-wheat crop flours to meet desired characteristics. Non-wheat flours are usually made from grains, tubers, and legumes and have limited nutritional and physicochemical properties.

Composite flours are welcomed in developed countries where they meet consumer desire for variety and nutrition [2], and, depending on their composition, may address the demand for gluten-free products. Public awareness of health issues is expected to further increase the popularity of composite flours in the future. Non-wheat composite flour made from local crops and their products has been reported to add nutritional and functional value. Tiger nut flour supplementation increased protein, lipid, vitamin, and mineral content of plantain flour [3]; cowpea and African yam bean supplementation increased protein, lipid, and crude fiber content of rice flour [4]; 20% baobab pulp flour enriched iron, calcium, magnesium, potassium, and vitamin C of rice cookies [5]; and common bean flour lowered calories and enriched protein, dietary fiber, phenolic content, and antioxidant activity in a corn-based extruded snack.
Apart from using local crops, some composite flours have been developed using by-products that retain good nutritional and functional values. These include residues from sweet potato and potato starch extraction [7], pseudo-stems from banana harvesting [8], beet pulp and apple pomace from sugar and cider/apple juice production, respectively [9], and okara from soymilk and tofu production [10].

Okara is a potential source of dietary fiber [11][12], omega-3 fatty acids, and complete protein [12]. Substituting okara flour into white corn flour significantly enhanced ash, lipid, protein, and dietary fiber content, but reduced starch content [13]. Therefore, this composite flour has potential for development as a raw material for functional foods. Understanding the amylograph profile and microstructure of flours and starches is very important for determining their potential applications. However, this information, including data on gelatinization or pasting, was not previously available for white corn-okara composite flour. This research was conducted to investigate the effect of white corn to okara flour ratio on amylograph profile and microstructure of the resulting composite flours.

2. Research Methods

2.1. Materials

Composite flour was prepared from white corn flour obtained from the Technopark Grobogan Factory under Indonesian Agency for The Assessment and Application of Technology (BPPT) supervision, okara was obtained from Tofu “Mr. Gundul,” a Small & Medium Enterprise (SME) located in Purwogondo, Kartasura, Sukoharjo, Central Java.

2.2. Tools

Okara was processed into flour using a hydraulic press, steamer, pan, gas stove, cabinet dryer, dry mill blender, and sieving device. White corn flour and okara flour were mixed using a sealed plastic box to produce composite flour. The amylograph profile was analyzed using a Pertin Instruments RVA-4500 and microstructure was analyzed using an FEI Inspect S50 Scanning Electron Microscope.

2.3. Research Stages

2.3.1. Okara Flour Making and Composite Flour Making. Okara flour was made according to a method described by Yuwono and Zulfiah [14]; the composite flour was made according to a method that had been previously utilized by the team [13]. Composite flour was prepared in 5 ratios of white corn flour to okara flour, as follows: 100%:0% (F1=control); 95%:5% (F2); 90%:10% (F3); 85%:15% (F4); and 80%:20% (F5).

2.3.2. Amylograph Characterization. Samples (3 grams) were dissolved in aquades (25 ml) and then heated to 50°C for 1 minute. The temperature was then raised to 95°C at a rate of 11.84°C/minute and maintained at a constant temperature for 2.5 minutes. The temperature was gradually lowered to 50°C at a rate of 11.84°C/minute and maintained at a constant temperature for 2 minutes. During the process, the sample was stirred at 160 rpm.

2.3.3. Microstructure Characterization. Samples were placed in a cross-section with a carbon tape base, coated with AUPD (gold-palladium) using a sputter coater for 3 minutes, and then placed in the equipment. The SEM was operated at 10-15 kV using an initial magnification of 150-300X. Images captured by the sensor were displayed on the monitor.

3. Results and Discussion

3.1. Amylograph Properties

Table 1 Peak time of white corn flour without okara flour substitution (F1=5.67 minutes) was determined to be slightly higher compared to the composite flours F2, F3, F4, and F5 (5.27-5.53 minutes). Peak time was the time at which starch started to form a paste and reach its highest viscosity, and is shown as the peak of the graph in Figure 1. This figure also displays pasting temperature or gelatinization temperature as the temperature at which starch viscosity began to increase during the heating process. According to Winarno [15], starch gelatinization was indicated by irreversible starch granule swelling. The pasting temperature range of white corn and okara-based composite flour was
narrow, varying from 78.30-79.90°C (Table 1). Pasting temperature was influenced by amylose content. Lower amylose content triggered starch granules to absorb more water and to gelatinize at lower temperatures [16][17][18]. A previous study showed that the amylose content of composite flours made with the same materials and ratios tended to decrease as the okara flour ratio increased [13]. However, no correlation was observed between those parameters due to the narrow pasting temperature range of the composite flour being observed. Sample F3 had the highest pasting temperature, while sample F2 had the lowest. Pasting temperature was used as a time indicator in rice cooking and as an economic indicator related to energy utilization. The composite flour in this research had a high pasting temperature (>74°C) [19]. This indicates that white corn-okara composite flour is resistant to swelling and rupture [20].

Substituting okara flour into white corn flour resulted in declines in peak viscosity, trough viscosity, final viscosity, and setback viscosity in the composite flour. The higher the ratio of okara flour, the greater the decrease, except for in F3. Peak viscosity of composite flours F1, F2, F4, and F5 ranged from 1892cP to 1977cP, while F3’s was 1261cP (Table 1). Peak viscosity indicates starch’s ability to form the highest viscosity paste during the heating process [21]. Some research has reported a correlation between peak viscosity and amylose content, but other research disagrees with this finding. Both positive and negative correlations were found between amylose content and peak viscosity [17]. Peak viscosity of the composite flour in this research tended to fall as the ratio of white corn flour decreased, except in sample F3, which had the lowest peak viscosity (Table 1). This finding was in line with the amylose content of the same composite flour, as previously reported by the team [13].

Trough viscosity, the lowest viscosity reached while heat was maintained at 95°C, was shown as the lowest point of the graph in Figure 1. Trough viscosity demonstrated the amylose leaching rate, starch granule swelling, and amylose-lipid complex formation [22]. It indicated the rupture of swelling starch granules at high temperatures [23]. Trough viscosity of the white corn-okara composite flour ranged from 1016cP to 1596cP with a tendency to diminish as the ratio of okara increased, except in F3 (Table 1). On the other hand, breakdown viscosity increased as the okara ratio rose, except in F3, which had lower breakdown viscosity compared to white corn flour F1. Overall, the composite flour developed in this research had a low breakdown viscosity ranging from 245cP to 516cP, which is similar to the breakdown viscosity of rice with normal amylose content [17]. Low breakdown viscosity is usually associated with high shear resistance, low hydration power, and low swelling power [24]. Therefore, the white corn-okara composite flour in this research is suitable for use as raw material for products that are not brittle nor break easily, for example analog rice. This is supported by the fact that the composite flour had a higher final viscosity compared to its peak viscosity, similar to rice [25]. The final viscosity of the composite flour was 2079cP-3248cP (Table 1). A bigger ratio of okara flour would reduce the flour’s final viscosity because the higher proportion of okara would increase fiber and protein [13], except in F3. Protein and fiber reduce water absorption by starch granules, which inhibits starch gelatinization and lower final viscosity [21]. Final viscosity was also affected by amylose interactions that triggered gel formation. Final viscosity of the white corn-okara composite flour declined as the white corn flour portion decreased (Table 1) which correlated with the decrease in amylose content reported previously [13]. The difference between final viscosity and trough viscosity is called setback, and reflects the tendency of amylose to undergo retrogradation. Generally, the higher the setback value, the easier for the starch to experience retrogradation [26]. During cooling, amylose sets and causes increased viscosity [20][26][27]. As with final viscosity, the composite flour’s setback viscosity tended to rise as the ratio of white corn flour increased, except in F3. It ranged from 1063cP to 1652cP (Figure 1 and Table 1) which indicates the composite flour would retrograde when cooled. Overall, the white corn and okara-based composite flour had high viscosity, which indicates it is easy to cook, while the lower viscosity flour is the opposite [16].
Figure 1. Amylograph Profile of White Corn and Okara Composite Flour. F1 (100% white corn flour:0% okara flour), F2 (95% white corn flour:5% okara flour), F3 (90% white corn flour:10% okara flour), F4 (85% white corn flour:15% okara flour), F5 (80% white corn flour:20% okara flour).

| Formula | Peak Time (min) | Pasting Temperature (°C) | Peak Viscosity (cP) | Trough Viscosity (cP) | Breakdown Viscosity (cP) | Final Viscosity (cP) | Setback Viscosity (cP) |
|---------|----------------|--------------------------|---------------------|-----------------------|--------------------------|----------------------|-----------------------|
| F1      | 5.67           | 79.85                    | 1977                | 1596                  | 381                      | 3248                 | 1652                  |
| F2      | 5.53           | 78.30                    | 1914                | 1491                  | 423                      | 3101                 | 1610                  |
| F3      | 5.40           | 79.90                    | 1261                | 1016                  | 245                      | 2079                 | 1063                  |
| F4      | 5.27           | 78.95                    | 1893                | 1404                  | 489                      | 2974                 | 1570                  |
| F5      | 5.40           | 79.00                    | 1892                | 1313                  | 516                      | 2845                 | 1532                  |

F1 (100% white corn flour:0% okara flour), F2 (95% white corn flour:5% okara flour), F3 (90% white corn flour:10% okara flour), F4 (85% white corn flour:15% okara flour), F5 (80% white corn flour:20% okara flour).

3.2. Microstructure

Figure 2 shows that the particles of white corn flour have a diameter of 5-30 μm with a round, polygonal and irregular shape, similar to that described by Thomas and Atwell [28]. The size, shape, and structure of white corn flour particles vary depending on the source of the raw material. The particle size of white corn flour affects physicochemical properties such as gelatinization and paste or gel formation, resistance to enzymes, and solubility [29]. Generally, due to its small particle size, flour has a lower gelatinization temperature than large starch granules. The white corn flour particles are larger than the rice starch granules. Large particles tend to expand more during cooking [30].
Figure 2. Microstructure of white corn and okara composite flour using magnification 2000X. F1 (100% white corn flour: 0% okara flour), F2 (95% white corn flour: 5% okara flour), F3 (90% white corn flour: 10% okara flour), F4 (85% white corn flour: 15% okara flour), F5 (80% white corn flour: 20% okara flour).

The okara particles’ irregular shape was clearly different from that of the white corn flour particles (Figure 2). Okara particles were larger than white corn particles and ranged from 20–60μm. The greater the percentage of okara flour, the more okara particles will appear. This is because the composite flour was prepared by slowly mixing the dried flour at low temperature. Therefore, the particles of okara and corn white flour did not break.

4. Conclusions

The peak time and pasting temperature range of white corn-okara composite flour was narrow and no correlation with the ratio of the raw materials was shown. Peak time ranged from 5.27-5.67 minutes and pasting temperature ranged 78.30-79.90°C. Peak viscosity, trough viscosity, final viscosity, and setback viscosity declined as the ratio of okara increased, while breakdown viscosity rose. Peak viscosity ranged from 1261cP-1977cP, trough viscosity ranged from 1016cP-1596cP, breakdown viscosity ranged from 245 cP-516cP, final viscosity ranged from 2079 cP-3248cP, and setback viscosity ranged from 1063 cP-1652cP. White corn and okara flour particles were clearly observed since the flour preparation did not break the particles. Research focused on the composite flour’s application to rice-based products or analog rice is needed since the flour had similar amylograph properties to those of rice.

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