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Original Article

Structure and functional properties of starch and flour from bambarra groundnut

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Abstract

Structure and functional properties of starch and flour from Bambarra groundnut (*Voandzeia Subterranea*) were investigated. The bambarra groundnut flour contained 58.38% of carbohydrate, 15.48 % of protein, 7.90% of fat, 4.19% of ash and 2.54% of fiber content. The starch isolated by the alkaline method had low content of protein (0.61%), fat (0.44%) ash (0.47%) and fiber (0.60%). Amylose content of bambarra groundnut starch was 21.67%. The starch granule shape appeared to be oval and round having an average diameter of 31.11 mm. X-ray diffraction pattern of the starch granules revealed an A-type with 43.69% of crystallinity. Thermal transition temperature of the starch assessed by DSC was 71.69°C at onset (T_0) and gelatinisation enthalphy (ΔH) was 11.73 J/g. Water and oil absorption capacity of bambarra groundnut starch were 1.67 and 1.01 ml/g, respectively. Bambarra groundnut starch showed a two-stage swelling pattern indicating a fairly restricted swelling starch. The pasting properties of the starch showed pasting temperature, breakdown and setback of 77.7°C, 170 BU, 220 BU, respectively. The starch showed similar pasting characteristics at the pH range 4.6 to 7.0. Compared with bambarra groundnut flour, the starch exhibited higher swelling power, breakdown and setback, but lower gelatinisation temperature, pasting temperature, water and oil absorption capacity.

Keywords: bambarra groundnut, starch, structure, functional property

1. Introduction

Bambarra groundnut (*Voandzeia subterranea*) is a drought tolerant and easy-to- cultivate legume. It is very adaptable to hot temperature but it is also tolerant to rainfall (Wriggley, 1981). It is widely cultivated throughout tropical Africa, India, Sri Lanka, Indonesia and Malaysia (Goli, 1995). It also has a good potential for cultivation in southern part of Thailand. Bambarra groundnut seeds are consumed in various forms for food. Fresh seeds may be consumed raw, boiled, grilled or dry seeds made into a powdery form to make cakes (Adenowale and Lawal, 2002). The seeds were found to contain 11.4% protein, 53.1% carbohydrate, 6.1% fat, 6.1% fibre, 4.4% ash, 0.097% calcium, 0.007% iron, 1.2% potasium and 0.003% sodium (Amarteifio *et al.*, 1997). The higher carbohydrate content of bambarra groundnut makes it a possible source of starch for food industries.

Starch contributes greatly to the textural properties of various foods and has many industrial applications as a thickener, colloidal, stabilizer, gelling agent, bulking agent, water retention agent and adhesive (Singh *et al.*, 2003). However, the development of value-added products from starch depends on a thorough knowledge of its the structure and functional properties. A few studies have reported on the structure and functional properties for bambarra groundnut starch and flour. Adebowale *et al.* (2002) reported that the swelling capacity increased with increase in temperature for both starch and flour of bambarra groundnut. This bean flour had higher water absorption capacity than that of Great Northern bean, reported by Sathe and Salunkhe (1981).

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Adebowale and Lawal (2004) found that emusifying stability of bambarra groundnut flour increased progressively as concentration increased until it began to decline with increasing flour concentration from 6% upward. A progressive increase in foam capacity was also observed as the concentration of this bean flour in solution increased.

The objective of this work was, therefore, to evaluate the structure and functional properties of starch and flour from bambarra groundnut. It is expected to provide useful information that can offer further support to the consideration of bambarra groundnut as an alternative source of starch in the food industries.

2. Materials and Methods

2.1 Flour preparation

Bambarra groundnut seeds were obtained from local market in Pattalung province, Thailand. The seeds were screened to eliminate the defective ones. Water was added to the samples and left overnight. The seeds were manually dehulled, dried in oven at 45°C, then dry milled to a fine power, ground to pass through a 60 mesh sieve and stored in sealed plastic bags at 4°C prior to use.

2.2 Starch isolation

The method of Adebowale and Lawal (2002) was employed, with modifications, for the starch isolation. One kg of bambarra groundnut flour was suspended in 10 L of 0.3% (w/v) NaOH solution. It was stirred for 4 h at 25°C. After stirring, the suspension was centrifuged at 1600g for 30 min. The supernatant was discarded and the sediment was resuspended in distilled water and centrifuged, this process was repeated three times. The starch suspension was then neutralized and the sediment starch was dried at 45°C for 12 h, ground to pass through a 60 mesh sieve and stored in sealed plastic bags at 4°C prior to use.

2.3 Chemical compositions

Moisture, protein, fat, ash and fiber contents of starch and flour from bambarra groundnut were determined on dry basis (db) by AOAC method (AOAC, 2000). Amylose content was measured using iodine binding procedures (Shanthy *et al.*, 1980; Sowbhagya and Bhattacharya, 1979).

2.4 Morphology

The starch granule shape was determined using Scanning Electron Microscope, SEM, (JSM-35, Japan) with a magnification of 2000X.

2.5 Granule size and size distribution

Size and size distribution of starch granules were determined using a Laser Particle Size Analyzer (COULTER LS 230).

2.5 Crystallinity pattern

Crystallinity pattern of the starch granule was determined by using the Wide-Angle X-Ray Diffraction (PHILIPS X'Pert MPD), in which the X-ray generator produces monochromatic copper K_a radiation and operates at 40 kV 50 mA and 0.154 nm wavelength.

2.6 Gelatinisation characteristics

Measurements were performed using a Differential Scanning Calorimetry (DSC-7, Perkin Elmer Inc., UK) equipped with a thermal analysis data system. Measurements were made on starch/flour: water slurries (1:4) (w/w). After sealing, the pans were equilibrated for 12 hrs and the samples heated in the calorimeter from 10-95°C at 10°C/min. The temperatures of the characteristic transitions, onset (T_0), peak (T_p) and conclusion (T_c) were recorded and the enthalpy (ΔH) of the transition was expressed as J/g on a dry weight basis.

2.7 Water and oil absorption capacities

The water absorption capacities (WAC) and oil absorption capacities (OAC) of starch and flour from bambarra groundnut were determined by the procedure of Adebowal and Lawal (2004).

2.8 Swelling power

The swelling power of starch and flour from bambarra groundnut was determined over the temperature range of 50 to 95°C by the procedure of Schoch (1964).

2.9 Pasting Behavior

Pasting behavior of the starch and flour (6%, db) at pH 7.0 was determined using a Brabender Viscograph (Viscograph, PT-100). The starch or flour suspensions (total weight of 500 g suspension) were heated gradually from 50°C to 95°C, kept at this temperature for 15 min, then cooled to 50°C and held at this temperature for 30 min. The starch paste stability was also obtained with a Brabender Viscograph at pH 3.6, 4.6, 5.6 and 7.0 using acetate-phosphate buffer solution.

3. Results and Discussion

3.1 Chemical compositions

The chemical compositions of bambarra groundnut flour and starch are presented in Table 1. The flour contained 58.38% carbohydrate, 15.48% protein, 7.90% fat, 4.19% ash and 2.54% fiber content. These results are comparable with that reported by Amarteifio and Moholo (1998). The bambarra groundnut flour contained lower protein content and higher fat content than that of mung bean flour (Amarteifio and Moholo, 1998). Bambarra groundnut starch was isolated from the flour by alkaline method. The yield of the starch was 45.57% (calculated based on 100g of flour). The isolated starch had low protein (0.61%), fat (0.44%) ash (0.47%) and fiber (0.60%) content. The results indicate that pure starch could be obtained by the isolation method. The amylose content of the bambarra groundnut starch (21.67%, db) was lower than that of mung bean starch (34.5%, db) (Su *et al.*, 1997).

3.2 Granule size and microscopic appearance

The scanning electron micrograph of the starch granules is presented in Figure 1. The shape of the starch granules appeared to be oval and round and those with have round shape were smaller in size. The surface of most granules was rather smooth. The bambarra groundnut starch showed the same pattern of multimodal distribution of size (Figure 2). The first group had a diameter range between 1 to 48 mm, the second and the third groups had a diameter range between 49 to 92 mm. The granule size mean diameter of the starch was 31 mm, which was higher than that of mung bean starch (14.3 mm) (Chen *et al.*, 2003). The shape and size of starch granules from bambarra groundnut were similar to those reported by Adebowale and Lawal (2002).

3.3 Crystallinity of starch granule

The crystallinity is produced by the ordering of the amylopectin chains. The clustered branches of amylopectin occur as packed double helices. The crystalline structure exhibited distinct X-ray diffraction pattern that can be classified into three categories: A, B and C type crystal (Hizukuri, 1996). Figure 3 shows a typical A-type diffraction pattern for bambarra groundnut starch, because there is a strong peak at d-space about 5.78, 5.17, 4.86 and 3.78 °A (Zobel, 1964). The double helices of the A-type crystalline in a monoclinic lattice having the maltotriose as a repeating unit and four

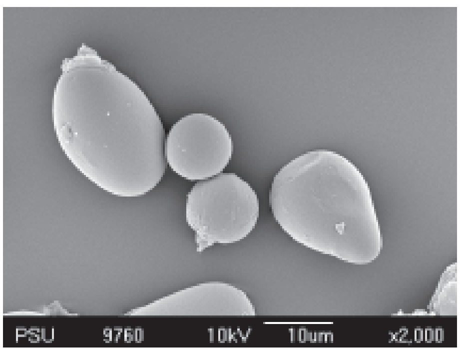

Figure 1. Scanning electron micrograph of starch granules from bambarra groundnut at magnification 2000X

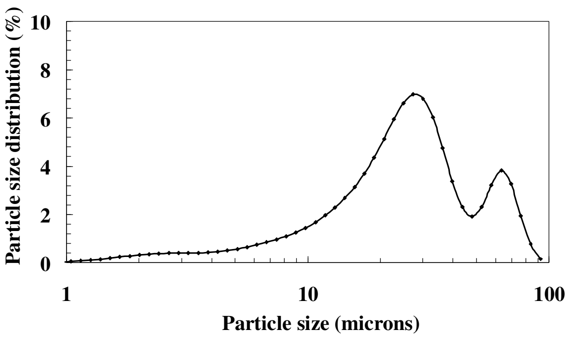

Figure 2. Granule size distribution of bambarra groundnut starch

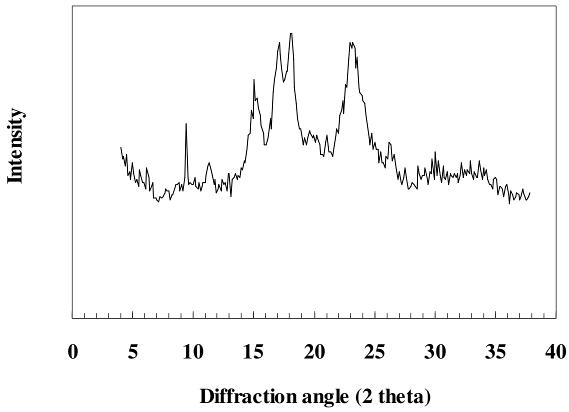

Figure 3. X-ray diffraction pattern of bambarra groundnut starch

Table 1. Chemical compositions of starch and flour from bambarra groundnut

Composition*	Flour	Starch
Moisture (%, db)	11.51±0.32	8.90±0.18
Fat (%, db)	7.90±0.01	0.44±0.05
Protein (%, db)	15.48±0.12	0.61±0.08
Ash (%, db)	4.19±0.03	0.47±0.03
Fiber (%, db)	2.54±0.38	0.60±0.05
Carbohydrate (%, db)	58.38±0.86	88.98±0.23
Amylose (%, db)	ND	21.67±1.43

* mean of three replicates
ND = not detected

water molecules per unit cell (Biliaderis, 1998). According to Gidley (1987), the A-type crystal is the most thermodynamically stable form. The degree of crystallinity of bambarra groundnut starch was 43.7%. This agrees with Zobel (1988), crystallinity values for the A-type showing values between 33% to 45%.

3.4 Gelatinisation characteristics

Gelatisation describes the irreversible disruption of molecular order within a starch granule when heated in

Table 2. Gelatinisation parameters of starch and flour from bambarra groundnut

Sample	Gelatinisation parameters*				
	T_0 (°C)	T_p(°C)	T_c(°C)	T_c - T_0	ΔH (J/g)
Starch	71.69±0.10	75.33±0.29	79.17±0.45	7.48	11.73±1.15
Flour	76.84±0.12	80.75±0.23	85.82±0.40	9.0	6.00±1.10

* mean of three replicates

excess water. Starch gelatinisation temperature and gelatinisation enthalpy are influenced by starch compositions, molecular structure of amylopectin and granule architecture (Tester, 1997). Gelatinisation parameters of starch and flour from bambarra groundnut are presented in Table 2. Gelatnisation temperature of starch obtained from bambarra groundnut was 71.69°C at the onset (T_o), 75.33°C at the midpoint (T_p) and 79.17°C at the end of gelatinisation (T_c). The enthalpy of gelatinisation (ΔH) was 11.73 (J/g). The gelatinisation temperture of the flour was higher, while the enthalpy of gelatinisation was lower than that of the starch. The results were due to the interaction of starch with other flour component such as protein, lipid or fiber (Czuchajowska *et al.*, 1998). The higher gelatinisation temperature for bambarra groundnut starch comparing to mung bean starch reported by Su *et al.* (1997) may result from the more rigid granular structure (Singh *et al.*, 2003). The difference in (T_c- T_o) between starch from bambarra groundnut (7.48) and mung bean (17.2) suggests a higher degree of homogeneity of crystallites within granules of bambarra groundnut starch (Hoover and Ratnayake, 2002).

3.5 Water and oil absorption capacities

Imbibition of water is an important functional trait in foods such as sausages, custards and doughs. Moreover, oil absorption capacity is useful in structure interaction in food especially in flavor retention, improvement of palatability and extension of shelf life particularly in bakery or meat products (Adebewale and Lawal, 2004). The water and oil absorption capacity (WAC and OAC) of starch and flour from bambarra groundnut are presented in Table 3. The values of WAC and OAC of starch and flour from bambarra groundnut are consistent with those previously reported by Adebewale and Lawal (2004). The WAC of bambarra groundnut flour was higher than that of the starch. This result suggests that the flour was more hydrophilic due to a higher protein and carbohydrate content (Table 1). The higher OAC of the flour could be due to its higher protein and fat contents, which can entrap more oil. Basically, the mechanism of OAC is mainly due to the physical entrapment of oil by capillary attraction (Kinsella, 1976). However, the hydrophobicity of proteins also plays a major role in oil absorption (Voutsinas and Nakai, 1983)

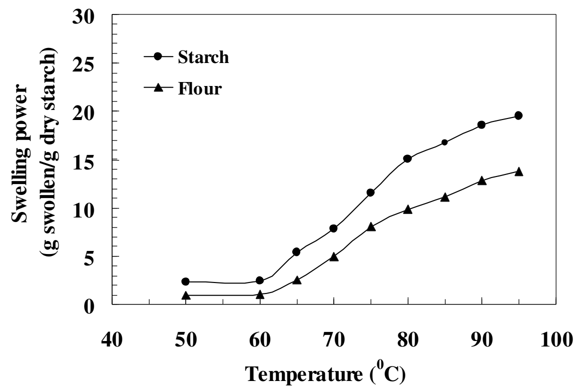

Figure 4. Swelling patterns of starch and flour from bambarra groundnut

Table 3. Water and oil absorption capacities of starch and flour from bambarra groundnut

Sample	Water absorbed* (ml/g)	Oil absorbed* (ml/g)
Starch	1.67 ± 0.12	1.01± 0.05
Flour	2.27 ± 0.15	1.30± 0.06

* mean of three replicates

3.6 Swelling power

Granule swelling of starch and flour from bambarra groundnut was investigated over the temperature range of 50-95°C (Figure 4). The starch showed a two-stage swelling pattern. This type of swelling has been reported to be typical swelling pattern of legume starch (Oates, 1991). This is indicative for different mechanisms of interaction force within the starch granules. A first association was relaxed from 60-75°C and was followed by a strong interaction from 75-95°C, which is in agreement with the previous results on mung bean starch (Schoch and Maywald , 1968; Singh *et al.*, 1989). The swelling power has been shown to be influenced by the amylose/amylopectin ratio and by the characteristics of amylose and amylopectin in terms of molecular weight distribution, degree of branching, length of branches and conformation of the molecules (Ratnayake *et al.*, 2002). The lower swelling values obtained for bambarra groundnut flour

Table 4. Pasting characteristics of starch and flour from bambarra groundnut at the concentration of 6% (db) over the pH range 3.6-7.0

Parameters	Starch				Flour
	pH 3.6	pH 4.6	pH 5.6	pH 7.0	pH 7.0
Initial pasting temperature[1] (°C)	76.4[a]	76.8[a]	77.3[b]	77.7[b]	80.5[c]
Peak viscosity[1] (BU) (P)	565[c]	570[c]	570[c]	545[b]	243[a]
Viscosity[1] (BU) :					
- at 95°C hold (H)	275[b]	365[c]	395[c]	375[c]	205[a]
- at 50°C (C)	430[b]	585[c]	600[c]	595[c]	202[a]
Breakdown[1] (BU) (P-H)	290[c]	205[b]	175[b]	170[b]	38[a]
Setback[1] (BU) (C-H)	155[b]	220[c]	205[c]	220[c]	57[a]

[1] mean of three replicates
values followed by the same letter, in the same row are not significantly different (p>0.05)

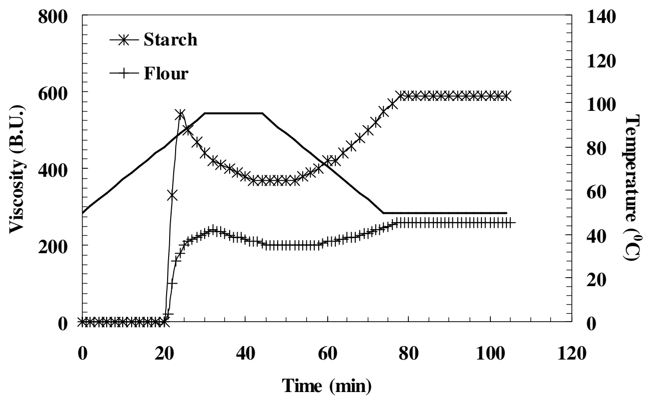

Figure 5. Pasting curves of starch and flour from bambarra groundnut at the concentration of 6% and pH 7.0

may mainly be affected by the presence of lipid and protein (Table 1), which are also important factors in controlling the swelling (Leach, 1965).

3.7 Pasting properties

The transition from a suspension of starch granules to a paste, when heat is applied, is accompanied by a large increase in viscosity. The Brabender viscograph technique is commonly used to determine the changes of viscosity consistency during pasting (Su *et al.*, 1997). The pasting curves of starch and flour from bambarra groundnut at a concentration of 6% (db) and pH 7.0 are presented in Figure 5. The starch viscosity began to increase at about 77.7°C and this can be interpreted as the start of starch gelatinization. The starch demonstrated a pronounced peak viscosity of 545 BU and underwent a relatively slight breakdown of 170 BU as well as increase viscosity during cooling at setback of 220 BU (Table 4). According to Schoch and Maywald (1968), this starch paste viscosity pattern is classified into type A, which is similar to cereal starches. The increase in paste viscosity when a hot paste is cooled reflects amylose leaching out of swollen granules, so that the paste can able to from a network on cooling (Ibadan *et al.*, 1992). Comparative pasting characteristics of flour and starch from bambarra groundnut are shown in Table 4. When the flour was used instead of starch, a lower peak viscosity was observed followed by a slight viscosity decrease and more stability during the holding period at 95°C, showing that the flour are more resistant to heat than that of the starch. This may be explained by interaction between starch and lipid/protein during heating (Gujska *et al.*, 1994).

3.8 Starch paste stability

The pasting characteristics of starch from bambarra groundnut at the concentration of 6% (db) and pH range of 3.6 to 7.0 are shown in Table 4. At the pH range 4.6 to 7.0, the starch showed similar pasting characteristics: hot paste viscosity (365-375 BU), cold past viscosity (585-600 BU), breakdown (170-205 BU) and setback (205-220 BU), which indicates good resistance to acid at these pH ranges. When decreasing pH to 3.6 pasting temperatures, hot paste and cold paste viscosity and setback significantly decreased, whereas breakdown markedly increased. The result indicates that some acid hydrolysis of the starch granules might occur at pH 3.6 (Siriwong *et al.*, 2003).

4. Conclusions

The bambarra groundnut flour is highly nutritive, and contains high quantities of carbohydrate, protein and fat. It has good potential to be developed as a new food crop in Thailand. The bambarra groundnut starch has high amylose content and the starch granules are oval and round with an A-type pattern, which is the most thermodynamically stable form. Bambarra groundnut starch showed a two-stage swelling pattern with a similar viscosity profile to cereal starch. The starch exhibits a good resistance to acid at the pH range 4.6 to 7.0. Compared with bambarra groundnut flour, the starch exhibits higher swelling power, breakdown and setback, but lower gelatinisation temperature, pasting temperature, water and oil absorption capacity.

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