Comparison of the expansion ability of fermented maize flour and cassava starch during baking

Christian Mestres,[1]* Oreste Boungou,[1] N Akissoë[2] and Nadine Zakhia[3]
[1]CIRAD-CA, Programme Cultures Alimentaires, TA 70/16, 73 avenue JF Breton, 34398 Montpellier Cedex 5, France
[2]Faculté des Sciences Agronomiques, Département de Nutrition et Sciences Alimentaires, Université Nationale du Bénin, BP 526, Cotonou, Bénin
[3]CIRAD-AMIS, TA 40/16, 73 avenue JF Breton, 34398 Montpellier Cedex 5, France

Abstract: The modifications occurring during the fermentation (at 20 or 35 °C) and drying (under the sun or in an oven at 40 °C) of maize flour (ogi) and cassava starch along with their expansion ability during baking were characterised and compared. A high temperature accelerated the fermentation but favoured lactic acid synthesis for maize ogi and butyric acid for cassava starch. The increase in acidity was higher for maize, but dried maize ogi did not evidence any expansion ability whatever the experimental conditions. Cassava starch that had been fermented at 20 °C then sun-dried presented the highest expansion ability. It was associated with low paste viscosities and high swelling and solubilisation values. When the fermentation was carried out at 35 °C, an annealing of cassava starch occurred that delayed starch gelatinisation and which could be involved in its lower baking expansion ability.

Keywords: maize flour; cassava starch; fermentation; drying; baking expansion; differential scanning calorimetry; viscosity; swelling; solubility

INTRODUCTION

Cassava and maize are widely consumed starchy crops in tropical countries. Their traditional processing often involves a natural lactic acid fermentation, responsible for the specific functional properties and/or required organoleptic characteristics of the end-product.

Sour cassava starch is traditionally produced in Brazil and Colombia through the natural lactic acid fermentation (20–30 days) of the wet extracted starch followed by sun-drying.[1,2] It is used for preparing typical expanded products (dried snacks or cheese brioche) with alveolar crumb structure. Expansion occurs during the baking of a sour cassava starch-based dough but is much less important with native non-fermented cassava starch.[3] Brioche and snack expansion results in two phenomena: the gas production (the driving force) linked to water vaporisation or CO_2 desorption that can be produced and sorbed during starch fermentation[4] and the presence of a surface-active material that can trap the gas bubbles. For sour cassava starch this function should be realised by the gelatinised starch itself as no surface-active material is added to the dough before baking. Thus the functional properties of sour cassava starch are of great importance to explain its baking expansion. Indeed, the unique expansion ability of sour cassava starch was shown to be linked to the decrease in hot starch paste viscosity[1–5] and the macromolecule degradation during processing.[5,6]

In Africa, particularly in the Guinean zone, ogi and mawé are obtained through the natural lactic acid fermentation of wet maize flours for 2–5 days and are used for preparing porridges and thick pastes.[7–10] The fermentation slightly modifies the pasting properties of maize flours.[11]

Although fermented cassava starch (in Latin America) and maize flours (in Africa) are widely known and consumed, their economical development is still limited owing to their regional specificity and small-scale processing. Improving the control, mainly of the fermentation and sun-drying steps, would allow standardisation and scaling-up of the production. In addition, transferring the sour cassava starch technology to Africa and applying it to other starchy crops such as maize would contribute to add value and diversify the use of indigenous African raw materials.

This paper aims at comparing the physicochemical and functional changes occurring during the natural fermentation and drying of cassava starch and maize flour. The traditional processing conditions encountered in Latin America (20 °C) and Africa (35 °C) were reproduced in the laboratory, and two drying proce-

* Correspondence to: Christian Mestres, UNB/FSA (CIRAD), BP 526, Cotonou, Benin
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dures, ie oven- and sun-drying, were tested. The end-products were compared for their chemical characteristics, pasting behaviour and baking expansion ability.

MATERIALS AND METHODS

Raw materials

Maize grains (Gbogboué cultivar) were obtained from the Center for Research for Food Crops in Benin. Cassava starch was extracted in a small-scale plant in Colombia by washing, peeling and rasping the roots; starch was drained off through sieving the mash under running water. After 24 h of decantation, the top liquor was discarded. The major part of the sediment was air-dried at ambient temperature, sheltered from the sun, to obtain native cassava starch. The rest was processed traditionally, ie allowed to ferment in excess water for 20 days, the top liquor discarded and the sediment sun-dried; the obtained sour cassava starch was used as reference.

Experimental conditions

Wet-milled maize flour (ogi) was prepared in the laboratory by precooking of maize grains and then soaking in water for 18 h at room temperature. After grinding, the maize mash was wet-sieved with a 315 μm mesh; the ogi was recovered after decantation of the filtrate.[11] Both ogi and native cassava starch were rehumidified in the laboratory, by immersion in excess spring water (Volvic, France; 100 g water per 27 g dry matter), then covered and allowed to ferment naturally at either 20 or 35 °C for 15 days. After fermentation, the sediments were either oven-dried (24 h at 40 °C) or sun-dried for 10–12 h. In the latter case the product was laid out to a thickness of 5 mm; the temperature of the product ranged between 30 and 50 °C and the received solar radiation energy during drying was 2.5–3.5 kJ cm^{-2}. Two replications were performed for each experimental condition. An analysis of variance was performed for each variable using Statitcf software (ITCF, Boigneville, France); the significance of the main effects (raw material, fermentation temperature and drying conditions) was tested and the standard deviation was calculated from the standard error of the residual.

Chemical analysis

Starch content was determined through enzymatic hydrolysis according to Mestres *et al.*[12] Protein and free lipid contents were determined respectively by the Kjeldahl method (N × 6.25) and Soxhlet extraction with ether.[13] The pH value and titratable acidity were measured on the fermentation supernatant according to Nago *et al.*[11] Organic acid and ethanol contents were determined by HPLC using an HPX87H column (Biorad, Hercules, USA) eluted at 60 °C with 5 mM sulphuric acid[6] with refractometric and UV 210 nm detectors.

Thermal analysis

Differential scanning calorimetry (DSC) was performed using a Perkin Elmer DSC7 device (Perkin Elmer, Norwalk, USA). The hermetic inox pans for sample (10 mg of sample and 50 μl of distilled water) and reference (60 μl water) were heated from 25 to 160 °C at a scanning rate of 10 °C min^{-1}, held at 160 °C for 2 min and then cooled to 50 °C at 10 °C min^{-1}.

Pasting behaviour

Hot paste viscosities were assessed using a Rapid Visco Analyzer (Newport Scientific, Narrabeen, Australia) on 7.1 percent dry matter suspensions in 0.2 M acetate or phosphate buffer (pH 4 or 7 respectively) by heating to 95 °C and then cooling to 50 °C according to Mestres and Rouau.[6] The measured parameters were the pasting temperature, the peak viscosity and temperature, the viscosity at the beginning of the plateau at 95 °C (V95b) and the final viscosity at 50 °C (V50).

Swelling and solubility determination

The dry matter (0.70 g) was dispersed in distilled water (total mass adjusted to 28 g) and cooked within the Rapid Visco Analyzer (RVA). The dispersion was heated from 35 to 75 °C at 6 °C min^{-1} and then held at 75 °C for 2.5 min with constant mixing at 160 rpm. The paste was immediately transferred to a 50 ml centrifuge tube. After centrifugation for 5 min at 5000 × g and 25 °C, the supernatant and sediment were collected and weighed. They were dried at 100 °C for 24 and 48 h respectively and then weighed (dry matter (DM)). Three parameters were calculated as previously described:[14] the concentration of solubilised material in the supernatant (SM), the swelling power (G) and the volume fraction of the dispersed phase (ϕ).

Baking expansion assessment

The expansion ability was evaluated using a protocol derived from the one used by Dufour *et al.*[3] for sour cassava starch in Colombia. The starchy material (24.1 g DM) and hydroxypropyl methyl cellulose (HPMC; Sigma #9004-65-3, 0.36 g) were mixed dry for 1 min and then spring water (Volvic, France) was added to give a total mass of 50 g; the dough was mixed in a Minorpin (Simon, England) for 6 min. Two balls of 20 g of the dough were then baked at 290 °C for 27.5 min. After cooling, the loaf volume was measured by rapeseed displacement. The specific volume (cm^3 g^{-1}) of the expanded products was calculated as the ratio of loaf volume to dry matter. The mean value of the two balls was calculated.

RESULTS AND DISCUSSION

Influence of the fermentation temperature on metabolite formation

During fermentation, the pH of maize ogi decreased

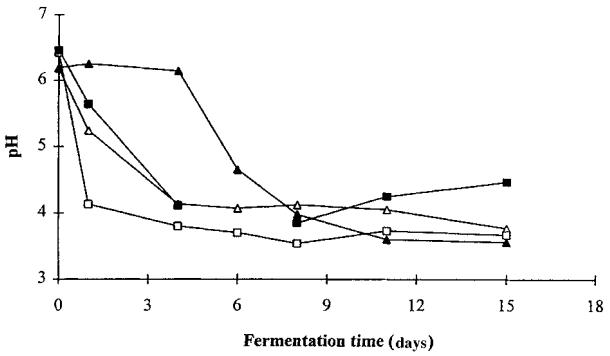

Figure 1. Evolution of pH in supernatant during fermentation of cassava starch (triangles) and maize ogi (squares) at 20 (free symbols) or 35 °C (open symbols) for 15 days.

more rapidly than for cassava starch (Fig 1). This decrease was more rapid when the fermentation took place at 35 °C; for cassava starch, 4 days were necessary to lower the pH value to 4 at 35 °C, and up to 8 days at 20 °C. In the traditional process in Colombia the pH of cassava starch reaches the same value (4) within only 3 days.[15] The higher velocity of the fermentation process in Colombia may be due to the presence of soluble metabolites, particularly free sugars, that are extracted from the roots but remain in the liquor submerging the cassava starch in the traditional process. In contrast, at laboratory scale the dried starch was rehumidified by spring water before fermentation.

The concentration of fermentation metabolites within the steeping liquor presented rather large standard deviations for both cassava and maize (Figs 2 and 3). Indeed, the fermentation was not induced as no starter was inoculated. The main metabolites recovered in the fermentation supernatants for cassava starch and ogi were lactic and butyric acids and ethanol. For cassava, lactic acid was the principal metabolite at 20 °C with a final concentration close to 1.5 mg ml^{-1}, whereas butyric acid was 10 times more abundant at 35 °C with a final concentration of 4 mg ml^{-1}. In the traditionally fermented products the total acidity was reported to be two to three times higher, and lactic acid was always the main fermentation metabolite, along with minor amounts of acetic acid and sometimes butyric acid.[1]

For maize ogi, lactic acid was the most abundant metabolite at either 20 or 35 °C, with a four-times

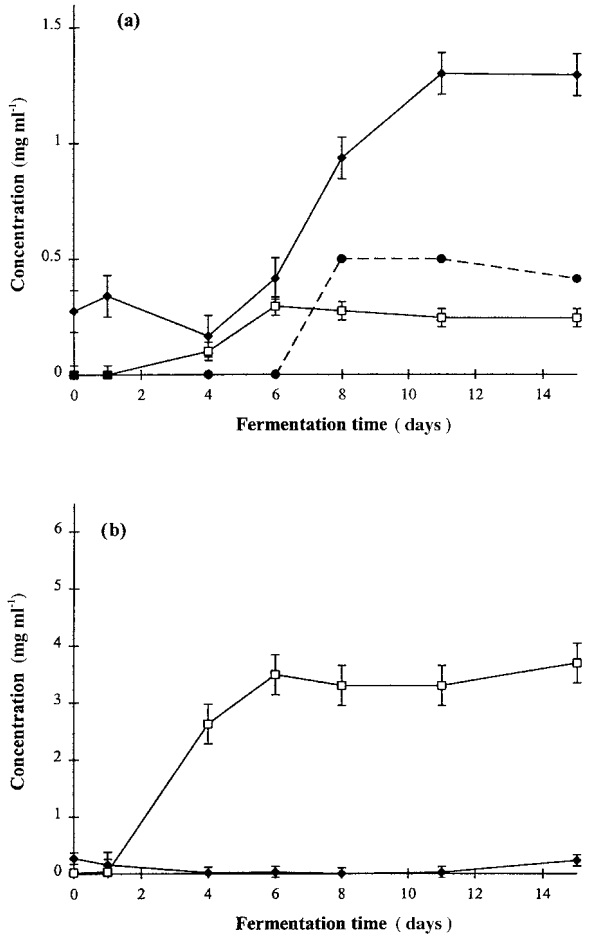

Figure 2. Evolution of metabolite concentration (◆, lactic acid; □, butyric acid; ●, ethanol) in supernatant during cassava starch fermentation at (a) 20 or (b) 35 °C for 15 days (standard deviation is represented by error bars).

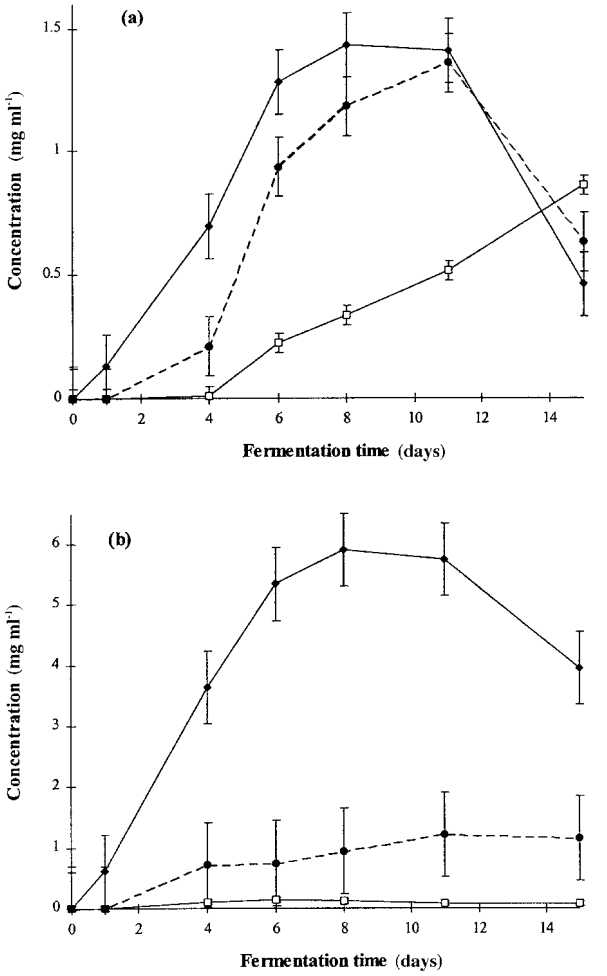

Figure 3. Evolution of metabolite concentration (◆, lactic acid; □, butyric acid; ●, ethanol) in supernatant during maize ogi fermentation at (a) 20 or (b) 35 °C for 15 days (standard deviation is represented by error bars).

higher concentration at 35 °C. The maximum lactic acid concentration was observed after about 8 days of fermentation at both temperatures, which confirmed the previous observations of Nago *et al.* [11] Ethanol was another abundant metabolite with similar concentrations at 20 and 35 °C. Butyric acid was only noticeable at 20 °C.

A higher temperature (35 °C) accelerated the fermentation for both starchy materials as evidenced by the decrease in pH and metabolite formation. However, it favoured lactic acid synthesis for maize ogi and butyric acid formation for cassava starch.

Proximate analysis and metabolite content of the dried end-products

The experimental conditions, ie fermentation temperature and drying procedure, did not significantly influence the proximate composition of the dried end-products. As previously described by Nago *et al*,[7] the maize ogi was mainly composed of starch (790 g kg^{-1} DM) but contained also an important fraction of proteins (82 g kg^{-1} DM) and some noticeable residual lipids (27 g kg^{-1} DM). In contrast, the extracted cassava starch was mainly composed of starch (910 g kg^{-1} DM) with minor protein (1.5 g kg^{-1} DM) and lipid (0.5 g kg^{-1} DM) contents. These proximate analysis results were very similar to previous data obtained for Colombian[6] and Brazilian[4] traditional cassava starches.

No ethanol and very little butyric acid were found in the dried end-products, for maize or cassava, either with oven- or sun-drying. As already observed within supernatants and despite a relatively high standard deviation of the residual (Table 1), the dried maize ogi had a significantly higher lactic acid content than the dried fermented cassava starch. In addition, a significant interaction was observed between fermentation temperature and raw material, ie a higher temperature increased the lactic acid content for maize and the butyric acid content for cassava. However, the butyric/lactic acid ratio was close to 1 in the dried cassava starch fermented at 35 °C whereas it was over 10 in the supernatant. This is certainly due to the evaporation of butyric acid during drying.

For our cassava samples prepared in the laboratory, the lactic acid content was significantly lower than for traditional sour cassava starch (close to 10 g kg^{-1} DM).[3,6]

Thermal properties

The gelatinisation of maize ogi occurred at a higher temperature and with a lower enthalpy than that of cassava starch (Table 2). Calculated on a starch basis, the maize gelatinisation enthalpy is about 15 Jg^{-1}, which is close to previous results.[16] However, for cassava starch the gelatinisation enthalpy (around 18–19 Jg^{-1}, starch basis) is slightly higher than already measured for traditional Colombian (15.5–17.4 Jg^{-1} DM)[6] and Brazilian (10.7–12.5 Jg^{-1} DM)[4] cassava starches. This may be linked to either the cultivar used or the environmental conditions of growth, which are known to influence the physicochemical characteristics of cassava starch.[17,18] For both materials the gelatinisation temperature was significantly higher when the fermentation was performed at 35 °C, whereas the enthalpy remained unchanged. This may be due to an annealing phenomenon occurring during the long-term fermentation at 35 °C as already observed for rice starch steeped in water at 40 °C for 5 days.[19] The presence of butyric acid in 35 °C fermented cassava starch could also influence starch thermal properties by delaying water absorption and the gelatinisation transition as observed for lipid molecules[20] and/or by complexing amylose as suggested by Phan and Mercier.[21] Complexes can be evidenced by DSC by the appearance of an exotherm during the cooling phase;[14] however, this was not observed for 35 °C fermented cassava starch. Furthermore, the replacement of water with a butyric acid solution (2% w/w) did not significantly modify the gelatinisation temperature of 20 °C fermented cassava starch nor induce exotherm appearance during the

Table 1. Concentration of lactic and butyric acids (g kg^{-1} DM) for fermented and dried cassava starch and maize ogi

Material	Fermentation temperature (°C)	Lactic acid		Butyric acid	
		Oven-dried	Sun-dried	Oven-dried	Sun-dried
Cassava starch	20	3.2	2.5	0.2	0.1
	35	1.2	0.9	1.6	1.4
Maize ogi	20	5.7	6.0	0	0.1
	35	10.3	10.2	0.1	0
Raw material effect (RM)[a]		122.7***		120.7***	
Fermentation temperature effect (FT)		5.6*		84.6***	
Drying procedure effect (DP)		0.1		0.9	
Interaction RM × FT effect		30.8***		85.1***	
Interaction RM × DP effect		0.3		1.0	
Standard error of residual (DF[b])		1.1 (8)		0.1 (8)	

* Significant at 5% level; ** significant at 1% level; *** significant at 1% level.

[a] *F* value of effect.

[b] Degrees of freedom.

Table 2. Gelatinisation properties of fermented and dried cassava starch and maize ogi

Material	Fermentation temperature (°C)	Onset temperature (°C)		Peak temperature (°C)		Enthalpy change (J g^{-1} DM)	
		Oven-dried	Sun-dried	Oven-dried	Sun-dried	Oven-dried	Sun-dried
Cassava starch	20	56.3	56.5	60.6	60.8	17.8	19.0
	35	60.9	60.8	64.5	64.2	18.4	18.4
Maize ogi	20	74.1	75.1	79.9	78.7	12.4	11.6
	35	73.2	75.0	80.6	80.4	12.2	12.3
Raw material effect (RM)[a]		479.5***		620.0***		261.0***	
Fermentation temperature effect (FT)		16.5**		11.7**		0.1	
Drying procedure effect (DP)		0.1		0.3		0.1	
Interaction RM × FT effect		4.5		3.1		0.1	
Interaction RM × DP effect		0.1		0.2		1.6	
Standard error of residual (DF[b])		1.4 (8)		1.4 (8)		0.7 (8)	

* Significant at 5% level; ** significant at 1% level; *** significant at 1% level.
[a] *F* value of effect.
[b] Degrees of freedom.

cooling phase. This proved that the presence of butyric acid did not influence the gelatinisation of starch nor induce complex formation with amylose.

Pasting and swelling–solubility behaviour

The 7.1% fermented cassava starch dispersions showed similar viscograms to those previously observed for native and sour cassava starch;[14] the consistency began to increase around 60 °C, presented a maximum close to 75 °C, then decreased at high temperature and increased again during cooling (Table 3). In contrast, no peak of viscosity was observed for maize ogi and the viscosities were significantly lower than for cassava starch. The paste viscosities of dried maize ogi were similar to those measured for fresh ogi[11] and maize flour.[14] The pasting temperature of maize ogi dispersions was about 20 °C higher than for cassava starch, similar to what was observed for the gelatinisation temperature. Indeed, the onset gelatinisation and pasting temperatures were highly correlated ($r = 0.96$). The pasting behaviour of maize ogi was similar using pH 4.0 or 7.0 buffer (results not shown), but as already observed,[6] the paste viscosity of cassava starch decreased when

Table 3. Pasting behaviour of fermented and dried cassava starch and maize ogi in pH 4 buffer

Material	Fermentation temperature (°C)	Pasting temperature (°C)		Vpeak (RVU[a])		V95b (RVU)		V50 (RVU)	
		Oven-dried	Sun-dried	Oven-dried	Sun-dried	Oven-dried	Sun-dried	Oven-dried	Sun-dried
Cassava starch	20	58.8	59.0	250	233	167	98	98	54
	35	61.8	62.2	210	197	197	143	98	78
Maize ogi	20	81.1	79.0	NP[b]	NP	47	50	54	55
	35	82.5	78.5	NP	NP	42	46	45	49
Raw material effect (RM)[c]		308***		—		175***		35.2***	
Fermentation temperature effect (FT)		2.6		4.1		4.3		0.18	
Drying procedure effect (DP)		1.6		0.6		13.2***		7.7*	
Interaction RM × FT effect		1.3		—		6.9*		3.4	
Interaction RM × DP effect		2.4		—		16.6**		10.5*	
Standard error of residual (DF[d])		2.2 (8)		27 (4)		16 (8)		11 (8)	

* Significant at 5% level; ** significant at 1% level; *** significant at 1% level.
[a] Rapid Visco Analyzer units.
[b] No peak detected.
[c] *F* value of effect.
[d] Degrees of freedom.

Table 4. Solubility and swelling values (measured at 75 °C) for fermented and dried cassava starch and maize ogi

Material	Fermentation temperature (°C)	Solubility (mg ml^{-1})		Swelling index (g g^{-1})		Volume fraction of dispersed phase (ϕ)	
		Oven-dried	Sun-dried	Oven-dried	Sun-dried	Oven-dried	Sun-dried
Cassava starch	20	10.4	11.9	30.4	31.1	0.69	0.69
	35	4.5	5.0	20.5	20.7	0.50	0.50
Maize ogi	20	2.7	2.4	6.4	6.1	0.18	0.17
	35	3.2	2.7	6.1	6.1	0.17	0.18
Raw material effect (RM)[a]		150.6***		1339.1***		890.9***	
Fermentation temperature effect (FT)		49.5***		93.9***		43.6***	
Drying procedure effect (DP)		0.5		0.1		0.2	
Interaction RM × FT effect		63.6***		86.8***		43.6***	
Interaction RM × DP effect		2.6		0.3		0.1	
Standard error of residual (DF[b])		0.9(8)		1.1(8)		0.03(8)	

* Significant at 5% level; ** significant at 1% level; *** significant at 1‰ level.
[a] *F* value of effect.
[b] Degrees of freedom.

the pH increased, especially for the sun-dried samples; for instance, the final viscosity of 20 °C fermented and sun-dried cassava starch was 8 RVU when the suspension was made with pH 7.0 buffer, and 54 RVU (Table 3) with pH 4.0 buffer.

Swelling and solubility indices were determined at 75 °C (for 2.5% dispersions) in order to explain these differences in pasting behaviour (Table 4). The swelling power of cassava starch ranged between 20 and 30 g g^{-1}, indicating a volume fraction for the dispersed phase (ϕ) of between 0.5 and 0.7. This implied that close packing was obtained for 7.1% dispersions. In contrast, the swelling power was 6 g g^{-1} for maize ogi and ϕ around 0.17; the calculated ϕ for 7.1% dispersions was then 0.51. As the starch dispersion consistency is primarily linked to ϕ,[14,22] the low value observed for maize ogi might explain the absence of measurable consistency at 75 °C. More generally, the lower swelling ability of maize starch at all temperatures[23] could explain its lower consistency along the heating step during the measurement within the RVA.

The effect of the fermentation temperature on the viscosity parameters was not significant (Table 3). However, considering cassava starch alone, the pasting temperature was significantly higher (3 °C more) when the fermentation was achieved at 35 °C. This might be linked to the lower swelling and solubility values (measured at 75 °C) for this fermentation condition (Table 4). This delay in starch swelling and leaching shows the same tendency as that observed for the gelatinisation temperature (Table 2) and should be due to the annealing phenomenon during steeping at 35 °C.

The drying procedure significantly affected the viscosity parameters V95b and V50 for cassava starch. The sun-dried samples had lower viscosities than the oven-dried ones, but sour cassava starch processed in Colombia had still lower viscosity (V50 = 43 RVU). This agrees with previous observations,[3,6] and Camargo *et al*[4] proposed that the lower hot paste viscosity of sour cassava starch was due to its high disintegration and solubilisation during pasting.

Expansion ability

An expansion occurred during the baking of cassava starch-based dough but not for maize ogi-based dough (Table 5). Both the fermentation and drying conditions significantly influenced the expansion ability of cassava starch. The 20 °C fermentation temperature and sun-drying led to the highest baking expansion (9.5 cm^3 g^{-1}), though the value was still lower than that measured for the reference sour cassava starch processed in Colombia (16.7 cm^3 g^1). This might be related to our experimental laboratory conditions that also led to lower lactic acid production and higher paste viscosities. In contrast, the cassava starch sample fermented at 35 °C and oven-dried gave a lower loaf specific volume (4.4 cm^3 g^{-1} DM) than the unfermented sample (6.4 cm^3 g^{-1} DM).

As previously observed,[3,6] the expansion ability of cassava starch during baking was negatively correlated with the paste viscosity (Fig 4). This should mean that the baking expansion increased with starch disintegration and degradation during cooking.[4] Indeed, Mestres *et al*[5] found that the baking expansion of cassava starch increased with its solubilisation capacity measured at 65 °C. In contrasts the maize ogi presented a very low starch disintegration at the beginning of cooking as shown by the low solubility and swelling values (Table 4) and did not expand during baking. Similarly, for cassava starch the samples fermented at 35 °C presented lower solubility and swelling values and less expansion during baking. Furthermore, these samples had a higher gelatinisation temperature that could also influence the expansion ability. Indeed, at the beginning of baking, the starch gelatinisation induces its partial solubilisation and swelling and leads to the formation of a viscoelastic material. This latter can trap the gas being produced

Material	Fermentation temperature (°C)	Specific volume ($cm^3 g^{-1}$ DM)	
		Oven-dried	Sun-dried
Cassava starch	20	6.8	9.5
	35	4.4	7.8
Maize ogi	20	2.3	2.3
	35	2.3	2.3
Raw material effect (RM)[a]		220.7***	
Fermentation temperature effect (FT)		9.9*	
Drying procedure effect (DP)		21.1**	
Interaction RM × FT effect		9.9*	
Interaction RM × DP effect		21.1**	
Standard deviation of residual (DF[b])		0.7	

Table 5. Specific volume measured after dough baking for fermented and dried cassava starch and maize ogi

* Significant at 5% level; ** significant at 1% level; *** significant at 1‰ level.
[a] *F* value of effect.
[b] Degrees of freedom.

during baking, mainly before the formation of a rigid crust due to the progressive dehydration and which can impede the dough expansion. Thus samples that present low temperatures of gelatinisation and pasting should have higher expansion during baking before hardening of the crust. In the case of maize ogi the presence of non-starch material, particularly fibres, may also impede the formation of the bubbles by disrupting the structure of the solid foam.

The relationship mentioned above between starch disintegration and expansion during baking was observed in acidic conditions, ie at the pH value (4) of the sour cassava starch-based dough, but was no longer valid at neutral pH. Indeed, the use of a buffer at pH 7 reduced both hot paste viscosity and loaf specific volume. In the case of traditional sour cassava starch, for instance, V50 was lowered from 43 to 3 RVU and the loaf specific volume from 16.7 to 9.6 $cm^3 g^{-1}$. This reduction of the starch functional properties has already been observed by Mestres and Rouau[6] but is still not understood. Nevertheless, this could suggest that the starch degradation should be low for favouring the expansion during baking.[4]

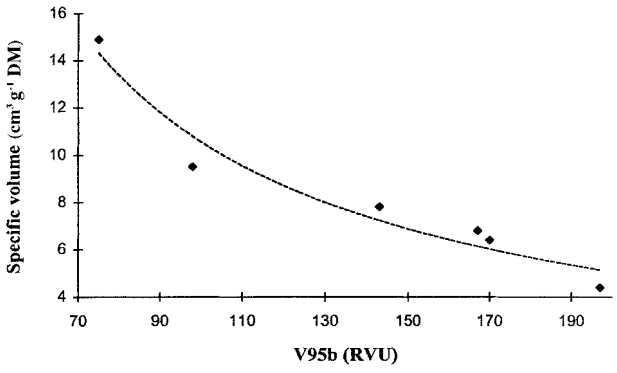

Figure 4. Relationship between loaf volume and paste viscosity (V95b) measured at pH 4 for fermented and dried cassava starch.

CONCLUSION

The lactic acid production and the resulting acidification were faster and more pronounced for maize ogi, though this latter did not expand during baking, in contrast to cassava starch, whatever the fermentation temperature and drying procedure. On the other hand, the usual temperature (20 °C) reported in the traditional fermentation of cassava starch in Colombia allows a predominant lactic acid fermentation to take place and promotes the expansion ability during the baking of a sour starch-based dough. Performing the fermentation at 35 °C causes a starch annealing that increases its gelatinisation temperature and reduces its swelling and solubility indices and hence its expansion ability during baking. The transfer of sour cassava starch technology from Latin America to Africa, though potentially interesting, should then be adapted to the African context, ie ambient temperatures around 35 °C. The sun-drying of fermented cassava starch proved to be a key step for acquiring the expansion ability during baking, in relation to the drop in starch hot paste viscosity. A study is under way for better understanding the influence of sun-drying on the structural and rheological changes of fermented cassava starch and thus the mechanism of its expansion during baking.

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REFERENCES

1 Cardenas OS and Buckle TS, Sour cassava starch production: a preliminary study. *J Food Sci* **45**:1509–1528 (1980).
2 Nakamura IM and Park YK, Some physico-chemical properties of fermented cassava starch (Polviho azedo). *Starch* **27**:295–297 (1975).
3 Dufour D, Larsonneur S, Alarcon F and Chuzel G, Improving

the bread-making potential of cassava sour starch, in *Cassa Flour and Starch*, Ed by Dufour D, O'Brien GM and Best R. CIAT, Cali, pp 133–142 (1996).
4 Camargo C, Colonna P, Buleon A and Richard-Molard D, Functional properties of sour cassava (Manihot utilissima starch: Polvilho Azedo). *J Sci Food Agric* **45**:273–289 (1988).
5 Mestres C, Zakhia N and Dufour D, Functional and physico-chemical properties of sour starch, in *Starch: Structure and Functionality*, Ed by Frazier PJ, Richmond P and Donald AM. The Royal Society of Chemistry, Cambridge, pp 42–50 (1997).
6 Mestres C and Rouau X, Influence of natural fermentation and drying conditions on the physicochemical characteristics of cassava starch. *J Sci Food Agric* **74**:147–155 (1997).
7 Nago M, Hounhouigan J, Akissoë N, Zanou E and Mestres C, Characterization of the Beninese traditional ogi, a fermented maize slurry: physico-chemical and microbiological aspects. *Int Food Sci Technol* **33**:307–315 (1998).
8 Hounhouigan DJ, Nout MJR, Nago CM, Houben JH and Rombouts FM, Composition and microbiological attributes of mawè, a fermented maize dough from Benin. *Int J Food Sci Technol* **28**:513–517 (1993).
9 Akingbala JO, Onochie EU, Adeyemi IA and Oguntimein GB, Steeping of whole and dry milled maize kernels in ogi preparation. *J Food Process Preserv* **1**:1–11 (1987).
10 Muller HG, Traditional cereal processing in Nigeria and Ghana. *Ghana J Agric Sci* **3**:187–195 (1970).
11 Nago M, Tétégan E, Matencio F and Mestres C, Effects of maize type and fermentation conditions on the quality of Beninese traditional ogi, a fermented maize slurry. *Cereal Sci* **28**:215–222 (1998).
12 Mestres C, Colonna P, Alexandre MC and Matencio F, Comparison of various processes for making maize pasta. *J Cereal Sci* **17**:277–290 (1993).
13 Nago M, Akissoë N, Matencio F and Mestres C, End use quality of some African corn kernels. 1. Physico-chemical characteristics of kernels and their relationship with the quality of 'lifin', a traditional whole dry-milled maize flour from Benin. *Agric Food Chem* **45**:555–564 (1997).
14 Mestres C, Nago M, Akissoë N and Matencio F, End use quality of some African corn kernels. 2. Cooking behavior of whole dry-milled maize flours; incidence of storage. *J Agric Food Chem* **45**:565–571 (1997).
15 Brabet C, Etude des mécanismes physico-chimiques et biologiques responsables du pouvoir de panification de l'amidon fermenté de manioc. *PhD Thesis*, Montpellier II (1994).
16 Cooke D and Gidley MJ, Loss of crystalline and molecular order during starch gelatinization: origin of the enthalpic transition. *Carbohydr Res* **227**:103–112 (1992).
17 Asaoka M, Blanshard JMV and Rickard JE, Seasonal effects on the physicochemical properties of starch from four cultivars of cassava. *Starch* **43**:455–459 (1991).
18 Defloor I, Lijskens M and Delcour JA, Impact of genotype and crop age on the breadmaking and physico-chemical properties of flour produced from cassava planted in the dry season. *J Sci Food Agric* **66**:193–202 (1994).
19 Nakazawa F, Noguchi S, Takahashi J and Takada M, Thermal equilibrium state of starch–water mixture studied by differential scanning calorimetry. *Agric Biol Chem* **48**:2647–2653 (1984).
20 Eliasson AC, Finstad H and Ljunger G, A study of starch–lipid interactions for some native and modified maize starches. *Starch* **40**:95–100 (1988).
21 Phan TH and Mercier C, Amélioration de la composition et de la texture du plat traditionnel africain le foufou par addition de monoglycérides au manioc. *Sci Alim* **4**:109–120 (1984).
22 Ring S and Stainsby G, Filler reinforcement of gels. *Prog Food Nutr Sci* **6**:323–329 (1982).
23 Leach HW, McCowen LD and Schoch TJ, Structure of starch granule. I. Swelling and solubility patterns of various starches. *Cereal Chem* **36**:534–544 (1959).