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Effect of Two Milling Techniques and Flours Particle Size on Some Physicochemical Properties of Millet Flour

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Abstract: Two techniques of milling (milling with wooden mortar and milling with hammer grinder) for the production of millet flours were compared in term of physical, biochemical and nutritional aspects and digestibility of the produced flours. A batch of millet grains with candle (*Pennisetum glaucum* L. R.BR) was purchased from a local market for flour production, while the flour digestibility tests were achieved with an enzymatic crude extract get from gastric juice of and snails (*Archachatina marginata*). The different rough flours obtained from both milling techniques showed significant differences ($p<0.05$) in their granulometric profiles and their biochemical composition. The mortar milling gave flours with higher contents in dry matter, ash and sugars (total and reducing sugars) than hammer grinder one, excepted for total carbohydrates and starch. In addition, each flour fraction obtained after sieving rough flours also presented significant differences ($p<0.05$) in the biochemical composition and the digestibility. The flours with large particles (0.315 and 0.630 mm) had highest dry matter content and ash, but the flour with small particles (0.160 mm) was rich in soluble sugars, total carbohydrates and most digestible.

Key words: Milling, millet, digestibility, snail, wooden mortar, hammer grinder

INTRODUCTION

With a world production of about 2.038 billion tons planned for the year 2005, cereals occupy a place of choice in the human feeding (FAO/ICRISAT, 1997). For poorest populations, products resulting from cereal processing constitute the most significant elements of their diet. Cereals are particularly consumed under the form of baby cereal, dough, couscous or pancakes, which constitute the usual dishes of these populations. All these traditional preparations are flour-based foods with more or less coarse particles, obtained after grains husking and grinding (Robert *et al*., 2003).

Millet flour is a food product of everyday consumption in African households. Its manufacture by grain grinding involves various technologies likely to lead to a variation of quality and product uses (Brica *et al*., 1984).

The traditional grinding usually applied by rural women in villages, is done with the wooden mortar. Very accessible, this method is however, slow and very hard. The day production rarely exceeds 3 kg of flour perwoman per day (UNIFEM, 1988). This process thus, supported many attempts at introduction of technologies known as improved or semi industrial such as the use of mill with an aim of reducing women labour.

Grains grinding with mill have an unquestionable advantage because of the speed of the operation. Moreover, this process has the advantage of producing finer flour.

If these cereal grains grinding techniques (traditional wooden mortar or mill) were subjects of many studies, their real effect however, on nutritional quality of produced flours remains unknown. This study was therefore, carried out to assess the effect of 2 milling techniques and particles size after sieving on some biochemical and nutritional components of millet flours.

MATERIALS AND METHODS

This study was carried out on a batch of millet grains with candle (*Pennisetum glaucum* L. R.BR). Millet and

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snails (*Archachatina marginata*) from which enzyme was extracted were purchased from local market of SICOGI (YOPOUGON) in Abidjan, Côte d'Ivoire.

Preparation of flours: About 2 kg of millet grain were washed, cleaned, separated from damage grains and undesirable objects and then dried in a drying oven at 45°C during about 24 h. A sample of 800 g of these grains was milling with a mill (hammer grinder) (TD AFRIQUE, Abidjan, Côte d'Ivoire) comprising a sieve with small apertures. The same quantity of grains (800 g) was ground in parallel in a wooden mortar as done traditionally. The various flours obtained from each technique of milling were known as rough flours. They were preserved in plastic bottles for further analysis.

Granulometry study of rough flours: This study was carried out as previously described in the French Normalisation (AFNOR, 1994). One hundred gram of each rough flour were placed on a vibrating support containing 16 sieves stacked in decreasing order of the aperture sizes (from 5-0.01 mm). The device was switched on, leading the sieves in ellipsoidal movements for 15 min. Then the grains were collected in function of sieves aperture sizes and weighted to calculate the percentage of particles collected. These collected particles were also analysed for their biochemical characteristics and for *in vitro* digestibility.

Biochemical analysis: Flour sugars were analysed after their extraction according the ethylic alcohol method as described by GAY LUSSAC. Total sugars were determined by the phenol sulphuric acid method according to Dubois *et al.* (1956), while the reducing sugars were quantified as previously described by Bernfeld (1955). Total carbohydrates were determined according to the method of Bertrand and Thomas (1910). Starch content was deducted by calculating the difference between total carbohydrates content and total sugars content. All the results were expressed in percentage of dry matter.

Dry matter content (%) was determined by drying 5 g of flour sample at 105°C for 24 h in an drying oven and weighted until a constant weight (Kimaryo *et al.*, 2000).

Ash was determined by incineration of 0.5 g of flour in muffle furnace at 550°C for 5 h.

In vitro digestibility of flour starch

Preparation of rough enzymatic extract from gastric juice of snail: The extraction of snail gastric juice was carried out on a batch 50 snails (*Archachatina marginata*) beforehand put without food during 4 days. the digestive tract was insulated and emptied of its contents. The liquid collected (10 mL) was mixed with 20 mL of a sodium chloride solution (NaCl 0.9%). The resulting mixture underwent to a sonication for 10 min and a centrifugation at 5000 tours min^{-1} during 30 min. The supernatant, constituting the enzymatic crude extract was preserved at -20°C for digestibility study of prepared flours.

***In vitro* digestibility:** *In vitro* flour digestibility consisted to a reaction between the enzymatic crude extract and an amount of gel of flour at 1% (w v^{-1}). The reaction medium was constituted as follow: 100 μL of acetate buffer (100 mM, pH 5), 20 μL of enzymatic crude extract and 80 μL of 1% of flour gel. The mixture was then incubated at 37°C for 160 min under agitation in a Marie-bath. Aliquots of the reaction medium were taken every 10 min until the end of experience (160 min) for reducing sugars determination according to the method of Bernfeld (1955). The experience was repeated 3 times for each samples. The digestibility expressed in percentage was determined as the ratio of reducing sugars released to amount of starch at the beginning of the experience.

Statistical analysis: Experimental results were subjected to analysis of variance (ANOVA) and differences between means were assessed by Duncan's new multiple range test at the significance of 0.05 using StatSoft software (Statistica, 99ème Edition, France).

RESULTS AND DISCUSSION

The granulometric profile of both rough flours is shown on Fig. 1. These flours contained particles which sizes varied between 2 and 0.1 mm with significant differences ($p<0.05$) in the percentages of particles of both flours. But the maximum of particles for both flours was retained at sieves which aperture sizes were superior or equal to 0.5 mm. Indeed, for the mortar flour, 93.90% of particles had a size superior or equal to 0.5 mm against 73.45% for the mill flour. These results indicated that the

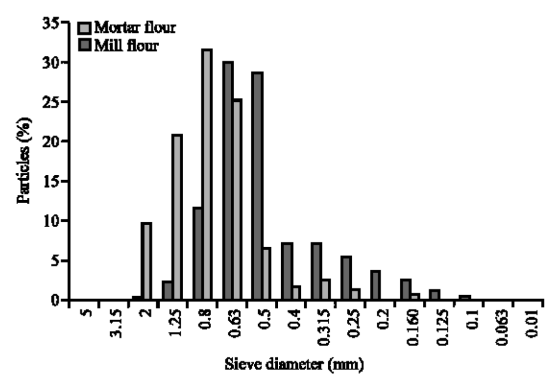

Fig. 1: Granulometric profiles of both rough flours obtained from 2 milling techniques used

Table 1: Chemical composition of millet flours obtained by milling grains with wooden mortar and electrique grinder

	Dry matter (%)*	Ash (%)*	Reducing sugars (%)*	Total sugars (%)*	Total carbohydrates (%)*	Starch (%)*
Mt F	92.13 ± 1.24^{a}	2.56 ± 0.47^{a}	4.45 ± 0.1^{a}	7.85 ± 0.07^{a}	77.39 ± 0.37^{a}	69.34 ± 0.34^{a}
Ml F	89.33 ± 1.24^{b}	1.00 ± 0.00^{b}	3.42 ± 0.01^{b}	6.04 ± 0.06^{b}	84.05 ± 0.56^{b}	75.32 ± 0.53^{b}

Table 2: Effect particles size on the nutritional profile of both sieved rough flours (mortar and mill flour)

	Dry matter (%)*	Ash (%)*	Reducing sugars (%)*	Total sugars (%)*	Total carbohydrates (%)*	Starch (%)*
Mt F	92.13 ± 1.24^{a}	2.56 ± 0.47^{a}	4.45 ± 0.10^{a}	7.85 ± 0.07^{a}	77.39 ± 0.37^{a}	69.34 ± 0.34^{a}
Ml F	89.33 ± 1.24^{e}	1.00 ± 0.00^{e}	3.42 ± 0.01^{e}	6.04 ± 0.06^{e}	84.05 ± 0.56^{e}	75.32 ± 0.53^{e}
Mt $F_{0.630\ mm}$	93.30 ± 0.50^{b}	1.00 ± 0.00^{b}	3.69 ± 0.05^{b}	12.49 ± 1.47^{b}	76.19 ± 0.01^{b}	68.30 ± 0.06^{b}
Ml $F_{0.630\ mm}$	93.10 ± 1.50^{f}	1.00 ± 0.00^{e}	4.48 ± 0.05^{f}	8.46 ± 0.01^{f}	79.71 ± 3.64^{f}	71.41 ± 2.03^{f}
Mt $F_{0.315\ mm}$	95.00 ± 0.0^{c}	2.90 ± 0.50^{c}	3.98 ± 0.32^{c}	11.89 ± 0.01^{c}	75.20 ± 0.16^{c}	79.95 ± 0.14^{c}
Ml $F_{0.315\ mm}$	92.8 ± 3.00^{g}	2.90 ± 0.40^{f}	3.50 ± 2.10^{g}	12.55 ± 0.02^{g}	82.00 ± 1.63^{g}	73.47 ± 1.44^{g}
Mt $F_{0.160\ mm}$	92.5 ± 0.50^{a}	1.00 ± 0.00^{b}	4.51 ± 4.07^{d}	12.89 ± 0.01^{d}	78.66 ± 0.05^{d}	70.45 ± 0.25^{d}
Ml $F_{0.160\ mm}$	91.3 ± 1.50^{e}	1.00 ± 0.00^{e}	5.04 ± 0.08^{h}	13.22 ± 1.2^{h}	84.16 ± 0.44^{h}	75.42 ± 1.38^{h}

*Percentage of dry matter; Values are means of 3 determinations; In a column means values followed by different superscript are statistically different ($p\leq0.05$); Mt F = Mortar Flour; Ml F = Mill Flour

mortar flour had a roughest texture than the mill one's and evidenced the impact of both milling techniques on flour texture. Indeed, during the milling with the mill, contact forces applied on millet grains created a three-dimensional field of constraints set out no uniformly in the material. These constraints involved deformations related on the size and/or the mass of initial grains. Thus, these deformations were at the origin of millet grain cracking into smaller and finer fragments comparatively to the pestle shocks grains, which would cause less grain bursting (Melcion, 2000).

Proximate composition of millet flours are displayed in Table 1. As observed for each parameter analysed, we could noticed that the milling caused important changes in the composition of flours. Indeed, the percentage of dry matter (92.13%), ash (2.56%), total sugars (7.85%) and reducing sugars (4.45%) in the wooden mortar flour were significantly higher than those of the hammer grinder one (89.33% of dry matter, 1% of ash, 6.04% of total sugars and 3.42% of reducing sugars).

On the other hand, the mortar flour contained least total carbohydrates (77.39%) and starch (69.34%) against 84.05 and 75.32%, respectively in the electric grinder flour.

The differences in flours chemical composition could be explained by the fact that milling grains in the mortar takes a long time, thus, favours an important loss of water due to contacts between the pestle and grains and an important production of heat contrarily to the machine grinding which is faster and undergoes a short time of heating and a least significant effect of wringing. Carré (2000) showed that grinding is a technological treatment which, in addition of modifying particles size by mechanical constraints, also modified their constitution due to effect of the heat.

In addition, the results showed that the grinding conducted by a mortar also favoured an improvement of sugar (reducing and total sugars) contents compared to grinding with an hammer grinder. This improvement could be explained by the fact that grinding with the mill eliminates a stronger proportion of farinaceous albumen (rich in starch-based reserves and vitamins), of germ and films contrary to crushing with the mortar (N'Djouenkeu *et al*., 1989). In the same way, UNIFEM (1988) noticed that the elimination of certain parts of grains involved a change in the concentration of some nutrients by increasing for example their proportion in the end product.

The variability of particle size of the flours had significant effects on their chemical composition (Table 2). The results showed significant variations in both flours chemical composition for each fraction retained at the various sieves (0.630, 0.315 and 0.160 mm).

In general, the dry matter of flours is higher in large particles of 0.315 and 0.630 mm of diameter. The values ranged from 93.3 and 93.1% for mortar and electric grinder flour's 0.630 mm of diameter particles, respectively against 95 and 92.8% for particles of 0.315 mm of diameter for both flours. For particles of 0.160 mm of diameter, the dry matter content was similar to that of both rough flours and these values were 92.5 and 91.3%, respectively.

Ash content was similar in both mortar and grinder flours and that for each particle size studied. But the highest value (2.9%) was get with particles of 0.315 mm of diameter. The flours of 0.160 and 0.630 mm diameter particle size contained only 1%. That implies that the 0.315 mm particle size flour contained more minerals than the others.

The concentrations of soluble sugars (total and reducing sugars), total carbohydrates and starch also varied significantly according to the size of particles. The results showed that contrarily to the dry matter content, the contents of these nutriments were lower in the flours with large particles (0.315 and 0.630 mm) than those of the flours with small particles (0.160 mm). For example, the

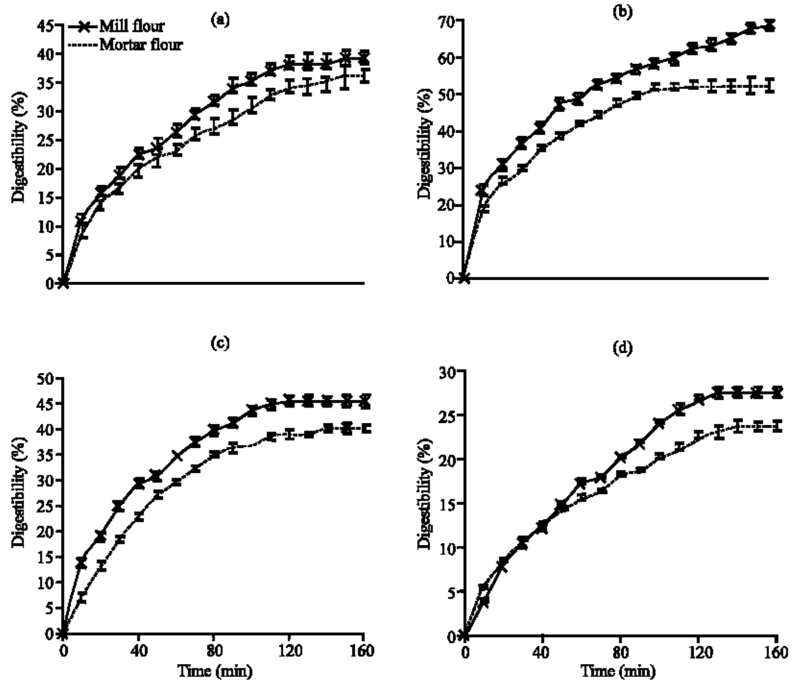

Fig. 2: Digestibility of flours in function of time, a: Rough flours; b: 160 μm particle size flours; c: 315 μm particle size flours; d: 630 μm particle size flours

0.630 mm particles size mortar and grinder flours contained 3.69 and 4.48% of reducing sugars, respectively, against 3.98 and 3.50% in both flours with 0.315 mm particles size and 4.51 and 5.04% for small particles of 0.160 mm.

The different variations observed in the concentrations of the nutrients could be in relation with the crack effect of millet grains during the process of crushing. Indeed, the small particles of 0.160 mm of diameter could come from simple cracks of grains. These cracks would have a density close to the grain, so a dry matter content similar to that of whole grain. Considering the 0.630 and 0.315 mm particles, they would result from the combined effect of cracks and condensation. This condensation would generate a significant water loss by wringing. That would explain why the dry matter contents of the flours with particles of 0.630 and 0.315 mm were higher than those of 0.160 mm. The water which leaves the coarse particles under the effect of pressure (lost water) also involved the lost of sugars, total carbohydrate and starch. This could explain why the concentration of these nutrients in the flours with large particles was lower than those of the flours with particles of small sizes. In addition, the majority of ash content could closely be associated with structures of fiber. They would not be pulled by water loss under pressure, leading an ash content equivalent between flours with particles of 0.630 and 0.160 mm of diameter.

The Fig. 2 shows the influence of the mode of milling (milling with mortar and milling with machine) and the flours particle size on the *in vitro* digestion of millet flour starch by the crude extract of snail gastric juice.

According to the kind of milling, starch digestion progressively increased with time for both flours (mortar and machine). There was significant difference in the kinetics of digestibility of both rough flours. The grinder flour had a higher starch digestibility than mortar flour. In addition, particle sizes also influenced the flours digestion, since it had the smallest particles size among the flours (Fig. 2a and c). Particles size of 0.160 mm of diameter presented a better digestion. Indeed, starch hydrolysis tended to be more rapid and more complete than bigger particles (>0.160 mm) (Fig. 2b). Values of the rate of digestion ranged between 50 and 70%, respectively for mortar flours and mill flours.

Values of digestion rate of flours with 0.630 mm particles size ranged between 24 and 27.5%, respectively for mortar flours and mill flours (Fig. 2d). The lower digestibility of flours with particles of 0.315 mm and 0.630 mm was essentially due to the size of flour particles. Previous studies confirmed that using whole grain and coarse-grains pieces in food products reduced the starch digestibility contrarily to the use of processed grains e.g., refined/fine flours (Carré, 2004). Van der Merwe *et al.* (2001) suggested that in porridge, enzyme accessibility to starch was done by contact surface between enzymes and substrate (starch). During the digestion of porridge matrix, enzymes contact the outer surface of particles and as these particles were released, the contact surface of enzymes with the substrate would increase.

The greater accessibility of starch could be explained by the disruption of the structure of the starch contained in grains and cellular walls during the process of grinding. In the case of grinding with electric grinder, this disruption was much accentuated, so that the flour obtained was finer and thus, easily accessible to the enzymatic action. Garcia-Alonso *et al*. (1996) and Tovar *et al*. (1992) reported that the process of grinding, by disturbing tissues and cellular walls of grains, increased the rate of digestion of cereal starch.

Starch granule size may affect its physicochemical properties, such as gelatinisation and pasting, enzyme susceptibility, cristallinity and solubility (Lindeboom *et al*., 2004). In addition, the results obtained revealed that the differences in particle size between the flours contributed to the difference in digestibility. Indeed, the digestibility is marked when the particle size decreases (0.630-0.160 mm). This finding agrees with Savant (2000), who observed that a finer grinding improved this digestibility.

However, it is wise to mean that flours with large particles (0.630 mm), thus, with low digestibility had special nutritional significance because of its physiological advantages in terms of planning of the diet of people suffering from diseases (obesity, diabetes, cardiovascular diseases, cancers) sensible to any glycaemic index variations (Him *et al*., 2006).

CONCLUSION

The 2 milling techniques (milling mortar and milling with machine) offered flours of different chemical composition. However, milling with the machine could be more advantageous because it offers a more digestible fine flour. In addition, a sifting of the rough flours obtained after millet grains grinding was necessary insofar as this operation permitted to separate the biggest particles in which nutriment contents were optimized. Among all flours analyzed, those with 0.315 mm particles size were in term of chemical composition the most improved. However, further studies of some physical properties such as viscosity and glycaemic index of food resulting from these starchy flours and ways of nutriments enrichment may be undertaken in order to define the characteristic of the best flour.

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