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A comparative study of the hydrothermal behavior of four corn flours and their starches in Madagascar

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Abstract

In Madagascar, maize constitutes the third staple food. Traditionally, cereal gruel (made up from rice or maize flour) is the supplementary food for Malagasy children. This work involved a comparative study of the hydrothermal behavior of four maize flours sold on the market and their starches, in order to identify their best use in food systems, especially in infant nutrition. Studies of functional properties such as swelling power, solubility and viscosity were undertaken. At 90°C, the swelling power value range was between 4.81 (g/g) and 8.2 (g/g) for flours and between 6.72 (g/g) and 9.1 (g/g) for their starches. While solubility was 11.8 (%) and 16.4 (%) for flours at the same temperature (90°C), for starches, it was between 12.6 (%) and 22.8 (%). The viscosity peaked at 90°C, ranging from 648 (cP) to 2728 (cP) for flours and from 220 (cP) to 2268 (cP) for starches.

Keywords: Maize; Flour; Starch; Swelling power; Solubility; Viscosity

1. Introduction

Cereals are important to humans, they are a staple food crop in many parts of the world [1]. Among the cereals cultivated in Madagascar, rice and corn are the most consumed. Maize is Madagascar's third staple food after rice and cassava. It is cultivated largely for human food (85%) while 15% of the total production is used as animal feed [2]. Its large cultivation areas in Madagascar are located in particular in the Middle West, the Highlands, and the South West. As a substitute for rice, maize represents an important issue for food security in the South West. It is mainly marketed in the form of dry grains and flour. Complementary food means any food intake other than breast milk given to infants or young children to meet their nutritional needs [3]. During weaning, mothers generally feed their young children with traditional gruels made from simple or compound flours from grains and tubers which are high in carbohydrates but low in proteins. This study was based on corn flours used for cooking. The functional properties of flours, particularly the thickening properties, are based on those of their starches and are important in the choice of infant food. This work aimed to evaluate the functional properties of four corn flours and their starches to determine their best use in food systems, especially in infant nutrition.

2. Material and methods

2.1. Materials

Four types of corn flour sold in Antananarivo markets were used. These were Ff (Cream of Corn Product Fiombonana), Fs (Cream of Katsaka Soa Corn), Fp (Probo Corn Flour), Fk (Koba Katsaka Corn Flour). The starches were extracted from the corresponding flours according to the wet extraction method inspired by that of Banks and Greenwood [4] and were

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designated as follows: Af (starch from the cream of corn Product Fiombonana), As (starch from the cream of corn Katsaka Soa), Ap (starch from Probo corn flour), Ak (starch from Koba Katsaka corn flour).

2.2. Methods for the determination of moisture and dry matter

In a previously dried and tared capsule, 5g of flour were introduced. After 24 hours of steaming at 103°C, the capsule was cooled in a desiccator and then weighed until a constant weight was obtained [5, 6].

$$H (\%) = [(m1-m2) / (m1-m0)] \times 100$$

With H (%) = moisture content of the sample expressed in g per 100g of the sample, m0 = mass of the empty capsule, m1 = mass of the capsule with the sample before baking, m2 = mass of the capsule with the sample after baking in gram (g).

The dry matter content (DM %) was deduced according to the following relation:

$$DM (\%) = 100 (H \%)$$

2.3. Amylose/Amylopectin

The technique used was that of the ISO 6647 standard [7]. The amylose content was determined by reading the optical density of the test sample suspended in a NaOH solution in the presence of an iodine solution, at 620 nm, compared to a standard curve prepared beforehand. The amylopectin content was deduced by the difference between the starch content and that of the amylose.

2.4. Swelling power

The swelling power was determined by the method of Leach [8]. 10% (W/V) solutions were prepared [10 (g) of the sample in 100 (ml) of distilled water] and placed in a water bath at different temperatures ranging from 50°C to 90°C with intervals of 10°C for 30 minutes with constant agitation. The mixtures were then placed under maximum agitation for 5 min with a vortex and centrifuged at 4000 revolutions/min for 15 minutes. Then the collected pellets were weighed and placed in an oven to obtain the dry matter (4 h at 130°C). The dry pellets were then reweighed. The rate of swelling was given by the following formula (TG):

$$TG (g/g) = (Mh - Ms) / Ms$$

With: TG = swelling rate, Mh = mass of the wet pellet, Ms = mass of the dry pellet (g).

2.5. Water solubility

The solubility in water was determined by the method of Kainuma [9]. Suspensions of 10% (W/V) of the samples studied [10 (g) in 100 (ml) of distilled water] were prepared. The beaker containing the suspension was placed in a water bath at different temperatures ranging from 50°C to 90°C with intervals of 10°C for 30 minutes without mixing. The mixture was then centrifuged at 4000 rpm for 15 minutes. The supernatant was dried, weighed and then the solubility was calculated using equation (1).

Equation (1):

$$\%\ \text{Solubility} = \frac{\text{weight of the soluble starch (g)}}{\text{weight of te sample (dry basis)}(g)} \times 2 \times 100$$

2.6. Viscosity measurements

The viscosity measurements were carried out on a suspension of 10 (%) (W/V) of the samples studied according to a method inspired by that of Hounhouigan [10] and Nago [11]. The viscosities of the flours and starches were measured using a Brookfield RV viscometer, model VISCO STAR R. In a beaker, suspensions of flour and 10% starch were prepared [10 (g) in 100 (ml) of distilled water] and placed in a water bath at temperatures ranging from 50°C to 90°C with 10°C intervals for 10 minutes. The mobile RV2 of the viscometer was used and the device was adjusted to 100 (rpm) (rotation per minute). The viscosity was determined by multiplying the value read on the screen by the corresponding factor. For a measuring system (viscometer + mobile) and a given rotational speed (rpm), the liquid viscosity was equal to the percentage of the torsion scale multiplied by a factor that depends on the mobile user.

3. Results and discussion

3.1. Moisture content

The moisture contents (H %) of the samples studied are summarized in Table 1 and Table 2 below:

Table 1 The moisture contents of flour

Samples	F_F	F_S	F_P	F_K
H(%) (mean ± standard deviation)	12.53 ± 0.05	12.94 ± 0.06	12.44 ± 0.01	12.70 ± 0.22
DM (%)	87.47	87.06	87.56	87.3

The moisture content of flour between 12.44 (%) and 12.94 (%) was regulatory according to the Codex Alimentarius. Indeed, the moisture content of corn flour must be a maximum of 15 (%) [12] to have a good conservation. This low moisture content shows advantages in terms of storage time, the prevention of the multiplication of microorganisms, and the inhibition of the rate of oxidation and of the enzymatic activity which can lead to a deterioration of the product [13].

The moisture content of the flour thus plays an important role in its shelf life and the taste of the finished product.

Table 2 The moisture contents of starch

Samples	A_F	A_S	A_P	A_K
H(%) (means± standard deviation)	12.04 ± 0.02	12.29 ± 0.07	11.73 ± 0.05	10.96 ± 0.29
DM (%)	87.96	87.71	88.27	89.04

Corn starch had a moisture content of 10.96 (%) to 12.29 (%). This rate is consistent with those found by Chanvrier [14] for corn starches between 7.1 (%) to 12 (%).

3.2. Amylose and amylopectin content

The amylose and amylopectin contents of the samples studied are summarized in Table 3 below:

Table 3 Amylose and amylopectin content in corn flour starches

Corn starch / Contents	AF	AS	AP	AK
Amylose content (% starch)	18.05	16.01	14.11	21.97
Amylopectin content (% starch)	81.95	83.99	87.89	78.03

The amylose and amylopectin contents contribute to the rheological property of starch. The amylose content was between 14.11 (%) and 21.97 (%) for the various corn starches. The lowest content was observed for AP and the highest value for FK. The values obtained for the various starch samples studied were quite similar to those reported by

Seetharaman [15], who reported an amylose content of 16.1 (%) to 23.3 (%) for 35 landraces of maize. The amylose content of starch granules varies with the botanical source of the starches and is affected by climatic and soil conditions during grain development [16]. These studied various corn flours could be of different species. The content and the ratio of amylopectin varied from 78.03 (%) to 87.89 (%) for the starches.

3.3. Swelling power properties (g/g)

The swelling values of flours and their starches at different temperatures are presented in Figures 1a and 1b below. The increasing temperature during heating resulted in increased swelling [17], as expected. The general appearance of the graphs differed from flour to flour and the swelling values varied from 4.81 (g/g) to 8.2 (g/g) (figure 1a).

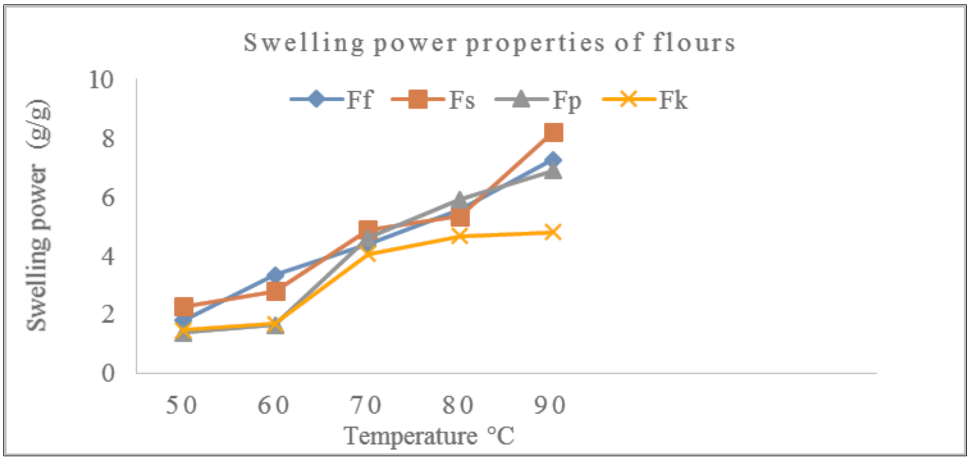

Figure 1a Swelling power of flour as a function of the temperature

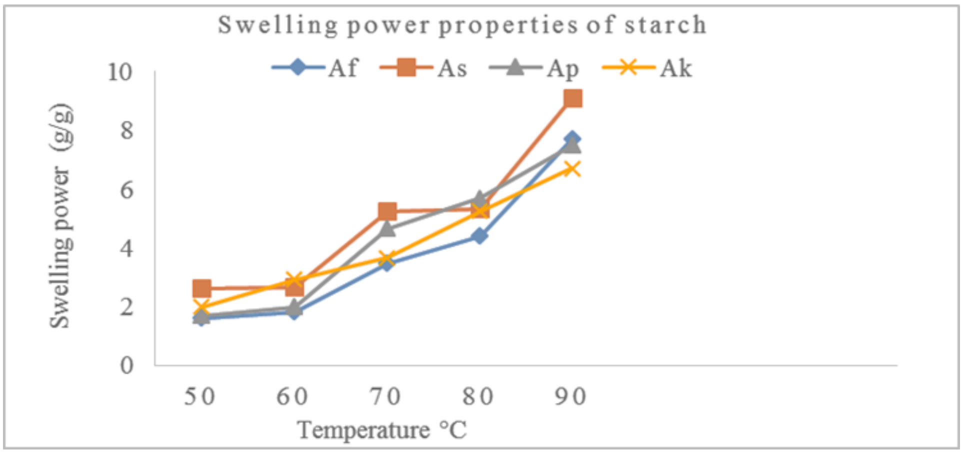

Figure 1b Swelling power of starch as a function of the temperature

At 90°C, FS flour had a higher swelling power of around 8.2 (g/g) compared to that of FK 4.81 (g/g). The maximum swelling rates achieved by the four flours were different. At any temperature, FK flour had the lowest water absorption capacity among the four corn flours. As for the starches (figure 1b), between 50°C and 60°C, the starch grains collected water and began to swell, this is sorption. The water absorption of the starch grains became greater between 60°C and 70°C for AP, AF, and AS. The water absorption capacity gradually increased between 70°C and 80°C and reached a maximum of 90°C for all starches. Starch swelling values ranged from 6.72 (g/g) to 9.1 (g/g) at 90°C. These starch swelling power results were lower than those found by Singh and Sandhu [18], who reported swelling power in the range of 13.7 to 20.7 grams of water per gram of dry starch at 90°C during the study of some properties of corn starch: physicochemical properties, gelatinization, retrogradation, textural properties of bonding, and gelation. The swelling indicates the degree of water absorption of the starch granules [19]. Gelatinization, which is a phenomenon occurring due to an excess of water and under the action of heat, occured in this study at 70°C for the studied samples . It corresponds to the irreversible destructuring of the starch grain as well as of its internal structure. Indeed, in their native structures, starches absorb less water, they absorb more water after gelatinization. Starches have a high water absorption capacity compared to corn flours. The low swelling observed in flours is due to the presence of fibers which serve as barriers to swelling.

The starch in the flour is not free therefore absorbs less water [20]. At 90°C, FS and AS exhibited the highest swelling powers while Fk and Ak the lowest. According to Singh [21], amylose plays a role in limiting swelling due to its formation which occurs more quickly after the exudation of amylose. This is the case in the present study because AK had the highest amylose content among the samples studied with the lowest swelling capacities.

3.4. Solubility properties (%)

The change in solubility as a function of the temperature was quite similar for the four flours according to Figures 2a and 2b. The solubility of the four flours varied from 11.8 (%) to 16.4 (%) at 90°C. Low solubility values were observed for FK flour and a high value for FS. FS flour had the smallest granular size and CF had the largest. According to Mirhosseini and Amid [22], the factors likely to influence the solubility of flours include the composition of the flour, the size of the particles, the processing and the storage conditions. Starch AS had the lowest solubility value at a temperature of 50°C to 80°C. The solubility patterns also showed a small difference for the four samples, AF showed the highest rate from 80°C. At 90°C, low solubility values were observed for AK. This change in solubility observed at 90°C between AK and AS is due to the leaching of amylose from the starch granule and diffusion during swelling. The solubility of starches varied from 12.6 (%) to 22.8 (%) at 90°C. Solubility is an indicator of the ability of water to penetrate starch and flour granules [23]. Solubility increases with increasing temperature from 50°C to 90°C. Corn starches have higher solubility values compared to flours. Solubility also provides evidence for interactions between water molecules and starch chains in crystalline and amorphous regions. According to Zobel [24], crystallinity is exclusively associated with the amylopectin component, while the amorphous regions represent amylose. Heating is a process that leads to the breakdown of starch, and the release of amylose affects the solubility of starch.

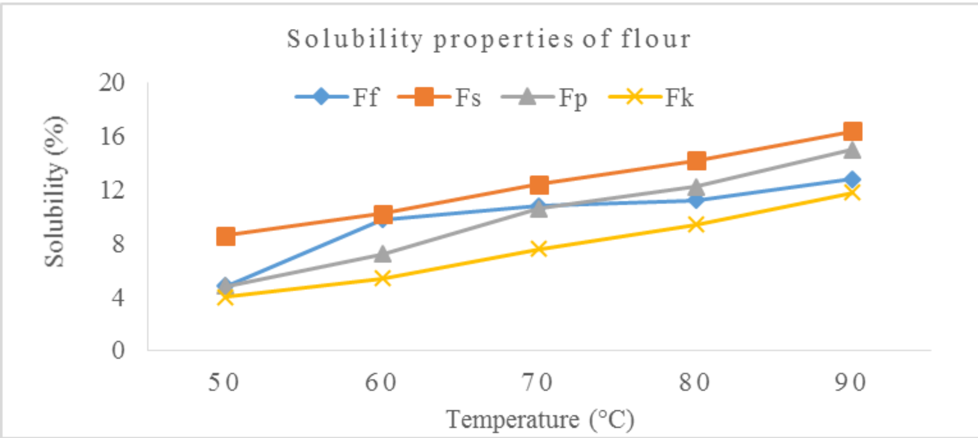

Figure 2a Solubility of flour as a function of temperature

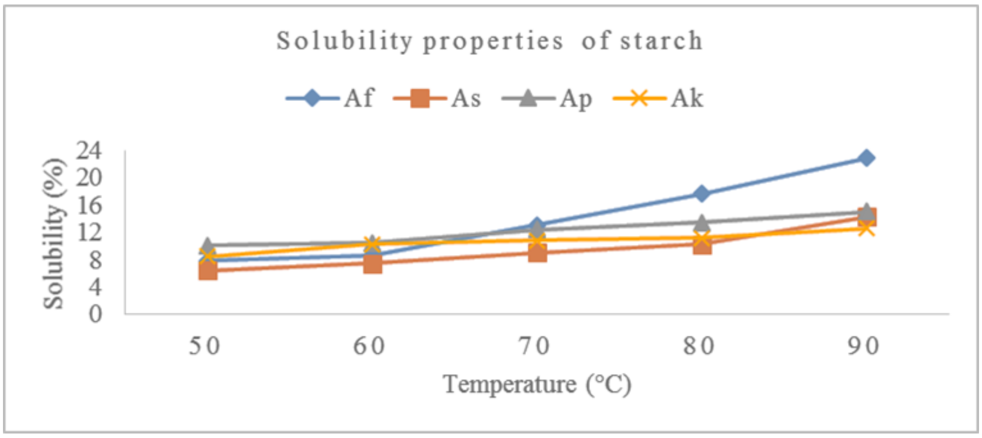

Figure 2b Solubility of starch as a function of the temperature

3.5. Viscosity (cP)

The experiment was carried out with temperatures ranging from 50°C to 95°C for the viscosity. From figure 3a, FS flour has the highest viscosity value, while FK has the lowest. High swelling flour was found to represent high viscosities. The maximum viscosity (at 90°C) corresponds to what can be reached during heating. Maximum viscosities of 648 (cP) to 2728 (cP) were obtained for the four flours. The viscosity at 95°C was between 600 (cP) and 2548 (cP) for the studied samples. The relatively low maximum viscosity of CF flour indicates that the flour forms a thinner dough. The shapes of the viscosity curves for the three starches AS, AF, and AP are quite similar, unlike that of AK (Figure 3b). A slow viscosity growth was noted between 50°C to 80°C for Ak. The maximum viscosity, also 90°C, is the ability of starches to swell freely before they collapse and indicates the strength of the pastes formed during gelatinization [25]. From the curve above, the maximum viscosity for the various corn starches is between 220 (cP) and 2268 (cP), the lowest for AK and the highest for AS. These viscosity values obtained are lower than those found by Moses and Olanrewaju [26] for different varieties of corn of the order of 2236.5 (cP) to 2760 (cP). The viscosity at 95°C indicates the difference in consistency between the maximum viscosity and that of the bearing temperatures [27]. It varies from 168 (cP) to 2088 (cP) for starches.

The corn flours had high viscosities compared to their starches except for FP and AP. All corn starches and flour showed a gradual increase in viscosity to peak with increasing temperature (Figure 3a and 3b). The increase in viscosity with temperature is attributed to the removal of water from the amylose exuded by the granules during their swelling [28]. Between 50°C and 70°C, the viscosities increase slightly. The gelatinization temperature, which is the temperature at the start of the viscosity increase [18], for the various flours and their starches, was here between 70°C to 80°C. Seetharaman [15] reported gelatinization temperatures of 74.90°C to 84.70°C for local varieties of argentinine corn. Viscosities increase most significantly from 80°C to 90°C. The peak viscosities of each flour and each starch occured here at the same temperature of 90°C. According to Singh [21], the viscosity increases until reaching this peak of 90°C. At 95°C, a decrease in viscosity is observed. The viscosity will evolve up to the final viscosity of the flours and their starches. According to Niba [29], final viscosity is important in determining the ability of a sample to form a gel during heating and could be used for improving and optimizing the texture of infant foods. The measurements of the final and maximum viscosities are relevant, in general in the preparation of starch-based foods, for the determination of their thickening properties. Normally, all flours should have lower viscosities than starches due to the encapsulation by the plant walls, total or partial, which limits the swelling and the solubilization of the starch. The use of the BROOKFIELD viscometer and the choice of concentration (10%) probably explain the obtained results.

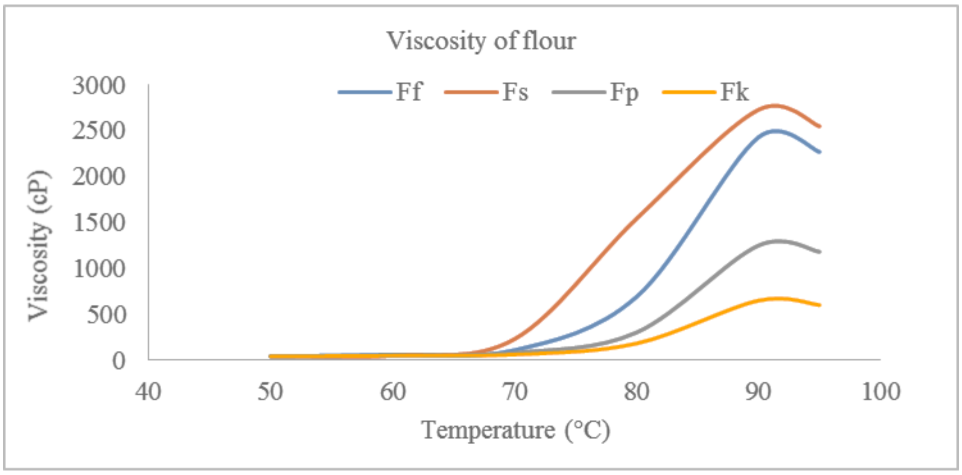

Figure 3a Viscosity of flour as a function of the temperature

Infant flours must cover the energy and nutrient needs of children during the period of complementary feeding. Gruels, usually cereal-based, have very high viscosity for children from 6 to 9 months. The viscosity of the slurries should not exceed 1500 cP to be easily acceptable to young children [30]. In previous studies, many techniques have been described to improve the properties of infant flours such as the addition of amylase, the fermentation and germination technique, or the extrusion. These different methods improve the consistency and energy densities of porridge, thus increasing the potential for infants and young children to overcome malnutrition. Among these methods, the most effective method of reducing the viscosity of slurries is the incorporation of amylases which allows the length of the linear portions of amylose and amylopectin to be reduced [31]. This enzyme breaks down starch granules which are difficult to digest by infants. The advantage of incorporating α-amylase industrially produced for the preparation of flour for cooking is to obtain appropriated gruel consistency and energy density which allow a substantial increase in energy intake in young children [32].

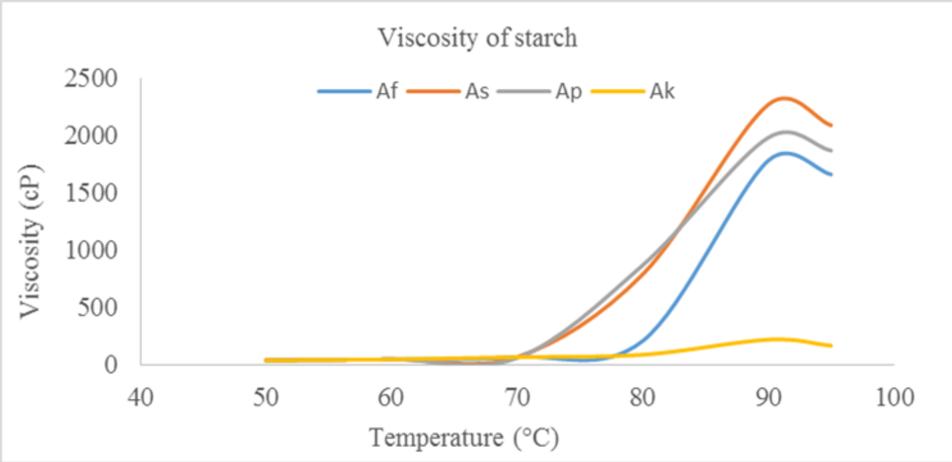

Figure 3b Viscosity of starch as a function of the temperature

4. Conclusion

According to the analyzes that were carried out during this study, the flours had a low water content (12%) allowing a good conservation. The swelling, solubility, and viscosity of the weaning food are important physicochemical factors. They influence the amount of food that a child can eat. FS flour and AS starch had significantly higher bulking powers and viscosities than the other three corresponding flours and starches. The solubilities of the flours were lower than those of the corresponding starches. Determining these thickening properties is essential for the future use of these flours as a basis for infant foods to achieve the recommended adequate energy density over time.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

The authors declare that there are no competing interests related to this work

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