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Malting Germination Effect on Rheological Properties and Cooking Time of Millet (*P. typhoïdes*) and Sorghum (*S. bicolor*) Flours and Rolled Flour Products (Arraw)

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Abstract: The aim of this study was to reduce the cooking time of rolled flour products Arraw using incorporated germinated millet and sorghum flours separately. Rolled flour products Arraw were made by adding 5 and 10% shelled germinated flour. Physico-chemical analysis showed 40.78 and 42.87% starch degradation, 10.23 and 11.48% increase of total sugar and 7.39 and 8.95% for the reducing sugar after 3 and 4 days of millet flour germination respectively. For the sorghum, 14.19 and 24.73% starch degradation after 3 and 4 days of germination respectively were observed. Correlation was found between germination time, shear stress and porridge viscosity. Moreover, reduced cooking time was observed according to the diameters ($p<0.05$) of Arraw and the percentage of germinated flour. However, Arraw produced by adding 5 or 10% of 4 days germinated millet flour significantly reduced the cooking time, while the viscosity was under the limit of consumer's acceptability.

Key words: Millet, sorghum, germination, shear stress, viscosity, cooking time

INTRODUCTION

Sorghum (*S. bicolor*), is essentially composed of endosperm (85% of the whole grain) with composition cells affected the nutritional quality of the whole grain, germ (9.55%) and pericarp (6.5%). The cells' endosperm are rich in starch (more than 80%), relatively low in proteins and lipids around 10% and lower than 1%, respectively (Helland *et al*., 2002; O'Kennedya *et al*., 2006; Serna-Saldivar and Rooney, 1995). As in barley, the sorghum's endosperm structure is broken down during malting by enzymes. Similar data have been reported for millets, although there are fewer studies (Edney and Mather, 2004; O'Kennedya *et al*., 2006).

Around 1/3 of the world millet cultivated acreage is in Africa 70% of which is in West Africa alone. In 2001, 1.1 millions hectares was estimated for millet cultivated lands with 0.58 t ha^{-1} yield equivalent to 0.63 millions tons (Gret, 2002).

Millet belongs to the family of Gramineae while sorghum called big millet is belonged to the family of Poaceae (FAO, 1995). The difference in composition is especially based on phenolic compounds (flavonoids), vitamins, minerals and fibers. In fact various fibers such as cellulose, hemicelluloses and soluble dietary fibers composed both millet and sorghum. But for millet the pericarp's resistance is higher than of sorghum (Hulse *et al*., 1980; Bhattacharya and Zee, 1999). Millet provides more calorie than sorghum (FAO, 1995).

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Millet (*P. typhoïdes*) contains pigments responsible for its color. These pigments are essentially glucosylflavonoids composed by glucose linked with C-C bond to the aromatic ring (C-glycosylflavones). Glucosylvitexin is the major goitrogenic glucosylflavonoid presented in millet followed glycosylorientin and vitexin (Gaitan *et al*., 1995; Hulse *et al*., 1980).

High tannin content appears to improve weatherability, mold tolerance of sorghum and may have neutraceutical benefits due to their powerful antioxidant activity. Furthermore, sorghum's tannins possess melanogenic activity and directly inhibit formation of melanoma colony cells (Earp *et al*., 2004).

Millet and sorghum flours are essentially composed by starch. In fact, starch granule has a very complex structure, built around change in the composition and structure of the components (Tester *et al*., 2004). Cooking starch texture is influenced by the amylose content. Stickiness is related to the amount of amylose leached from the gelatinized starch granules and the protein content (Del Nobile *et al*., 2005).

Starch is swelled and gelatinized when heated in water. Gelatinization describes several changes including losing crystallinity, absorbing water and leaching of some components (e.g., amylose) in the starch granule. Consequently, substantial rheological changes of starch dispersions occur during heating. Therefore, the swelling power in sorghum flour is higher than in millet flour at 90°C, this has been confirmed by the Water Bonding Capacity (WBC) (Cheftel and Dsenuelle, 1977; Li *et al*., 2008). Therefore, the swelling power in sorghum flour is higher than in millet flour at 90°C, this has been confirmed by the Water Bonding Capacity (WBC) (Cheftel *et al*., 1977). Starch from cereals is composed of amylose (22-26%) and amylopectin (74-78%).

In fact, rolled flour millet products or (Arraw in Senegalese local name) is a highly prized traditional product by the people of Senegal, Gambia and Mali and in many other countries of Africa (with using different names for Arraw). Furthermore, this product is gaining importance in some US markets and also some parts of Europe especially France, Italy, Spain etc. because of a large community of these countries' immigrants.

However, due to the long cooking time around 37 min according to The National committee of millet/sorghum concerted initiative project in Senegal, the consumption is dropped in the western countries. Furthermore, to increase the competitiveness in the western and US markets and to add some values to the rolled flour millet products (Arraw), the reduction of cooking time is crucial.

The objective of this research was to reduce the cooking time of the Senegalese rolled flour millet product Arraw.

In this study, millet (*Pennisetum typhoïdes*) and sorghum (*Sorghum bicolor*) were chosen because of their similarity in structure and composition. On the other hand, many works have been done on Sorghum concerning germination (Bhattacharya and Zee, 1999; FAO, 1995; Gret, 2002). Moreover, for the production of high cereal products quality, integrated conditions of the raw materials and their transformed procedure deserved to be considered (Albert *et al*., 2001). In addition, the reduction cooking time of Arraw necessitate a perfect control of previous parameters of the flours, the physical characteristics and the nutritive values. From this assumption, it is probable that starch which is the main element of the flour should, have a great impact on our target.

In this study, after germination process of the millet and sorghum grains, the rheological properties were investigated. After the preparation of the rolled flour (in millet and in sorghum) products Arraw by incorporated 5 and 10% of the malting flours to the normal ones cooking times were assessed using traditional cooking method to reflect the reality of the consumers during processing at home.

MATERIALS AND METHODS

Grains

Treated millet and sorghum grains were supplied by a local cereal company Vivriere in Dakar (Senegal) closely working with ITA.

Preparation of the Different Samples Including Flours and Rolled Flour Products

Malted (germinated) sorghum and millet grains separately were proceeded according to Fig. 1. Millet and sorghum (decorticated and undecorticated) without germination were used as control for the rheological tests. For the germinated grains of sorghum and millet (Fig. 2) none shelled were used for the shear stress and viscosity tests to study the effect of the malting germination on the whole grain. The flour used to make rolled flour products (Arraw) has been shelled in the millet as well in the sorghum and the bran removed to reflect the same condition as the consumers used. Arraw control for

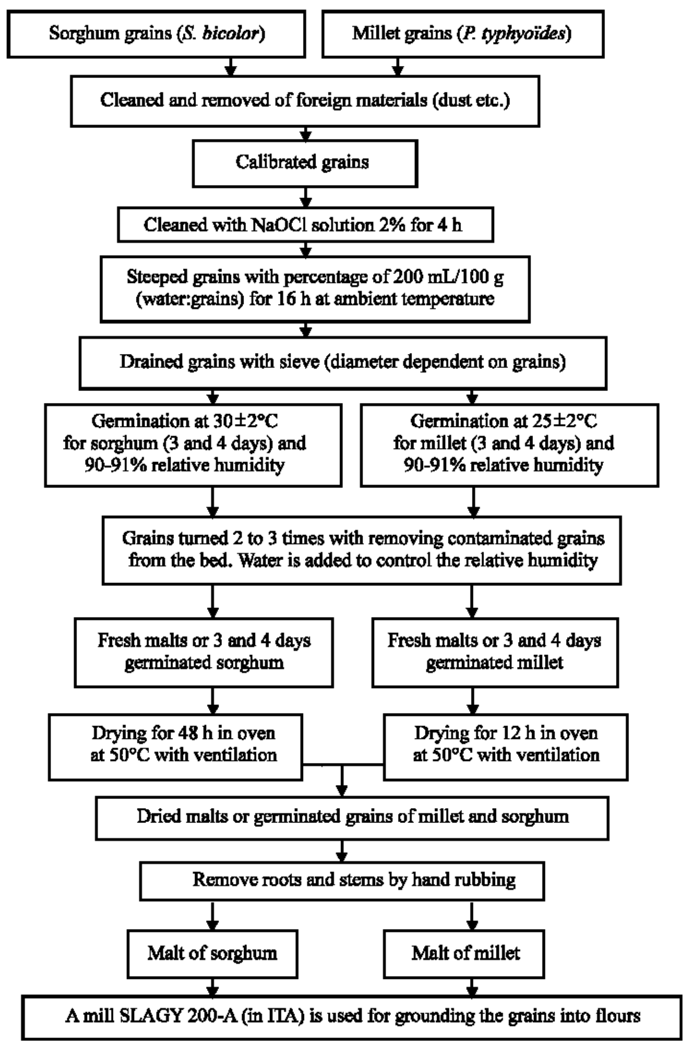

Fig. 1: Flow chart of sorghum and millet malt flours production

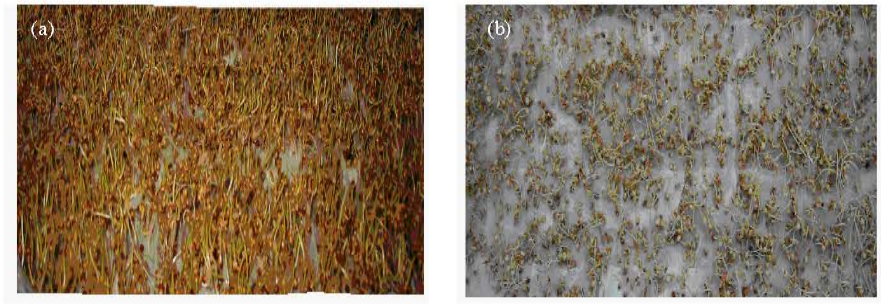

Fig. 2: (a) Millet (*P. typhoïdes*) and (b) Sorghum (*S. bicolor*) grains in germination

Table 1: Characteristics of the rheometer used during the tests

System	X factor	Y factor for spring I	K constant for spring I	Volume (mL)	Height (mm)
D15	1.4	0.0283	20.2	95	42

millet and sorghum flours have been done. On the other hand, after 5 and 10% incorporation of germinated flours into the raw ones, the Arraw were oven dried for 2 h at 50°C (with ventilation) before separated calibration for various diameters. In addition, the cooking time tests have been realized in the institute's (ITA) kitchen in Dakar using traditional cooking method with a same utensil and gas flame for all the tests. A group of 3 women specialized on testing rolled flour products cooked in water were allocated for testing whether the cooking was effective.

Physico-Chemical Analysis

Water content, starch content, reducing sugar and total sugar contents were determined according to the standards AOAC methods (AOAC, 1995).

Rheological Measurement

Rheological measurement was assessed in a manually controlled shear rate cylinder rheometer (Viscotron Brabender, Brussels, Belgium). Samples were prepared using 5 g of each kind of flour (sorghum and millet, ungerminated and germinated) with 100 mL of deionized water. The slurry was heated in a thermostatically controlled water bath at 95°C. It was allowed to be heated for 15 min. After cooling, the temperature control system of the rheometer is fixed at 45°C to proceed directly to rheometer measurement in the cylinder container. Prior to measurement, 95 mL of gelatinized flour was connected to the temperature control system until study. Within 2 min the average of the maximum and minimum reading values (digital number) was recorded according to the speed. Then using, the characteristics of the rheometer the shear rate, the shear stress and the viscosity were computed respectively according to the following basic formula and the related characteristics in Table 1.

$$D = n.X \ (s^{-1})$$

where, n is speed used (rpm) and X the rate factor

$$\zeta = BSY \ (Pa)$$

where, B is scale used, S the digital reading value and Y stress factor

$$\eta = \frac{BSK}{n} (mPa.s)$$

where, B, S, n represent the same factors described above and K the calibration constant

Cooking Time

Interval of 5 min was chosen to give 3 evaluators to test whether the rolled flour products is cooked or not. The deionized cooking water was fixed at 1 L after some preliminary tests.

Statistical Analysis

p-values were analyzed using a paired Student's t-test software program (Startview 5.1; Abacus Concepts, Berkeley, CA). Results were considered statistically significant at $p<0.05$.

RESULTS AND DISCUSSION

Physico-Chemical Analysis

Some physico-chemical parameters are shown in Table 2 for sorghum and millet flours germinated and ungerminated. During germination process, reserves (starch, proteins, lipid etc.) were used for the stems and roots to appear on external porosity by nutrients released and the internal porosity on starch access by amylase enzymes (Dicko, 2005).

With approximately, the same water content, starch and sugar content showed a difference in the degree of germination and the kind of grains. Decreases of 40.78 and 42.87% in starch content were observed for the millet flours on 3 and 4 days germination respectively compared to the control. On the other hand an increase of 10.23 and 11.48% in total sugar, 7.39 and 8.95% for the reducing sugar was observed after 3 and 4 days germinated millet flour respectively. For sorghum flours 3 and 4 days germination, a decrease of 14.19 and 24.73% of starch was observed while an increase of 0.86 and 2.95% of reducing sugar has been evaluated. Furthermore, an increase of 2.2 and 3.3% of total sugar was noted for 3 and 4 days germinated sorghum flour. The starch degradation is linked to the α-amylase and β-amylase during germination. Similar behavior was observed by Dicko (2005) and Helland *et al*. (2002) on germinated sorghum α-amylase used in brewing, preparation of low-viscosity weaning food and on maize porridge for producing porridge with low viscosity and high calorie density respectively. However β-amylase from sorghum varieties has shown low activity or total absence making the saccharification of the starch incomplete (Dicko, 2005). The further decrease in starch in

Table 2: Physico-chemical analysis of germinated and ungerminated, millet flours and sorghum flours from whole grains[A]

Parameters	Water content	Starch[B]	Reducing sugar[B]	Total sugar[B]
	(%)			
Millet flour				
Non shelled millet flour	(8.13-8.88)	(66.84-68.53)	(0.99-1.62)	(3.37-3.98)
	8.72±0.31	67.35±0.53	1.33±0.22	3.41±0.43
Germination for 3 days	(8.45-8.94)	(26.14-27.10)	(7.66-9.92)	(13.3-14.01)
and non shelled millet flour	8.74±0.18	26.57±0.30	8.72±0.80	13.64±0.25
Germination for 4 days	(8.1-8.64)	(23.46-25.96)	(9.24-11.48)	(14.5-15.04)
and non shelled millet flour	8.47±0.20	24.48±0.91	10.28±0.76	14.89±0.24
Sorghum flour				
Non shelled sorghum flour	(8.96-9.25)	(52.74-58.63)	(2.36-2.89)	(0.83-1.11)
	9.09±0.1	54.45±1.25	2.56±0.19	0.96±0.12
Germination for 3 days	(8.73-9.12)	(38.71-4233)	(3.22-3.62)	(2.50-4.22)
and non shelled sorghum flour	8.87±0.15	40.26±1.31	3.42±0.18	3.20±0.84
Germination for 4 days	(8.1-8.59)	(28.31-31.13)	(5.04-5.97)	(3.91-4.46)
and non shelled sorghum flour	8.35±0.17	29.72±0.92	5.51±0.32	4.26±0.21

[A]Results expressed as mean±SD of three determinations, [B]Based on dry matter

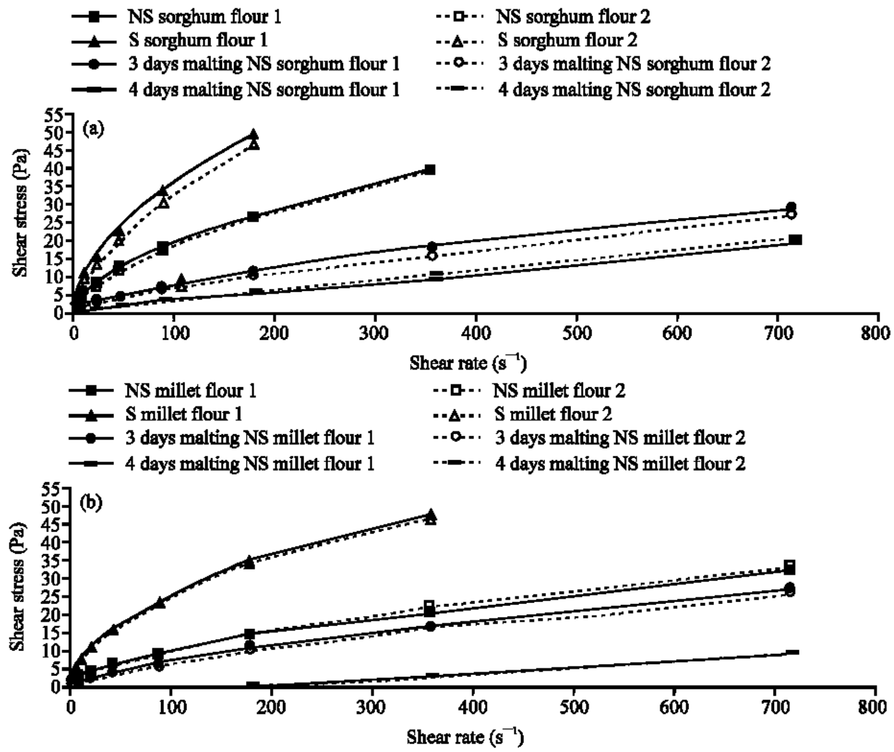

Fig. 3: Shear stress (a) sorghum flours at different shear rates and (b) millet flours at different shear rates

the 4 days germination of millet and sorghum germination compared to 3 days is due to the malting conditions including time. The starch degradation has been noted by many researchers including Ya *et al*. (2001) and Dicko (2005).

The increase of reducing sugars and total sugars is essentially due to the germination time and the nature of the grains (millet and sorghum). Many researchers have reported the sugars increase after germination (Larreta, 1997; Manohara *et al*., 1999; Ya *et al*., 2001). Dicko (2005) found that the involved sugars are mainly glucose and fructose. Manohara *et al*. (1999) revealed that total sugars are essentially dextrins and maltoses released during the germination process. The high increase in sugars observed in millet compared to sorghum is due to the sensitivity sensibility of millet during germination and its α-amylase and β-amylase efficiency.

Rheological Analysis

Figure 3a and b show the shear stress at different shear rate for sorghum and millet flours with germinated and ungerminated at constant temperature 45°C. The shear rates were computed according the reading digital values using different speeds. The speeds were used in two senses (increasing = 1 and decreasing = 2) in duplicate.

Figure 3a, b and 4a, b, shows little bit difference between two curves with 1 and 2. This was to make sure for the replication.

For the shelled (S) ungerminated sorghum flour, the shear rates of 150 and 200 s^{-1} corresponded to shear stress of 45 and 50 Pa compared to 350 and 400 s^{-1} shear rates of the shelled (N) ungerminated millet for the same shear stress. Similar changes were observed in their respective viscosity 3636.0 mPa s and 4068.8 (Fig. 4a, b).

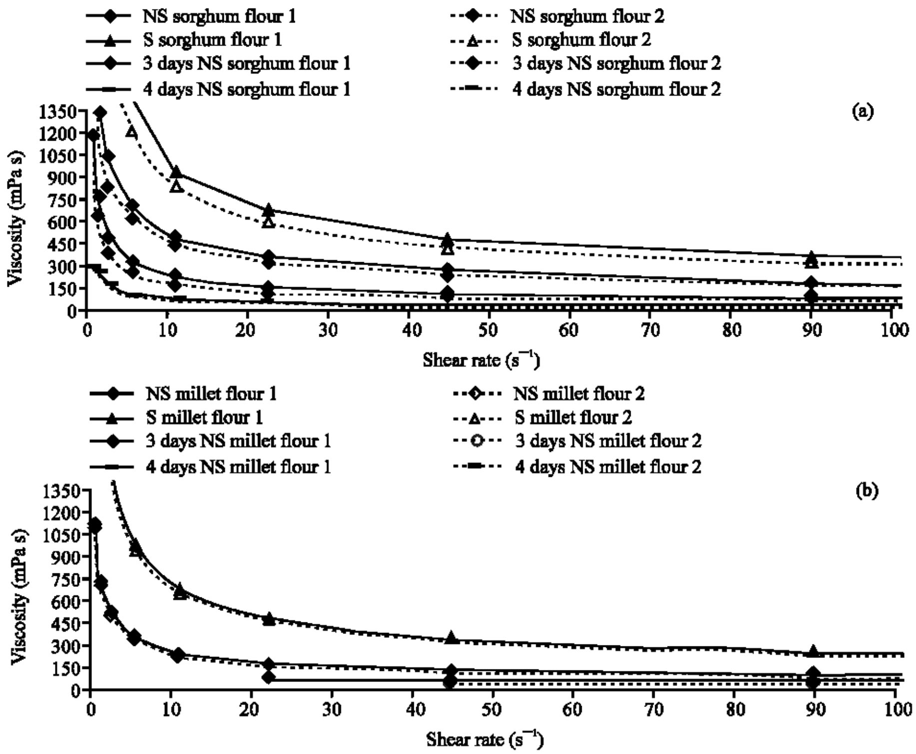

Fig. 4: Apparent viscosity (a) sorghum flours at different shear rates and (b) millet flours at different shear rates

The S ungerminated millet and sorghum flours have shear stress and viscosity higher than those of non shelled (NS) ones. Also, the S flours contained more starch than the NS ones. The starch difference would increase the reticulation when the porridge temperatures became small. The difference between NS ungerminated sorghum flour and that of millet could be explained by the amylopectin content. Sorghum flour contains less amylopectin than millet flour (FAO, 1995). Gelatinized amylopectin usually forms strong networks for extern forces; hence the shear stress and viscosity of millet flour were higher than the sorghum's ones.

It can conclude the interdependence between the shear stress and viscosity against shear rate.

For a shear rate between 700 and 800 s^{-1}, 3 days malting NS sorghum flour showed a shear stress between 25 and 30 Pa while <25 Pa were observed for millet flour. On viscosity test, 798 and 15 mPa s were observed respectively for 3 days NS sorghum flour and 3 days NS millet flour at same shear rate (1.4 s^{-1}). The same trend for the sorghum and millet 4 days germination showed viscosities of 26 and 9 mPas respectively at speed of 716 s^{-1}. As we saw, millet grain is more sensitive compared to sorghum by the amylases produced during the germination. The justification can be provided from the very low and constant viscosity of 4 days NS millet flour compared to 4 days NS sorghum flour. This came to confirm the physico-chemical analysis from the Table 2. The smallness of millet grain conferred less days germination compared to sorghum. Dillon (1989) suggested 2 days germination to attain the maximum enzyme activity of the grain. More so, germination over 2 days reduced significantly the viscosity (Helland *et al*., 2002). The sorghum and millet germinated flour presented a certain shear thinning in a certain range before becoming constant whatever the shear rate used.

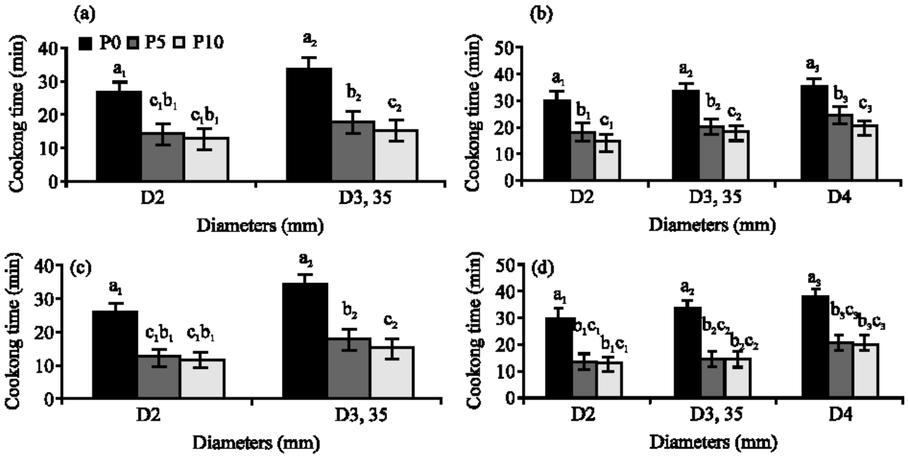

Fig. 5: Effect of diameter and germination on cooking time. (a, b) 3 days millet and sorghum rolled flour (Arraw) respectively (c, d) 4 days millet and sorghum rolled flour respectively. Means in the same or different diameter with same letter are not significantly different (α = 0.05). P0, P5 and P10 represent respectively 0, 5 and 10% incorporation

Reduction of Cooking Time

The average of ten cooking times were plotted according to their diameters using 0, 5 and 10% malting flours (millet and sorghum separately) incorporation (Fig. 5a-d).

From Fig. 5a, cooking time was 25 min for P0 compared to 14 and 12 min respectively for P5 and P10 2 mm diameter (D2). Also, cooking time between 30 and 33 min was recorded for P0 while 17 and 15 min were registered for P5 and P10, respectively. No significant difference was observed between P5 and P10 for D2. However, at 3.35 mm diameter (D3.35), the cooking times showed significant difference. Between D2 and D3.35 the differences are significant. The results showed that the germinated flour incorporation and the diameters of the rolled flour products Arraw influenced greatly the cooking time. Similar results were observed for the 4 days germinated millet flour incorporation (Fig. 5c).

From Fig. 5c, the cooking times for P5 and P10 dropped again respectively on 13 and 9 min for D2, while D3.35 showed 15 and 13 min for P5 and P10, respectively. Furthermore, the same conclusion according to the differences was observed. The physico-chemical analysis and the rheological tests indicated a net appreciation of starch degradation during 3 and 4 days germination. The starch degradation entailed amylose and amylopectin reduction. Furthermore, reduction cooking time could be linked to the fall of gelatinization peak (Chandrasekar and Kirleis, 1998). With these two aspects we can find an explication for the reduction time of P5 and P10 compared to P0. Between P5 and P10 for the 3 days germinated flour incorporated at D2 the gelatinization peaks are too close to make seen that there was no significant difference. When the diameter was 3.35 mm the difference became significant because of the gelatinization peak difference. The high decrease of the cooking time in the 4 days millet flour incorporation could be explained by the fact that longer germination time reduces starch more. Therefore, amylose and amylopectin content decreases hence the gelatinization becomes easy with close peaks for P5 and P10 in D2 case which showed no significant difference between the average cooking times. Li *et al*. (2008) presumed the presence of amylose in the starch granules acted to retard the granular swelling of the normal rice varieties as compared to the waxy varieties. Therefore the decrease of amylose after germination might act as a factor decreasing gelatinization peaks.

Figure 3b shows 3 diameters versus cooking time for P0, P5 and P10. For D2, the cooking times were 16 and 14 min, respectively for P5 and P10 while P0 showed 30 min in the case of 3 days sorghum flour incorporation. From 3.35 mm diameter the cooking times were 33, 19 and 17 min, respectively for P0, P5 and P10. Moreover, P0 (37 min), P5 (27 min) and P10 (23 min) were recorded when the rolled sorghum flour diameter was 4 mm diameter.

In the case of 4 days sorghum flour incorporated (Fig. 5d), 12, 11 and 30 min were recorded for P5, P10 and P0 respectively when D2 was used. In addition, D3.35 showed 33, 15 and 14 min for P0, P5 and P10, respectively. For D4, cooking times were 19, 18 and 37.5 min respectively for P5, P10 and P0. These results emphasized the importance of the diameters during the cooking times.

From the results shown above, the fall in the gelatinization peaks was induced by the degradation of the starch (Chandrasekar and Kirleis, 1998).

The rolled flour millet millet Arraw with 5 and 10% germinated incorporated flour presented cooking times shorter than those from sorghum flour at 2 and 3.35 mm diameters. In fact, the physico-chemical analysis showed high degradation of millet flour producing more sugars than sorghum flour. This difference was observed on the viscosity tests. More so, the stronger the shear stress, the higher the viscosity and the cooking time is important. The phenomenon could be explained by the fact that various gelatinization peaks arise from many spaces of the malting flour due to the germination.

From these different results, the 3 days incorporation of germinated millet flour at 5 or 10% is widely sufficient to reduce the cooking time at low level keeping a reasonable viscosity. Using 4 days gave porridge which becomes much liquefied and in other words would lose the quality for consumers' acceptability. Consequently 3 days germination using 10% incorporation reduces significantly the cooking time and keeps the viscosity in an acceptable level.

Future Prospect

The germination produces amylases. It might be very important to optimize the enzymes activities by modifying the temperature. This will help the exact temperature to keep longer the enzymes' activity. In fact, during this work, the traditional way to cook the rolled flour millet products Arraw has been changed to make the enzymes efficient for the short time they have to react and reduce the starch into short chains such as sugars and dextrins. Furthermore, the ratio amylose/amylopectin is another way to optimize the germination on the starch degradation and therefore on the gelatinization peaks. The HPLC identification of the different sugars produced during germination such as simple sugars, dextrins is another way to carry information from the gelatinization. The pH variation by adding sugar, salt is another issue to make this work more satisfied. In fact, during cooking some consumers added salt, sugar or both. In addition, because of the unavailability Ranghino's cooking test equipment; another cooking test should be done and compared to this traditional one.

CONCLUSION

Reducing the cooking time of rolled flour millet products Arraw has shown to be an important way for more consumers' convenience in such a way that it is possible to save cooking time. From 37 min without any treatment, the cooking time can be reduced to 9 min according to the diameters of the rolled millet flour products Arraw using 5 or 10% of malted millet flour. The results have shown a close similarity between sorghum and millet flour. Furthermore, to be able to see the germination influence, it was necessary to germinate the millet and sorghum for 3 and 4 days. Difference in viscosity and shear stress were detected porridge made with flours from 3 and 4 days germination.

It can be concluded that the millet with its small size compared to sorghum, necessitates only 2 or 3 days germination. However, the cooking time was smaller in rolled flour products Arraw with longer germination time (4 days) but the viscosity of such millet flour present liquefied porridge which affects its acceptability. This will influence the appreciation of the final rolled flour products Arraw.

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