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Effect of different process combinations on the fermentation kinetics, microflora and energy density of *ben-saalga*, a fermented gruel from Burkina Faso

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Abstract

Three different processes combining cooking (C), addition of malt (M) and/or backslop inoculation (I) were investigated to increase the energy density (ED) of *ben-saalga*, a millet-based fermented gruel and their effects on fermentation kinetics and microbiological characteristics were assessed. In the process combining cooking and inoculation (CI) and in the control (traditional processing methods), glucose and fructose were the main sugars and their concentrations decreased during the settling step (fermentation). In the process combinations that included the addition of malt (CM and CMI), maltose was the main sugar that accumulated during settling. In the CM process combination, the start of fermentation was considerably delayed due to the marked reduction in natural microflora during cooking. In contrast, in the CI and CMI process combinations, inoculation by back slopping accelerated acidification, resulting in a pH value of below 4.0 after 7 h of fermentation. Although malt was added at a very low rate (0.125%), gruels made using CM and CMI process combinations, and prepared at a suitable consistency, had an ED close to or above 84 kcal/100 g of sweetened gruel, the minimum value required for complementary food.

Keywords: Pearl millet; Lactic acid fermentation; Sugars; Organic acids; Complementary food; Energy density; Malt

1. Introduction

Traditional cereal-based fermented foods, such as *poto-poto*, *ogi*, *kenkey* and *ben-saalga*, are well accepted and widely consumed in Africa (Blandino, Al-Aseeri, Pandiella, Cantero, & Webb, 2003; Oyewole, 1997). Some of these traditional cereal-based fermented gruels are frequently used as complementary foods for infants and young children. However, they are characterized by a low energy and nutrient density (Lorri & Svanberg, 1994), well below the values recommended by Dewey and Brown (2003) for complementary foods. The consumption of high energy density (ED) gruels enables improvement of the infant's energy and nutrient intakes (Brown et al., 1995; Den Besten, Glatthaar, & Ijsselmuiden, 1998; Moursi, Mbemba, & Trèche, 2003; Vieu, Traoré, & Trèche, 2001).

The ED of cereal-based gruels depends on their flour content. However, this flour content is limited by the thickening of the gruels due to the swelling of the starch during cooking, which results in gruels with low EDs. One of the ways to obtain a thin cereal-based gruel with a high ED is to achieve partial hydrolysis of the starchy fraction. The effect of natural fermentation on the viscosity of cereal-based gruels has already been assessed. It has been shown that natural lactic acid fermentation of cereal gruels has a slight viscosity-reducing effect that cannot result in thin gruels with high ED (Lorri & Svanberg, 1993; Westby & Gallat, 1991).

Different technological methods have been tested to increase the ED of fermented and unfermented

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complementary foods for infants. The addition of α-amylase from commercial sources or produced from germinated cereals to gelatinize starch proved to be an efficient method (Kitabatake, Gimbi, & Oi, 2003; Mosha & Svanberg, 1983; Thaoge et al., 2003). Recently, several studies tested the combination of the use of germinated cereals and fermentation to increase gruel ED (Thaoge et al., 2003).

Ben-saalga is a pearl millet-based fermented gruel widely consumed by infants and young children in Ouagadougou (Burkina Faso). As it is the case in many other traditional cereal-based fermented gruels, the dry matter content of *ben-saalga* is very low (Guyot et al., 2003) and consequently its ED is not high enough to meet the energy requirements of infants and young children. Modifications of the traditional processing method are required to produce an improved gruel with the suitable characteristics.

The present work aimed at increasing the ED of this fermented gruel by implementing three different combinations of processes (pre-cooking, addition of malt flour and inoculation by back-slopping) in addition to the processes traditionally used to produce *ben-saalga*. These processes were chosen according to their potential ability to favour partial starch hydrolysis (pre-cooking and addition of malt) and also to promote rapid acidification by lactic acid fermentation (back-slopping) to improve hygienic conditions (Nout, Rombouts, & Havelaar, 1989). In addition to the assessment of the influence of these processes on the fermented gruel ED, special attention was paid to their effects on fermentation kinetics and on microflora.

2. Materials and methods

2.1. Materials

Pearl millet (*Pennisetum glaucum*) and aromatic ingredients such as ginger and mint used in the preparation of *ben-saalga* were purchased on the retail market in Ouagadougou. Malted grains of barley were obtained from Brakina, an industrial brewery in Ouagadougou.

2.2. Description of the processing conditions

The traditional processing of pearl millet into *ben-saalga* has been previously described in details (Tou et al., in press). It comprises the following main steps: washing, soaking the pearl millet grains and milling them in wet conditions, kneading and sieving the dough, settling the diluted slurry to allow natural fermentation to occur (fermentation step) and cooking the fermented slurry to obtain the gruel *ben-saalga*. The flow chart of traditional processing method (used as control), and the process combinations including new processes are presented in Fig. 1. These experiments were performed at pilot-scale using the facilities of the University of Ouagadougou, in the same conditions and with the same raw materials as local producers. Results are means of triplicate experiments for control and process combinations. The innovations introduced in the traditional process consisted in different process combinations: pre-cooking, addition of malt and inoculation by back-slopping of the slurry obtained after the sieving/kneading step. The process combinations were called "CI" for the combination of pre-cooking and inoculation, "CM" for the combination of pre-cooking and addition of malt and "CMI" for the combination of the three processes. The conditions for each process (pre-cooking, addition of malt and inoculation) are described below.

2.2.1. Pre-cooking step (C)

The pre-cooking step consisted in boiling the unfermented slurry resulting from sieving for 10 min to gelatinize the starch and to allow either the action of malt amylase in CM and CMI process combinations or the possible action of amylases produced by the natural microflora introduced by the inoculation.

2.2.2. Incorporation of malt (M)

Malted grains of barley were milled and sieved to obtain the malt flour used as the source of amylase. The malt flour was used at the rate of 0.125 g/100 g of the dry matter (DM) of the wet flour. It was added to the unfermented paste, when it had cooled down to 65 °C, 10–20 min after cooking.

2.2.3. Inoculation (I)

Inoculation of the paste by the back-slopping technique was used to favour fermentation after pre-cooking. A portion of fermented paste prepared the day before according to the traditional processing method was used as inoculum. It was added at a rate of 10% (w/w) to the unfermented paste after the addition of malt, when it had cooled down to 35 °C, after 2–3 h.

2.3. Preparation of gruels

For each experiment, five gruels were prepared at different DM contents by boiling the fermented paste for at least 5 min. The dry matter content of gruels was determined by oven-drying at 105 °C to constant weight. The consistency of the gruels was assessed by measurement in a Bostwick consistometer (CSC Scientific Company Inc., Fairfax, VA, USA) (Bookwalter, Peplinski, & Pfeifer, 1968). Measurements were made at 45 °C and the Bostwick flow value was expressed in mm/30 s. The ED of gruels was calculated by multiplying their dry matter content by 4 kcal, which was taken as the mean energy value of 1 g of DM. This ED was calculated for gruels with a suitable consistency, corresponding to a Bostwick flow of 120 mm/30 s (Vieu et al., 2001).

2.4. Fermentation kinetics

Samples were taken during the fermentation step (from 0 to 24 h) of the different process combinations and of the control experiment. The pH was recorded on-line using a pH-meter register (WTW 340i, Fisher Bioblock Scientific,

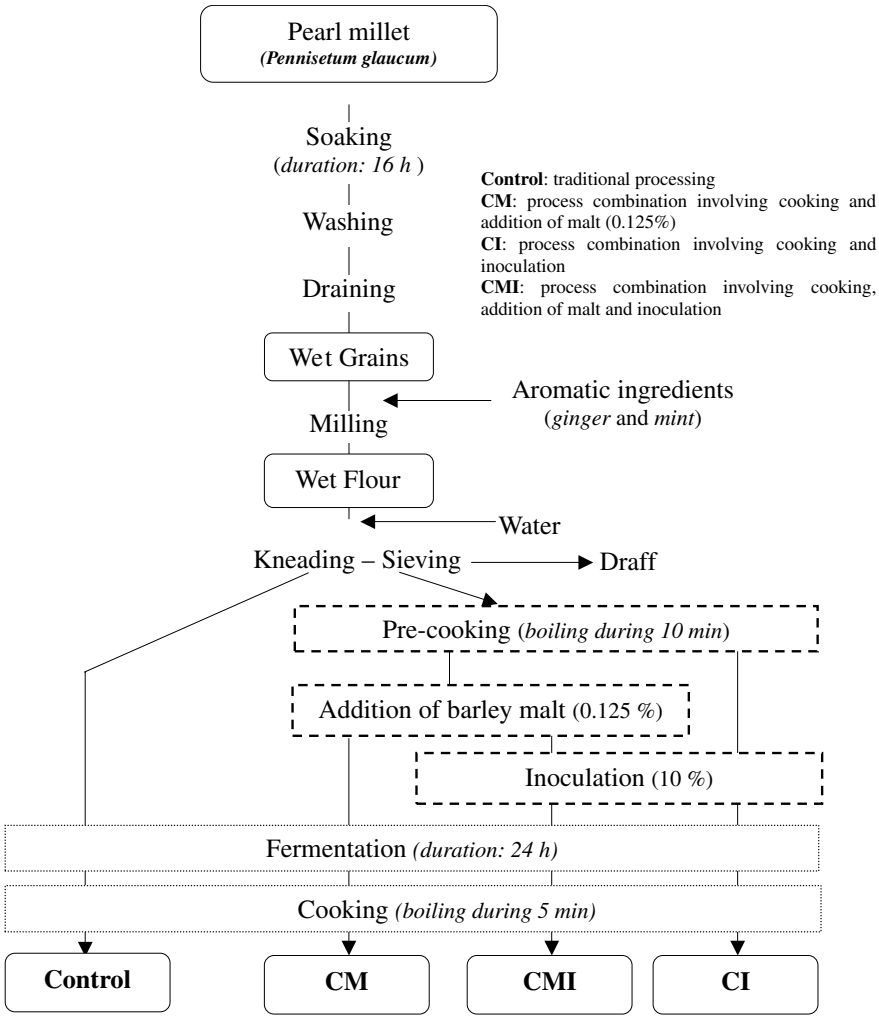

Fig. 1. Description of different process combinations to improve the energy density of *ben-saalga*.

France), and pH data were subsequently transferred to an Excel file for data processing.

2.5. Enumeration of aerobic mesophilic bacteria, lactic acid bacteria, amylolytic lactic acid bacteria and yeasts

Bacterial and yeast counts were isolated from samples taken during the fermentation step (from 0 to 24 h) in all process combinations after serial decimal dilutions in 9‰ (w/v) chloride sodium solution. Aerobic mesophilic bacteria, lactic acid bacteria (LAB), amylolytic lactic acid bacteria (ALAB) and yeasts were enumerated on the following media: Plate Count Agar (PCA, Difco, France), de Man, Rogosa and Sharp (MRS, Difco, France), modified MRS (without tween 80, and glucose was replaced by soluble starch at 20 g/L, Calderon, Loiseau, & Guyot, 2001) and yeast glucose chloramphenicol (YGC, Oxoïd, France), respectively. MRS and modified MRS plates were incubated at 30 °C for 48 h, PCA plates at 37 °C for 48 h and YGC plates at 30 °C for 3 days. Results are means of triplicate enumerations of microflora in samples of each experiment.

2.6. Measurements of organic acid and sugar concentrations

Ethanol, lactic and acetic acid concentrations in pastes sampled during the fermentation step were determined by HPLC using an Aminex HPX-87H column (Biorad, Yvry-sur-Seine, France).

Mono- and disaccharides (glucose, fructose, maltose and melibiose) were extracted from samples that were mixed with ethanol solution (80% v/v), agitated for 30 min in a thermostated bath at 90 °C and then centrifuged at 5000 rpm for 10 min at 4 °C. The supernatant was retrieved and the same procedure applied to the residue. The two mixed supernatants were dry evaporated overnight using a Speed vac centrifugal evaporator (JOUAN RC 10-10, Saint Herblain, France), then stored at 4 °C, before the determination of sugar contents by ionic chromatography using a Dionex DX 500 apparatus (Sunnyvale, CA, USA). After evaporation, the residue was mixed in millipore water and filtered. Glucose, fructose, maltose and melibiose contents were determined using a Carbo PA1 column. Detection was made by pulsed

amperometry and the eluant used was 90 mM sodium hydroxide solution. The results were expressed in mmol/l.

2.7. Statistical analysis

Data were submitted to analysis of variance (ANOVA). Duncan's multiple range tests was were used to separate means. Significance was accepted at the probability $P \leqslant 0.05$ (Duncan, 1955).

3. Results

3.1. Effect of the different process combinations (CI, CM, CMI) on fermentation kinetics

3.1.1. Changes in pH

In all process combinations, pH decreased during the settling step to reach a value below 4.0 (Fig. 2). Except in the process combination including pre-cooking and the addition of malt (CM), acidification followed a similar and classical pattern (Fig. 2).

The first phase of accelerated acidification occurred at the beginning of the fermentation step (from 0 to 6 h), and resulted in a pH decrease from an initial value around 6.0 to a final value around 4.0, followed by a phase of slow acidification (from 6 to 24 h), that resulted in a further decrease in pH to around 3.7. In the CM process combination, the pH was almost constant during the first 6 h of settling (5.73–5.53) and then decreased very slowly and continuously from 6 to 24 h to reach 3.8. In this case, acidification was considerably delayed by the fact that the natural lactic microflora has been seriously affected by the pre-cooking stage. This justify the need of the post-cooking inoculation step. As shown in Fig. 2, inoculation allowed a slightly more rapid decrease in pH than in the control.

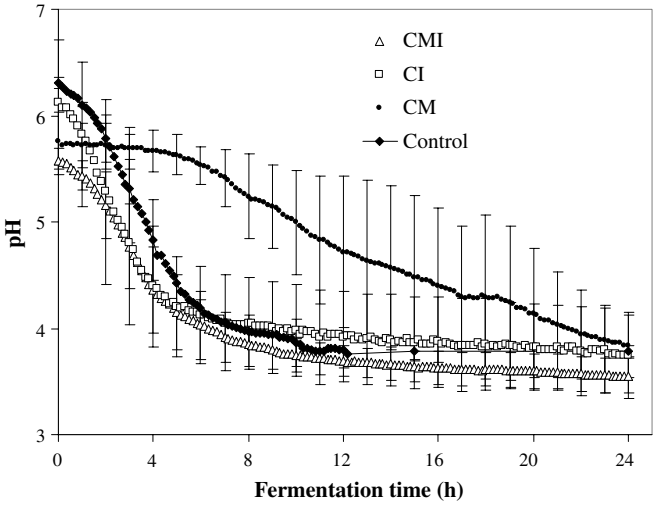

Fig. 2. Changes in pH during the fermentation steps in control and process combinations: pre-cooking and addition of malt (CM); pre-cooking and inoculation by back-slopping (CI); pre-cooking, addition of malt and inoculation (CMI).

3.1.2. Changes in mono- and disaccharide concentrations during the fermentation step

The analysis of mono- and disaccharides during fermentation of the slurry revealed the presence of maltose, glucose, fructose and traces of melibiose. The main sugar was glucose in the control and the CI samples (Fig. 3A and B) whereas it was maltose in the samples obtained after the addition of malt (CM and CMI) (Fig. 3C and D). Initial and final glucose ($P = 0.002$ and $P = 0.01$, respectively) and maltose ($P < 10^{-4}$) concentrations in the control and CI slurries were significantly lower than those of CM and CMI. In the samples of process combinations with the addition of malt (CM and CMI), not only were the glucose and fructose concentrations 10 times higher than those of the control and CI samples, but maltose was the main sugar produced (Fig. 3C and D). The increase of the concentration of maltose during the fermentation step indicates that the malt amylase is active in spite of the decrease in pH. It should however be noted that the highest maltose concentration was observed in the CM sample (Fig. 3C), which can be explained by an altered consumption pattern by the natural microflora affected by the pre-cooking step.

3.1.3. Changes in ethanol, lactic and acetic acids concentrations during the fermentation step

Ethanol, lactic and acetic acids were identified as the main fermentation products in the fermented slurries of control and process combinations (Fig. 4A–D).

Lactic acid was the main product formed during the fermentation step in all methods of processing. However, its final concentration in the control sample (25 mmol/L after 24 h of fermentation) was significantly ($P = 0.002$) lower than in CI and CMI samples (around 40 mmol/L or above). In the CMI sample, the final lactic acid concentration was the highest and reached 65 mmol/L (Fig. 4D).

In the CM sample, the final lactic acid concentration was not significantly ($P > 0.05$) different to that obtained in the CI sample, but a delay in lactic acid production was observed, as it began to increase only after more than 4 h of fermentation (Fig. 4C). This result is consistent with the acidification profile shown in Fig. 2 for the slurry of the CM process combination. Furthermore, in CM process, simultaneously with the increase in the concentration of lactic acid, there was also an important increase of ethanol concentration during fermentation (Fig. 4C). The final ethanol concentration was higher than in other process combinations but the difference was not significant ($P = 0.078$). Inoculation of the pre-cooked slurry with or without the addition of malt (CMI and CI process combinations, respectively) favoured a high level of production of lactic acid, as shown in Fig. 4B and D. Lactic acid production was significantly ($P = 0.002$) higher in the CMI sample than in the CM sample due to higher maltose consumption resulting from inoculation.

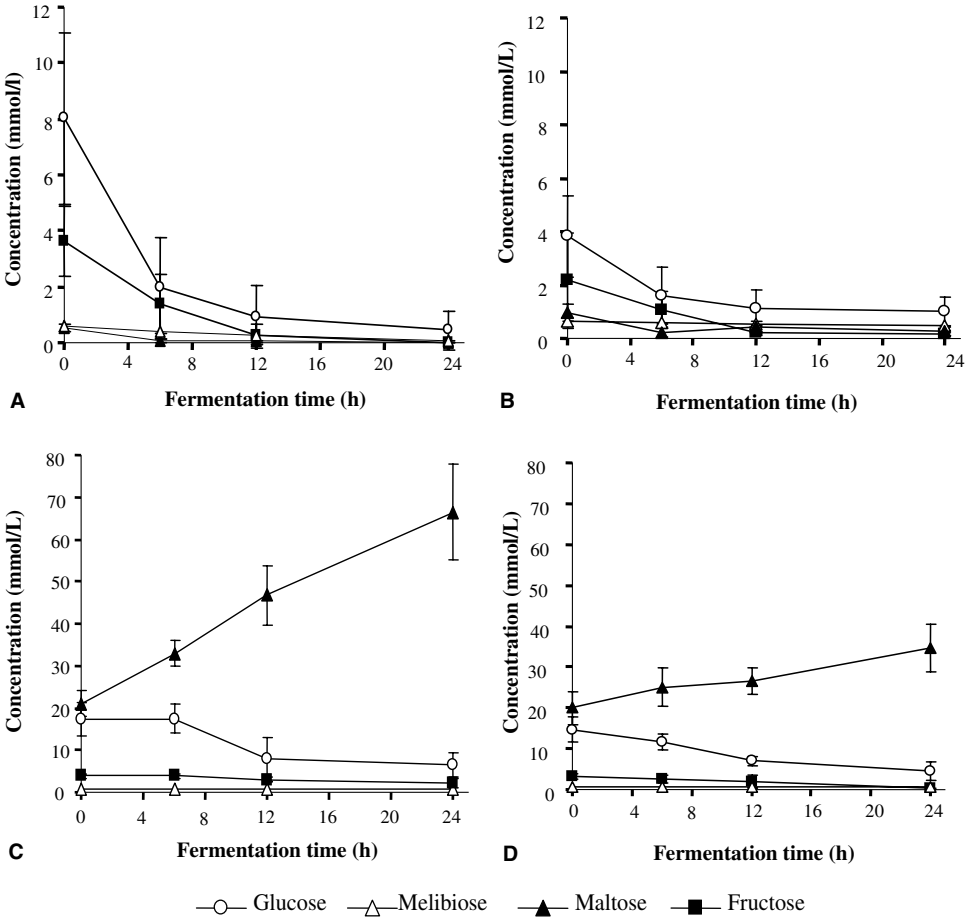

Fig. 3. Kinetics of sugar consumption and formation during fermentation at the settling step in control (A) and CI (B), CM (C) and CMI (D) process combinations. Bars are standard deviations.

3.2. Effect of the different process combinations on microflora during the fermentation step

To assess the effect of the process combinations on microflora (mesophilic aerobic bacteria, yeasts, lactic acid bacteria -LAB- and amylolytic lactic acid bacteria -ALAB-) microbiological analyses were performed during the fermentation step (Table 1).

Except for the process combination including pre-cooking and the addition of malt (CM), LAB were the dominant microflora isolated from the samples taken during fermentation. Among the samples obtained after the three different process combinations, the CM samples had the lowest counts for all microorganisms. The main effect of pre-cooking was to reduce the LAB concentration to undetectable levels at the beginning of the fermentation stage (Table 1). However, growth of LAB was detected during fermentation in the CM samples reaching a lower final concentration than those observed for samples from other process combinations. Surprisingly, no ALAB were found in the samples taken during the fermentation step in the CM process combination. The number of mesophilic aerobic bacteria and yeasts was also affected by pre-cooking and increased slowly during the settling step but were nevertheless from 10^3 to 10^4 times lower than for the other process combinations at the end of fermentation. Since LAB were detected during fermentation despite the fact they were drastically affected by pre-cooking, they were most probably introduced after pre-cooking through recontamination by the added malt and/or environmental conditions (air, dust, etc.). Microbial counts during the fermentation step of both process combinations with inoculation (CI and CMI) followed a similar pattern to that of the control. Inoculation after pre-cooking allowed the bacterial population to be restored to a similar level to that of the control at the beginning of the settling step. For yeasts, compared to the other process combinations, the process combination including inoculation and the addition of malt (CMI) was seen to favour their growth, and this process combination bears a certain similarity to the traditional brewing processes used to produce African beers.

3.3. Effect of different process combinations on gruel consistency and energy density

In order to assess the effect of the three different process combinations on gruel consistency, five gruels with different dry matter (DM) contents were prepared for each process combination and their Bostwick flow was measured (Fig. 5).

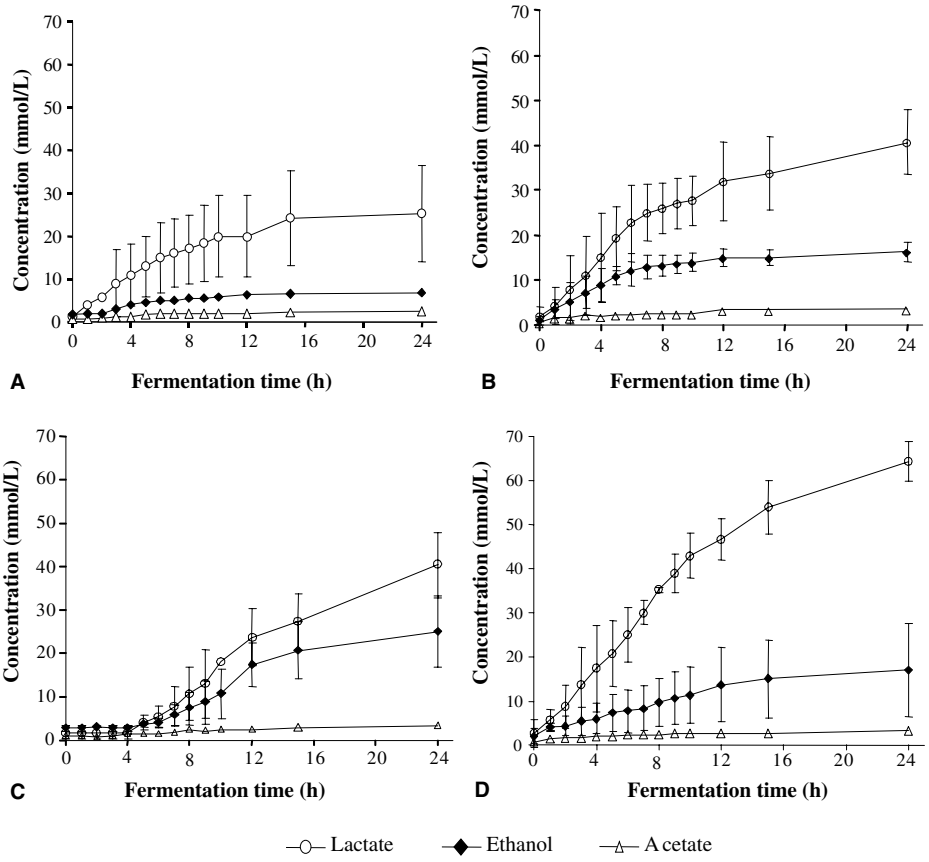

Fig. 4. Kinetics of the formation of ethanol and organic acids (lactic and acetic acids) during fermentation at the settling step in control (A) and CI (B), CM (C) and CMI (D) process combinations. Bars are standard deviations.

Table 1
Changes in microbial counts during the fermentation step of the control process and of the different process combinations

Hours	Microbial counts (CFU/ml)			
	0	4	8	24
Mesophilic aerobic bacteria				
Control	2.9×10^8	3.3×10^8	3.8×10^8	8.0×10^8
Cooking and addition of malt	1.8×10^3	1.0×10^4	2.8×10^4	4.2×10^4
Cooking and inoculation	2.4×10^8	3.7×10^8	7.5×10^8	7.0×10^8
Cooking, addition of malt and inoculation	2.9×10^8	4.0×10^8	5.5×10^8	4.8×10^8
Yeasts				
Control	2.1×10^6	1.4×10^6	4.1×10^4	5.0×10^4
Cooking and addition of malt	7.3×10^2	1.7×10^3	3.6×10^3	9.2×10^3
Cooking and inoculation	4.5×10^5	9.0×10^5	2.0×10^6	2.1×10^6
Cooking, addition of malt and inoculation	9.4×10^6	1.0×10^7	2.6×10^7	3.7×10^7
Lactic acid bacteria				
Control	2.6×10^8	3.1×10^8	5.9×10^8	8.0×10^8
Cooking and addition of malt	< 10	2.5×10^3	1.4×10^4	2.4×10^4
Cooking and inoculation	2.6×10^8	4.2×10^8	6.6×10^8	7.3×10^8
Cooking, addition of malt and inoculation	3.2×10^8	4.4×10^8	5.0×10^8	5.5×10^8
Amylolytic lactic acid bacteria				
Control	1.3×10^7	2.0×10^7	3.1×10^7	3.4×10^7
Cooking and addition of malt	< 10	< 10	< 10	< 10
Cooking and inoculation	1.3×10^7	3.0×10^7	3.3×10^7	3.8×10^7
Cooking, addition of malt and inoculation	2.3×10^7	2.8×10^7	3.4×10^7	3.2×10^7

The consistency profiles of gruels prepared using the CM, CI or CMI process combinations all shifted towards significantly higher DM contents compared to the control ($P < 10^{-4}$), showing that all three process combinations modified the gruel consistency through partial hydrolysis of starch. For all process combinations, the DM contents

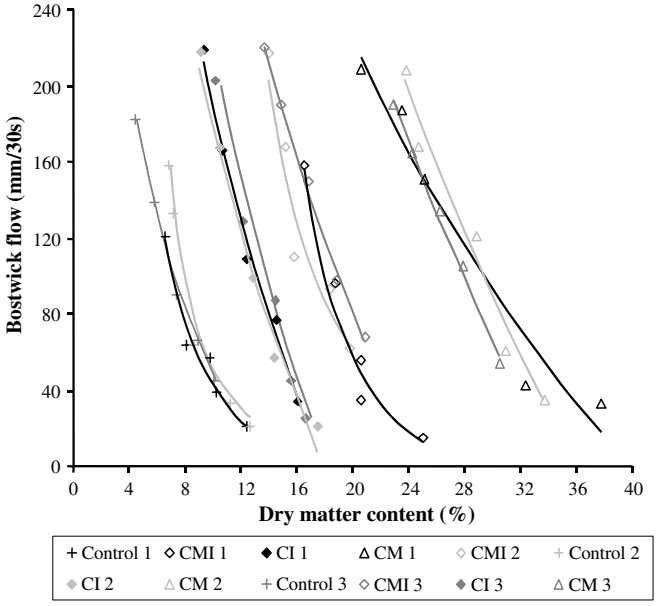

Fig. 5. Effect of the different process combinations, traditional (control), cooking and addition of malt (CM), cooking and inoculation (CI) and cooking, addition of malt and inoculation (CMI) on gruel consistency.

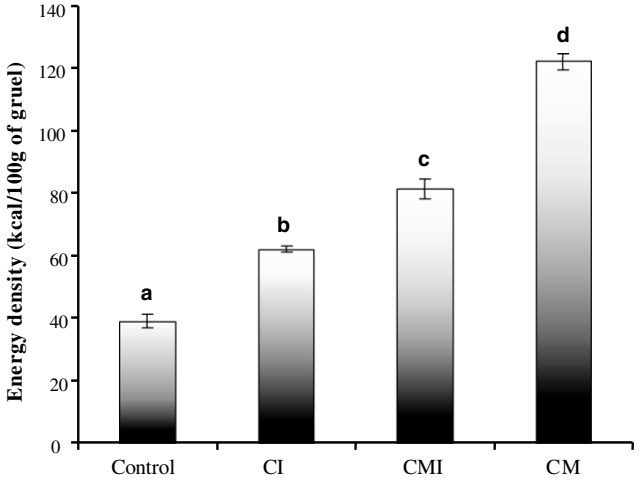

Fig. 6. Effect of the different process combinations, traditional (control), cooking and addition of malt (CM), cooking and inoculation (CI) and cooking, addition of malt and inoculation (CMI) on gruel energy density. Different letters indicate significantly different means ($P < 0.05$) as assessed by ANOVA and Duncan's multiple range test.

of gruels with a Bostwick flow of 120 mm/30 s corresponding to a consistency suitable for infants and young children (Vieu et al., 2001), were deduced from the curves (Fig. 5). The DM contents of gruels prepared using the traditional processes (used as control), CI, CMI and CM process combinations were 6.5 ± 0.5, 12.4 ± 0.3, 17.5 ± 0.8 and 27.6 ± 0.7 g DM/100 g, respectively. The addition of malt to gelatinized starch considerably modified the consistency of the gruels, and the highest DM content (27.6 g DM/100 g) was obtained with the CM process combination. Taking into account the addition of 3 g of sugar/100 g of gruel before consumption and an energy value of 4 kcal/g of DM, the ED of sweetened gruels corresponding to the control, CI, CMI and CM process combinations were 39 ± 2.1, 62 ± 1.0, 81.3 ± 3.2 and 122 ± 2.6 kcal/100 g of gruel, respectively (Fig. 6). However, only the process combinations that included the addition of malt (CMI and CM) resulted in an ED close to or higher than the minimum value of 84 kcal/100 g of gruel recommended for children of 9–11 months of age at a rate of 2 meals/day added to average breast milk intake (Dewey & Brown, 2003).

4. Discussion

The process combination involving cooking and the addition of malt (CM) considerably delayed the start of fermentation. This is explained by the marked reduction of the natural LAB population of the paste during cooking that have to be followed by reactivation of spoiled cells or by post-cooking contamination by LAB to promote fermentation. It suggests that the LAB contaminants, even if they develop at a low concentration during fermentation, are highly competitive compared to the other microorganisms. There was a slow decrease in pH after a period of time of about 8 h together with simultaneous production of lactic acid and ethanol. These conditions favour malt amylase activity (Trèche, 1999), leading to a high rate of starch hydrolysis and consequently to a significant ($P < 10^{-4}$) increase in maltose concentration during fermentation, and a high ED of CM gruel (122 kcal/100 g of sweetened gruel). The CM process combination is quite similar to the process used to make *togwa,* an East-African maize-based fermented beverage (Kitabatake et al., 2003). Nevertheless, the 8 h delay before the beginning of the acidification process presents a high risk of contamination by foodborne pathogens or spoilage microorganisms, making this alternative process combination unsuitable for use in cottage-level production.

In contrast, when the pre-cooked slurry was inoculated (CI and CMI process combinations), acidification started without a noticeable delay. Compared to the control, the main differences in the fermentation profiles were observed for the CMI process combination in which there was an accumulation of maltose, indicating that the rate of maltose production exceeded its consumption by the microflora that had been introduced by inoculation. The main risk associated with the relatively high final maltose concentration together with a low final pH is post-contamination by spoilage yeasts, with possible product alteration if storage conditions are not appropriate. In this respect, the shelf-life of the final product need to be further investigated. Given that concentration of maltose and fermentation products – such as lactic acid – also increased considerably, there may be consequences for the organoleptic characteristics of the resulting gruel with possible enhancement of the sweet and sour tastes, respectively. The consequences for gruel acceptability thus also need to be assessed.

More generally, it is interesting to notice that a closer examination of kinetics of product fermentation allow

some conclusions to be drawn about the metabolic activity of LABs involved in the different process combinations. Two stages were distinguished in the control and inoculated experiments (CI and CMI) but not in CM. The first stage corresponded roughly to the first half of the total fermentation time, when there was a simultaneous increase in both ethanol and lactic acid concentrations, and the second stage when there was no longer an increase in the concentration of ethanol, while the increase in lactic acid continued. The first stage indicates that both homo and heterofermentative LABs and possibly yeasts could be active, and the second stage that mainly homofermentative LAB could still be active in conditions, where the pH is very low. This variation in metabolic pattern is consistent with general descriptions given for many plant-based fermented foods in relation to temporal variations displayed by the different LAB species during the course of fermentation (Ampe, ben Omar, Moizan, Wacher, & Guyot, 1999; Brauman, Kéléké, Malonga, Miambi, & Ampe, 1996).

In the CI process combination, the implementation of the processes of pre-cooking and inoculation by back-slopping had a small positive effect on the gruel ED which reached 62 kcal/100 g for a sweetened gruel at a Bostwick flow of 120 mm/30 s, against 39 kcal/100 g for a sweetened control gruel. This could be explained by the fact that gelatinization during pre-cooking makes the starch more susceptible to a slight amylolysis by amylolytic lactic acid bacteria (ALAB). The counts of lactic acid microflora in fermented slurries indeed showed the presence of ALABs with an ALAB/LAB ratio of 0.06 (Table 1). Similar studies reported the presence of ALABs in many cereal-based fermented foods (Diaz-Ruiz, Guyot, Ruiz-Teran, Morlon-Guyot, & Wacher, 2003; Johansson, Sanni, Lonner, & Molin, 1995; Sanni, Morlon-Guyot, & Guyot, 2002) and the ability of their α-amylase to hydrolyze raw starch (Rodriguez-Sanoja et al., 2000). However, it is shown here that even if the gelatinized starch did favour amylolysis by ALAB amylases, natural fermentation was not efficient enough to reduce the viscosity of the gruel enough to obtain gruels with appropriate ED values.

The gruel obtained using the CMI process combination had an ED of about 82 kcal/100 g after sugar had been added. This ED is significantly higher ($P < 10^{-4}$) than that of traditional gruel and is close to the minimum value required for complementary foods, but it is significantly ($P < 10^{-4}$) lower than that of the gruel produced using the CM process combination. That could be explained by the fact that in the CMI process combination, due to accelerated acidification of the slurry, the pH reached a value of 4.7 after less than 3 h of fermentation, that considerably slowed down the amylase activity of barley malt (Mercier & Colas, 1967). Thus, the time of amylolysis was reduced compared to that in the CM process combination. Nevertheless, it should be noted that a very low percentage of barley malt (0.125%) was incorporated in this process combination. A slight increase of the percentage of barley malt added could allow to obtain gruel with an energy density above the minimum required. In comparison, in the study of Thaoge et al. (2003), the addition of sorghum malt flour at rates ranging from 5% to 15% was required to reduce fermented or unfermented gruel viscosity to suitable values.

5. Conclusion

All the different process combinations tested in this study allowed the positive effects of each process added to the traditional processing to be highlighted. Furthermore, the detailed analysis of fermentation kinetics for each process, provided a more rational basis to explain the effects of modifications introduced in the traditional processing method. The addition of malt to gelatinized starch after pre-cooking, even at a very low rate (0.125%), leads to sufficient starch hydrolysis to allows the preparation of thin fermented gruels with an appropriate ED (about 82 kcal/100 g of sweetened gruel). Inoculation by black-slopping allows the action of LAB, which were destroyed by the pre-cooking step, to be restored. Thus, taking nutritional and sanitary objectives into account, the process combination which seems to be the most promising to improve the gruel ED is the one involving pre-cooking, the addition of malt and inoculation. Beyond this increase in the ED of fermented gruel, it would be advisable to improve the nutrient balance of *ben-saalga*, particularly by increasing its lipid and protein contents. To this end, further studies are now in progress using the same kinetic approach to apply the CMI process combination to co-fermentation of millet with legumes (soybean, groundnut or cowpea).

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