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Effect of roasting and fermentation on viscosity of cereal-legume based food formulas

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Abstract. With the view of preparing semi-liquid weaning foods of high energy content, the influence of roasting (stationary hot air treatment) and fermentation (with natural and pure culture inocula) on the viscosity of maize-sorghum-soya porridges was investigated. Roasting resulted in porridges of significantly higher viscosity (cooked porridge cooled to 40 °C). Porridges made from the individual ingredients (maize, sorghum, soya) did not show this behaviour. Natural fermentation of mixed ingredients resulted in lower porridge viscosities (cooked porridge cooled to 40 °C, as well as hot-paste peak viscosity) when pH was 5.0–5.5. At lower pH the viscosity of the final porridges increased. Fermentation experiments of individual ingredients inoculated with pure cultures of *Lactobacillus plantarum* and *Candida famata* lead to the conclusion that various factors contribute to the effect of fermentation on porridge viscosity. Porridges of minimum viscosity are obtained at pH 5.0–5.5 corresponding with a moderate extent of fermentation. From a consumer safety point of view, it would be preferable to acidify to lower pH values (pH < 4.5). If necessary, viscosity adjustments could be made using malted cereals.

Introduction

The use of weaning foods as an addition to breast feeding often starts at an age of 6–12 months. With the view of the development of weaning formulas from tropical food ingredients, mixtures of cereals and legumes can be used. These must supply adequate amounts of metabolizable energy and protein. Especially at an age of 9–12 months, the nutrient intake is limited by a combination of inadequate masticating and swallowing ability and small stomach capacity [1]. Consequently a higher energy and nutrient concentration is required in a weaning porridge.

At a body weight of 7 kgs, approximately 3500 kJ daily are required [2]. If e.g. 50% of the energy must be met by 3 feedings of 200 ml in addition to breast milk, each feeding must provide about 600 kJ. Considering that a dry formulated mix has an energetic value of ca. 16 kJ/g dry solids, the weaning porridges should thus contain approximately 19% dry matter. Particularly if porridges are made from cereals and legumes, the products tend to be rather stiff and difficult to swallow for babies. Replacement of cereal by sugar or vegetable oil helps to reduce the viscosity but these ingredients are relatively expensive. Alternatively, the use of germinated (malted) cereals is effective in reducing the viscosity of gelatinised starchy gels [3]. Roasting and fermentation are operations which can be applied to reduce antinutritional factors and to increase bio-availability as well as microbiological safety [4]. Little is known about the effect of roasting on the viscosity of formulated porridges. Concerning the effect of fermentation on dry-milled cereals and legumes, reduction of the hot-paste Brabender peak viscosity of black gram (*Phaseolus mungo*) flour [5] and dry-milled maize [6], as well as increases for dry-milled maize [7, 8], were reported. The aim of this investigation was to evaluate the effect of roasting and natural lactic fermentation on the viscosity of high-energy multi-component porridges. Where relevant, comparisons were made with single ingredients.

Materials and methods

Materials. White sorghum (*Sorghum bicolor*) from Sudan and white dent maize (*Zea mays*) from Zimbabwe were obtained through Grano-Drente, the Netherlands. Abrasion-dehulled yellow seeded soya beans (*Glycine max*) from Brazil were obtained through V.O.F. Kleinjan, the Netherlands. Maize starch and sucrose were obtained from local supermarkets. *Lactobacillus plantarum* and *Candida famata* had been previously isolated from fermenting sorghum [9] and were grown and maintained on MRS (de Man, Rogosa and Sharpe) medium (Merck No. 10661, Darmstadt, Germany) and Malt extract (3%) broth (Oxoid L39, UK).

Ingredients processing. Maize, sorghum and soya beans were cleaned by sieving and aspiration. Coarse grinding (particle size 1–2 mm) was with a toothed disc mill (Condux type LV 15M, Condux-Werk, Wolfgang bei Hanau, Germany). Subsequent fine milling was carried out with a hammermill (Fritsch Pulverisette 14.702, Germany) equipped with a 0.12 mm screen. Intermediate storage was in polythene bags at 7 °C.

Porridge composition. The multi-component dry porridge mix consisted of sorghum, maize, soya and sucrose (weight ratio 33:33:23:11) and contained 1635 kJ metabolizable energy per 100 g. Using this mix, porridges of 19–20% dry matter content were made for viscosity assessment.

Roasting. A ventilated oven (BS250, Gallenkamp, UK) with air temperature of 230 °C was used. The material to be roasted was spread as a mono-layer for kernels or as a 2 mm layer for coarsely ground material on non-perforated trays. Roasting periods were taken from the moment of introduction into the pre-heated oven.

Natural fermentation. Accelerated natural lactic fermentation [10] was performed on the multi-component mix as follows. A mixture of finely milled sorghum, maize and soya beans (weight ratio 37:37:26) was mixed with an equal weight of tapwater. After inoculation with 10% (w/w) of a stabilized enrichment culture on the same flour mixture, incubation followed at 30 °C during 24 hours. At progressive stages of fermentation, samples were taken. Their pH was recorded, the required amount of sucrose and water was added and porridge was prepared (see below). In some cases, the fermented samples were neutralized with 2N NaOH to pH 6.30 and subsequently made into porridge.

Fermentation with added pure culture inocula. Pure cultures of *Lactobacillus plantarum* and *Candida famata* were cultivated on MRS medium and Malt Extract Broth, respectively, for 24 hours at 30 °C. These cultures were used to inoculate (2% v/w) single ingredients (ground soya beans, ground maize) mixed with equal weights of tapwater. Commercial maize starch was tested as well. To provide fermentable substrate, filtered maize steepwater was used instead of tapwater to achieve a suspension of 20% dry matter content. The steepwater was obtained by soaking maize kernels in water at 7 °C followed by filtration through muslin cloth. Fermentation of the inoculated ingredients, and sampling for porridge preparation was as described above.

Preparation of porridge. The ingredients (weights based on dry matter) required for 200 g porridge were mixed in a 250 ml glass beaker. Cold water was added to make up to 200 g and a smooth batter was made prior to heating on an electric hotplate. The mixture was heated to 80 °C within 10 minutes with continuous stirring. Heating continued for another 10 minutes after which the porridge was allowed to cool at room temperature for 1 hour to approximately 50 °C. Viscosity was measured at 40 °C, and dry matter content of cooked porridge was determined by oven-drying (3 hours at 105 °C).

Viscosity determination. The viscosity of cooked porridges was determined with a Rotoviscosimeter (Haake Mess-Technik, Germany) using sample bowl 'mV' and rotor 'mV–III' both covered with emery paper (Norton, Brazil, Korn 80) in order to prevent slip between the measuring body and the porridges. The measuring body constants for recalculation of the set rotation speed %D in the shear rate $\dot{\gamma}$ and of the measured torsion %τ in the shear stress σ were determined using two calibration fluids with a viscosity in the range of the porridges. The recalculation was done by $\dot{\gamma}=2.38$ %D [s^{-1}] and $\sigma=4.91$ %τ [Pa]. From these, the apparent viscosity η^* was calculated by $\eta^*=\sigma/\dot{\gamma}$ [Pa.s]. All measurements were carried out at $\dot{\gamma}=1.1\ s^{-1}$. The pasting behaviour was assessed in an Amylo-Viscograph (Brabender, Germany) using a measuring box of 500 cmg. A standard of 450 g suspension of ingredients in water was put in the mixing bowl and the temperature was increased to 90 °C within 30 minutes, held at 90 °C for 30 minutes and reduced to 50 °C within 30 minutes according to the programme. The apparent viscosity was recorded in arbitrary Brabender units.

Results and discussion

Figure 1 illustrates the rheological behaviour of multi-component porridge with maize, sorghum, soya and sucrose having 20% dry matter content. It shows that this type of porridge is shear-thinning and somewhat thixotropic with a corresponding hysteresis in the shear stress as a function of shear rate. The porridge had a yield stress of about 20 Pa as determined from the residual stress after stopping. All further measurements were carried out at a shear rate $\dot{\gamma} = 1.1\ s^{-1}$, obtained by increasing the rotation speed.

In Table 1, the effect of roasting of dry ingredients on the apparent viscosity of resulting multi-component porridges is presented. With increasing extent of roasting, the resulting porridges have significantly higher viscosities. As can be expected on the basis of better heat transfer, roasting is more effective with fine than with coarse particles or with intact kernels.

Table 2 summarizes the effect of the same roasting treatments on separate coarsely milled ingredients which were subsequently made into single-ingredient porridges. We choose to prepare porridges of such dry matter contents so as to obtain apparent viscosity data of the same order of magnitude of those

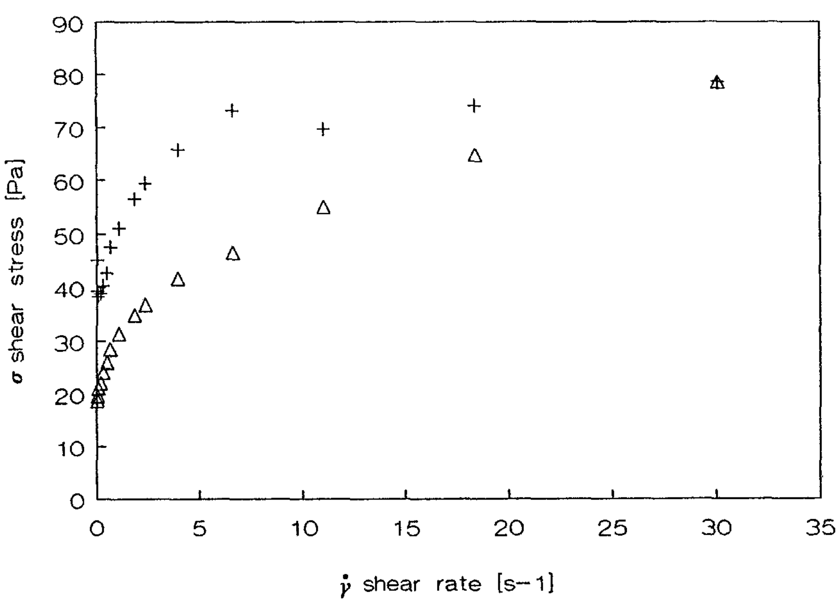

Fig. 1. Rheological behaviour of multi-component porridge (20% w/w dry matter, non-roasted, non-fermented).
+ increasing shear rate.
△ decreasing shear rate.

Table 1. Effect of roasting of ingredients on the apparent viscosity ($\dot{\gamma} = 1.1\ s^{-1}$) of resulting multi-component porridges[a]

Extent of roasting[b]	Method of roasting					
	Wholegrain, separate		Coarse grind, separate		Fine grind, mixed	
	Viscosity (Pa.s)	SD (n = 3)	Viscosity (Pa.s)	SD (n = 3)	Viscosity (Pa.s)	SD (n = 3)
No roasting	11.3	1.5	11.3	1.5	11.3	1.5
Light	13.5	2.5	24.6	1.6	77.1	15.6
Medium	54.5	12.3	37.8	6.8	80.0	14.9
Heavy	47.6	15.7	65.3	14.9	78.7	16.1

[a]Porridge dry matter 19.7% (w/w) (SD 0.7%) made up of 33% maize, 33% white sorghum, 23% soya beans and 11% sucrose.
[b]Light, medium and heavy roasting of separate ingredients represent 4, 8 and 12 minutes for maize; 3, 7 and 10 minutes for sorghum; and 2, 5 and 8 minutes for soya beans, respectively. Light, medium and heavy roasting of mixed ingredients represent 2, 5 and 8 minutes, respectively. All roasting was done on non-perforated trays in a ventilated oven at 230 °C.

Table 2. Effect of roasting of coarsely ground ingredients on the apparent viscosity ($\dot{\gamma} = 1.1\ s^{-1}$) of resulting single-ingredient porridges

Extent of roasting[a]	Single ingredients					
	Maize		White sorghum		Soya	
	Viscosity (Pa.s)	Porridge d.m. (%)	Viscosity (Pa.s)	Porridge d.m. (%)	Viscosity (Pa.s)	Porridge d.m. (%)
No roasting	8.0	9.4	11.6	9.3	45.1	19.2
Light	2.2	9.4	3.3	9.0	35.3	19.3
Medium	3.6	9.6	4.4	8.9	15.6	19.2
Heavy	12.9	9.5	14.3	11.1	4.4	16.7

[a]Light, medium and heavy roasting of separate ingredients represent 4, 8 and 12 minutes for maize; 3, 7 and 10 minutes for sorghum; and 2, 5 and 8 minutes for soya beans, respectively. All roasting was done on non-perforated trays in a ventilated oven at 230 °C.

of the multi-component porridges. Although direct comparison of apparent viscosity data of Tables 1 and 2 is thus not possible, it can be clearly seen that the effects of roasting on the various ingredients differ considerably. With soya beans a significant apparent viscosity reduction was achieved whereas, the cereals gave some apparent viscosity reduction at light and medium roasting. Based on the differences between single- and multiple-component porridges (cf. Tables 1 and 2), we assume that some components (probably proteins) of the maize, sorghum or soya are affected, probably denatured, and after higher treatments maybe even partly aggregated by the heat treatment during roasting. These changes make the components concerned potentially more reactive for (physical) cross-linking with components of other ingredients during cooking of multi-component porridges.

The effects of natural lactic fermentation and of pH adjustment by HCl on the apparent viscosity of multi-component porridges are shown in Figure 2. Viscosity data obtained with the rotoviscosimeter (cooked porridge cooled to 40 °C, in Pa.s) and the visco-amylograph (peak viscosity, in Brabender Units) show similar trends. Depending on the extent of fermentation, the apparent viscosity is at first reduced compared to the non-fermented mixture. Minimum viscosities were observed at approximately pH 5.0–5.5, followed by gradual viscosity increase with lowering pH. When the pH of non-fermented ingredient mixtures were adjusted before cooking the porridge, a similar trend in apparent

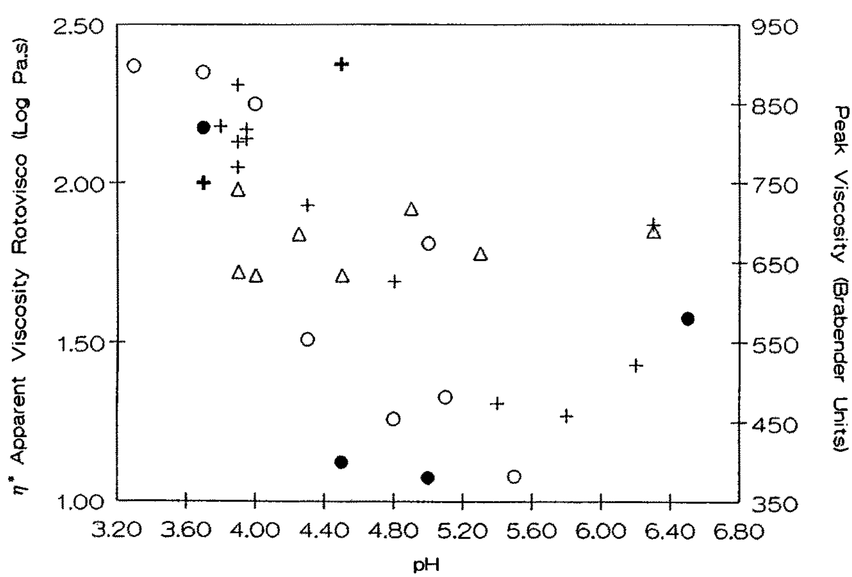

Fig. 2. Effect of natural lactic fermentation and pH on viscosity of multi-component porridge (19.2±0.6% w/w dry matter)
pH achieved by natural lactic fermentation (+ Rotoviscometer, ✚ Amylo-Viscograph);
fermented until pH indicated, followed by neutralization to pH 6.3 prior to porridge cooking (△ Rotoviscometer);
pH adjusted with HCl (non-fermented) (○ Rotoviscometer, ● Amylo-Viscograph).

viscosity as a function of pH was observed. When fermented ingredients were neutralized to the initial pH (6.3) prior to cooking, there were no significant viscosity effects. This implies that the effect of fermentation on viscosity could be ascribed to direct or indirect effects of pH resulting from fermentative acidification.

Table 3 summarizes data obtained with pure culture fermentation of single ingredients. Maize starch was included to compare with maize. A decrease of the maize starch pH before porridge preparation results in slightly reduced apparent viscosity of the cooked paste. Such a thinning may be caused by a slight acid hydrolysis during porridge cooking at a low pH [6, 11]. However, we found increased viscosities in fermented maize which must consequently, be associated with it's non-starch fraction. Fermentation of soya with the yeast *Candida famata* does hardly result in pH change nor in viscosity. On the other hand, in maize the pH decreased considerably with a corresponding viscosity increase. After neutralization the viscosity was of the same order of magnitude as the non-fermented control. Maize starch was also acidified by *C. famata*, the resulting apparent viscosity was clearly lower than of the non-fermented acidified paste. These data confirm that the paste viscosity of the maize starch fraction can be reduced somewhat by cooking at lower pH, and more effectively by organisms able to degrade starch, e.g. *C. famata* [12].

Lactobacillus plantarum is not able to degrade starch. This may have contributed to the paste viscosities of maize starch which were slightly higher compared to the non-fermented control. Both soya and maize were acidified by *L. plantarum* and this resulted in significant viscosity increases. The viscosity effect appears to be stronger in soya (cf. '*L. plantarum*' with '*L. plantarum* neutralized'). As soya does not contain significant quantities of starch, we hypothesize that proteins play the most important role by increasing the viscosity at lower pH values. Irrespective of pH, *L. plantarum* has a viscosity increasing effect on maize (cf. 'neutralized' with 'non-fermented'). This effect was observed to a lesser extent in maize starch and is possibly caused by the assimilation of non-starch solids by *L. plantarum* which results in increased starch content of the dry matter [7]. Another factor resulting in higher viscosity could be the gradual degradation of the endosperm matrix in which the starch granules are embedded. Conglomerates of starch granules cemented by matrix material will be of limited swelling capacity. Upon degradation of the matrix, the number of individual starch granules will increase, and so will the viscosity.

On the basis of the above data and those reported elsewhere [5–8], we conclude that acid fermentation of dry-milled mixtures of maize, sorghum and soya has at first a viscosity-reducing effect at pH 5.0–5.5. Although an increased viscosity might be expected because the starch content in the dry matter has increased somewhat, the actual decrease probably results from the maximum activity of grain α-amylase at this pH-level as well as from changes in protein conformation with pH. At extended fermentation ($pH < 4.5$) the starch content of the dry matter may have increased somewhat more, grain

Table 3. Effect of pure culture fermentation and pH on the apparent viscosity ($\dot{\gamma} = 1.1\ s^{-1}$) of resulting single-ingredient porridges

Fermentation treatment	Single ingredients								
	Soya			Maize			Maize starch		
	pH	Viscosity (Pa.s)	Porridge d.m. (%)	pH	Viscosity (Pa.s)	Porridge d.m. (%)	pH	Viscosity (Pa.s)	Porridge d.m. (%)
Non-fermented	6.75	13.8	11.6	6.00	33.0	16.4	6.30	30.8	10.0
							6.00	34.6	10.0
							4.60	26.8	9.8
							3.00	15.8	10.0
Candida famata	6.30	15.5	11.2	4.70	65.2	11.5	4.00	1.1	10.0
C. famata neutralized	6.60	2.3	11.6	6.60	27.2	14.7	6.25	4.7	10.0
Lactobacillus plantarum	4.50	74.3	11.7	3.70	104.6	13.3	3.30	33.2	10.0
L. plantarum neutralized	6.50	1.6	10.9	6.60	68.7	15.2	6.40	46.4	10.0

α-amylase is inhibited and probably the main factor aggregation of the protein molecules during cooking increases as the pH approaches their iso-electric point. All factors together result in a significant increase of the peak viscosity. The only factor restraining the viscosity increase would be some acid hydrolysis of starch resulting in some thinning of the starch gel.

In conclusion, it appears that roasting as applied is not a suitable method for reduction of dietary bulk. On the other hand, a moderate extent of souring to pH 5.0–5.5 leads to significantly less viscous porridges. However, such level of acidity is inadequate to achieve microbiological stability [13]. It would therefore seem more appropriate to ferment to a minimum pH for hygienic safety and to apply malted grain [3] during porridge preparation for viscosity adjustment.

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