Consistency of gruels for infants: a comparison of measurement procedures and the main influencing factors

Claire Mouquet
Laboratoire de Nutrition Tropicale, Montpellier, France

Abstract
For the improvement of infants' energy intake in developing countries, studies on the relationship between energy density and consistency of gruels are required. However, as for starch pastes, gruel consistency is difficult to characterize.

Various instrumental and sensorial methods are currently used for this purpose. Amongst the instrumental methods, viscosity measurements are the most widely used. However, due to its complex rheological behaviour, gruel shows variable viscosity values related to the viscometer type, measurement spindle, shear rate, shear time or gruel temperature. Hence, a specified gruel cannot be characterized only by a single viscosity value. Simple empirical measurements such as Bostwick or Adams consistencies can be useful for obtaining data in the field. Several studies are also based on sensory perception of gruel consistency, roughly classified in three groups: liquid, semi-liquid, or thick.

The actual effects of factors influencing the gruel nutritional value can be determined through an analysis of consistency data obtained in standardized conditions. These factors are mainly related to gruel composition. Gruels are substantially thickened by increasing dry matter and particularly starch contents. Oil or sugar addition have less influence. Processes applied to infant flours, like malting or extrusion cooking, induce starch modifications, such as gelatinization or partial hydrolysis. These changes also dramatically alter the relationship between gruel concentration and consistency.

The effects of these factors will be discussed on the basis of examples involving the use of various infant flours available in West Africa and Vietnam.

Introduction

Numerous studies have highlighted the practical problem related to the preparation of high energy density gruels in developing countries. If mothers just increase the flour concentration, gruels become too thick during cooking and can no longer be consumed by infants.

Improvement of infant's gruel energy density thus requires studies on the relationship between energy density and consistency. However, gruels are generally prepared with starch-rich raw materials and consequently have a complex rheological behaviour, similar to starch pastes. Their consistency is therefore difficult to characterize. Viscosity measurements are widely used for this purpose. Many gruel viscosity data are available in the literature, but comparisons and interpretations are often unfeasible because the measurement conditions are not always given in detail and change between studies. Viscosity values for gruels can vary markedly depending on the measurement conditions, *i.e.* viscometer type, measurement spindle, shear rate, shear time and gruel temperature. Hence, standardized methods and procedures are required to obtain pertinent data.

Most current measurement methods used to determine gruel consistency and the effects of each measurement condition mentioned above are reviewed in the present paper. Results obtained using standardized procedures when investigating various gruel types are analysed to highlight the main factors influencing gruel consistency and to assess the efficiency of technological processes for improving the relationship between energy density and consistency of gruels.

I. Methods for characterizing gruel consistency

Instrumental and sensorial assessment methods are commonly used for this purpose. Instrumental methods are restrictive as there is always a limited number of parameters involved, whereas sensorial assessments are based on visual and tactile impressions of the food products prior to and during their consumption.

I.1. Instrumental measurements

I.1.1.Viscosity measurements

Viscosity measurements are widely used to characterize gruel consistency. Viscosity should first be clearly defined in order to be able to efficiently use this parameter and understand its limits.

Viscosity is defined as "the internal friction of a fluid or its tendency to resist to flow" (Bourne, 1982). It is denoted η and defined by the following equation:

$$\eta = \frac{\sigma}{\dot{\gamma}} \text{ (in Pa.s)}$$

where the shear stress σ (in N/m^2 or Pa) is a stress applied tangentially to the product, and the shear rate $\dot{\gamma}$ (in s^{-1}) is the velocity gradient established as a result of the applied shear stress.

The viscosity η must be determined in well-defined shear conditions allowing laminar flow in which each layer of the product is sliding in a parallel direction. Some instruments such as viscoamylographs commonly used to characterize starchy products work under turbulent flow conditions, but the viscosity η can no longer be used and these methods are only comparative.

The viscosity measurement principle thus involves assessing the relation between shear stress and shear rate in well-defined conditions. For Newtonian fluids, the shear rate is directly proportional to the shear stress, and the viscosity is given by the slope of the shear stress-shear rate curve, also called the flow curve (Figure 1). The viscosity η can then be considered as a characteristic property of a given Newtonian product. For example, when measured at 20°C, the viscosities of water, milk or olive oil (which show Newtonian behaviour) are 1, 3 and 100 mPa.s, respectively. However, for non-Newtonian fluids such as infant's gruels, viscosity can vary as a function of shear time and shear rate - it is then an apparent viscosity which is linked to the measurement conditions.

Various apparatuses are used for viscosity measurements. The most appropriate for characterizing gruel consistency are rotational viscometers. Nevertheless, a distinction should be made between fundamental and empirical rotational viscometers.
In fundamental viscometers, the measurement cells (coaxial cylinders or cone and plate systems) are characterized by narrow clearance between the rotating member and the fluid-containing cup (Figure 2). A controlled shear rate can be applied with these viscometers. These viscometers are sold, for example, by Haake (Rotovisco, VT500) and Rheomat.
Empirical viscometers such as the well-known Brookfield type are based on torque measurements when a spindle of various size rotates in a container. The clearance between the rotating member and the container wall is usually large, leading to a variable shear rate in the fluid (Figure 1). In this case, the controlled parameter is just the rotating velocity of the spindle and not the true shear rate. For non-Newtonian fluids, the use of these viscometers allows the measurement of "Brookfield" viscosity, which is only useful for comparative purposes.

High-starch gruels have a complex non-Newtonian behaviour. Their viscosity values can thus vary on the basis of the measurement conditions and viscometer type. We noted that in 37 published studies dealing with gruel consistency, 70% used a viscometer with a rotating spindle (Brookfield LV model 25%; Brookfield RV model 39%; and Viscotester Rion VT04 3%), and the other 30% used one viscometer with coaxial cylinders (Haake model 28%).

Figure 3 shows the effects of maize gruel concentration on viscosity, as measured by three different systems selected from amongst those most commonly used for characterizing gruel consistency: a Haake VT500 viscometer with SVDIN coaxial cylinders, a VT04 Rion viscometer with a n°1 spindle, and a Brookfield RV viscometer with a n°6 spindle. The three resulting curves have almost the same shape, but the viscosity values obtained with the different viscometers when assessing the same gruel differed markedly, and this trend was accentuated as the gruel dry matter contents increased. For instance, viscosity measurements obtained with the Haake VT500, VT-04 Rion and Brookfield RV viscometers were 0.2, 0.4 and 0.5 Pa.s, respectively for a maize-flour gruel with 5.8 g DM/100 g, and 2.0, 10.2 and 28.7 Pa.s for a maize gruel concentration of 10.9 g DM/100 g. There were linear relationships between the viscosities measured with the different viscometers (Figure 4). Viscosity measurements should now be obtained with other types of flour to determine whether the parameters of these linear relationships can be generalized.

It should be pointed out that a change in spindle size on the same viscometer can also modify the viscosity results.

The non-Newtonian behaviour of gruels is primarily due to their marked shear-thinning properties. Indeed, irrespective of the types of gruel (simple flour or multi-component gruel) and viscometer used, their apparent viscosity decreases as the shear rate increases (Figure 5). The fact that viscosity measurements are dependent on the shear rate partially explains the observed differences between viscometers.
Figure 6 shows that, at a shear rate of 6.3 s^{-1}, the viscosity of gruel A (extruded rice flour) was much lower (1 Pa.s) than that of gruel B (crude multi-component flour prepared with millet, soybean, groundnut and sugar) (2.5 Pa.s). Then, at 100-120s^{-1}, gruels A and B show the same apparent viscosity ($\approx$ 0.4 Pa.s).

This shear-thinning phenomenon could be explained as follows: at a certain concentration threshold, starch macromolecules are close enough together to establish low-energy bonds, thus boosting the apparent viscosity of the gruel. Rotation of the viscometer spindle energizes the system, which halts these interactions, upsets the orientation and separates any chains that offer shear resistance, leading to a decrease in the apparent viscosity. These interactions begin occurring again and the apparent viscosity rises as this energy input decreases (*i.e.* as the shear rate decreases).

Similarly, the shear time can also modify the apparent viscosity, which decreases as shear time rises (Figure 8). This property, called thixotropy, is usually attributed to the progressive breakdown of aggregates of suspended particles under a given shear stress. As the number of disrupted interparticle bonds increases, the viscosity drops. A balanced particle aggregation state corresponds to each shear rate. In a standing state, these particle aggregates reform and the medium begins restructuring. Gruels are actually suspensions of swollen starch granules that can show thixotropic behaviour when prepared at high concentration.

Gruel temperature is also a factor that could substantially modify viscosity, *i.e.* viscosity generally increases as the gruel cools. This is a very common phenomenon that occurs with all types of gruel, irrespective of the concentration (Figure 8). However, the extent of this temperature dependence can vary according to the type of flour used. As shown in Figure 8, during the cooling process, the apparent viscosity of cassava gruel increases to a greater extent than for rice and maize gruels. It is therefore important to perform viscosity tests under thermostatically controlled conditions. The consistency measurement temperature should be chosen close to the temperature at which the gruel is usually consumed by infants. This consumption temperature generally ranges from 40 to 50°C, but varies slightly in different geographical contexts. In the literature, the most common temperatures at which viscosity measurements are performed are 40°C (Araya, 1991; Svanberg, 1987; Wanink et al., 1994) or 45°C (John, 1988; Trèche and Mbome Lapé, in press).

I.1.2. Empirical measurements

Many different empirical instruments are available for the evaluation of food consistency, but distance measuring instruments, such as Bostwick or Adams consistometers, are the most suitable for gruel consistency measurements. The Bostwick consistometer (Figure 9) has a level stainless-steel trough with two compartments separated by a spring-loaded gate

maintained by a trigger. The first compartment is filled with 100 ml of gruel whose consistency is to be tested. At t=0, the trigger is pressed, thus releasing the gate which springs up out of the way. The gruel is then free to flow by gravity from the first compartment to the second compartment. The distance it flows from the gate after 30 s is measured in millimetres as the Bostwick consistometer reading. The results given by this type of instrument cannot be converted into fundamental rheological parameters because factors other than viscosity, such as surface tension, wetting power or stickiness, may also be involved (Bourne, 1982).
There is a more sophisticated model of this type of consistometer named Polyvisc, which is distributed by Kinematica. It differs from the Bostwick consistometer because it is plastic, and automatically displays the distance covered by the gruel front after 30 s.

The principle of the Adams consistometer is similar to that of the Bostwick consistometer, but with an even simpler design: it consists of a levelled hard plastic sheet graduated with concentric circles at regular intervals. A cylinder is placed at the centre of the sheet and filled with the product to characterize. At t = 0, the cylinder is gently lifted and the product is allowed to flow out in two dimensions across the sheet. After a standard period of time, the distance of flow is measured from the outer edge of the cylinder to the external edge of the product in millimetres.

With these empirical instruments, reproducible experimental results can be obtained if the conditions set out by the inventors are respected. The disadvantage of the Adams consistometer is that a very high volume of product is required for each measurement (about 600 ml).

As an example, variations in the Bostwick consistency parameter as a function of the gruel concentration is given in Figure 10. The progressively higher values obtained when the flour content is increased confirms the relevance of this parameter for discriminating gruels of various consistencies. Figure 11 shows the relation between consistency measurements obtained with rice, maize and cassava gruels using Bostwick and Polyvisc consistometers. A linear regression gives the following equation:

Bostwick parameter = 0.97 x Polyvisc parameter

The slight difference observed is probably due to the different manufacturing materials of the instruments, but these variations were negligible.

As for the viscosity, gruel temperature has an important influence on Bostwick or Polyvisc consistency parameters and should be controlled during the measurements (Figure 12).
The Bostwick consistency parameter negatively varies with the viscosity (Figure 10). Values for the thicker gruels are close to 0, whereas they can reach 240 mm (upper limit of the Bostwick consistometer) for more liquid gruels. Note that relations between viscosity and the Bostwick consistency parameter can differ as a function of the type of gruel flour used. A viscosity of 1 Pa.s thus corresponds to Bostwick consistency parameter values of 28, 46 and 95 mm/30 s for corn, rice and cassava gruel, respectively.
In the light of these observations, the following question comes to mind: What instrumental parameter most accurately conveys mothers' and infants' sensorial evaluation of gruel consistency?

I.2. Sensory methods

Many authors use a rough 2-3 group classification to describe the effects of gruel consistency on infants' energy intake. The descriptors, however, are highly variable, *e.g.* the most diluted gruels are ranked as liquid, thin and fluid, while thick concentrated gruels are classified as thick, stiff, sticky or semi-solid, etc.(Marquis et al., 1993; Moussa et al., 1992; Rahman et al., 1994). Other authors use more flamboyant expressions, *e.g.* free-flowing, spoonable and drop batter, dough-like and sticky, to express thicker and thicker consistencies (Gopaldas et al., 1988).

This wide variety of descriptors highlights the difficulties involved in characterizing consistency, a multifaceted property, via single instrumental parameters. Sensorial assessments can simultaneously integrate all stimuli related to gruel consistency, but the most complicated aspect of these methods concerns the choice of vocabulary to describe specific sensations. Several authors have proposed correlations between descriptors and viscosity values (Table 1). These descriptors sometimes have qualitative definitions based on comparisons with other foods (yoghurt, soup, batter, etc.), or on the way the characterized food product has to be consumed due to its consistency (drinkable, spoonable).

Table 1: Correlations between descriptive terms used in sensory methods and viscosity range proposed in the literature.

Number of classes	short descriptive term or expression	qualitative definition	viscosity range (Pa.s)	Authors	viscometer type
3	- drinkable - **spoonable** - thick	 with the consistency of yoghurt 	<1 **1< <3** >3	Trèche and Mbome Lapé, in press	Haake, VT500 SVDin, 83s^{-1} 45°C, 10 min
6	- free-flowing liquid - soup-like - easily **spoonable** - thick, batter-like - very thick, non - spoonable - dough-like		<1 1< <3 **3< <6** 6< <10 10< <40 >40	Ashworth and Draper, 1992 (from data of Gopaldas et al; 1988)	Brookfield measurement conditions unknown
4	- liquid/semi-liquid - soft - semi-solid - solid (stiff)	free-flowing state which could easily be poured off from a table-spoon could easily be poured off in large drops from a table-spoon is poured off in one large piece from a table-spoon is stuck to the spoon and cannot be poured off	<3 3< <10 10< <20 >20	Svanberg, 1987	unknown

These classifications differ in many ways: number of classes, qualitative description used, and corresponding viscosity range. For instance, the viscosity expressed by the term "spoonable" ranges from 1 to 3 Pa.s according to Trèche and Mbome-Lapé (in press), but from 3 to 6 Pa.s for Ashworth and Draper,(1992). These wide differences could be explained by two factors: (1) the type of viscometer and the viscosity measurement conditions; (2) the author's culture and dietary habits.

Indeed, conditions for assessing gruel consistency have not been sufficiently standardized, with respect to both instrumental (ill-defined measurement conditions) and sensorial methods (ill-defined descriptors). Many published results cannot be compared with those obtained in other studies, thus often leading to contradictory conclusions concerning the impact of gruel consistency on energy intake (Rahman *et al.*, 1994; Stephenson *et al.*, 1994).

Finally, what gruel consistency characterization method could be recommended? There is no universal answer, but several different possibilities could be put forward, depending on the type of study that is to be carried out:

- if a laboratory study is planned to investigate the effects of a process on gruel consistency, the best approach would be to conduct viscosity analyses under standardized conditions (type of viscometer, measurement spindle, shear rate (or rotation velocity), shear time, gruel temperature, etc.). As an example, in our Tropical Nutrition Laboratory, for several years, we have been using a Haake VT500 viscometer with SVDIN coaxial cylinders under the following conditions: shear rate = 83 s^{-1} (64.5 rpm); gruel temperature = 45°C and readings are taken after 10 min shear time.

These measurement conditions were chosen for two reasons:

- first, they match conditions in which infants perceive gruel consistency: *i.e.* 45°C is close to the temperature at which gruels are consumed, and 83 s^{-1} is within the range of shear rates (10 to 100 s^{-1}) in a human's mouth when he/she consumes liquids with a viscosity ranging from 0.1 to 100 Pa.s (Shama and Sherman, 1973).
- secondly, they reduce the measurement variability associated with the non-Newtonian nature of gruels: preset shear rates and times (83 s^{-1} and 10 min) in order to take shear-thinning and thixotropic behaviours into account.

- if an experimental study is to be carried out in the field, a Bostwick consistometer or other types of heavy-duty and easy to use consistometers would be highly suitable.

Note that a viscosity value or a Bostwick consistency parameter value can only be useful if combined with the dry matter content of the gruel determined after cooking.

- in field surveys, where many different types of gruels can be encountered, it could be suitable to use a rough classification based on a qualitative description, but it is essential to use vocabulary that will be fully understood by the survey population.

Women and infants should be interviewed in surveys aimed at establishing correlations between instrumental parameters and sensorial perception of gruel consistency.

Concerning instrumental measurements, the second part of this paper highlights the fact that the main factors determining the gruel consistency/energy density can be clearly identified when standardized measurement conditions are used. For all of the tests discussed hereafter, apart from the viscosity and consistency measurements, gruels were prepared and cooked under standardized conditions.

II. Main influencing factors of gruel consistency

II.1. Influence of concentrations of different nutrients

1.1. Flour concentration

When the energy density of a gruel is to be increased, the first strategy that comes to mind is to increase the flour concentration, *i.e.* the dry matter content. However, an over-thick consistency problem soon arises. The consistency, as for starch pastes, closely depends on the flour concentration at which the gruels are prepared.

Figures 13 a and b show variations in viscosity and Polyvisc flow distance as a function of the dry matter content for gruels made with a simple rice flour and two multi-component flours (rice/soybean/green bean/sesame and pearl millet/cowpea/groundnut). These figures clearly demonstrate a very marked increase in viscosity and a decrease in the flow distance with slight increases in gruel dry matter content. For simple rice flour, once the dry matter content reached 12 g/100 g gruel, the flow distance was close to 0, corresponding to an almost solid consistency.

There was a shift in the consistency parameter curves towards higher concentrations when multi-component flours were used. For instance, for a viscosity of 3 Pa.s, concentrations of the corresponding gruels were 10.2, 13.4, and 18.8, respectively, for simple rice flour and rice/soybean/green bean/sesame and pearl millet/cowpea/groundnut multi-component flours. The viscosity level of 3 Pa.s, measured under the standardized conditions described earlier, could be considered as the upper limit for gruel that young infants readily accept. These behavioural differences noted with the three types of flour could be explained by their starch contents, *i.e.* 88.3, 64.0 and 44.4, respectively. These curves become almost superimposed when plotted as a function of gruel starch contents (Figures 14, a and b).

This shows that starch content is the main determinant of gruel consistency, regardless of whether this parameter is assessed by viscosity or Polyvisc flow distance.

Using multi-component flours enhances the balance of nutrients supplied by the gruel (protein and lipid supplements) and also substantially boosts the energy density of gruels without altering the consistency. This is clearly demonstrated in Figures 15 a and b, which show the viscosity and flow distance curves for these three types of gruel as a function of their energy density. For a maximum viscosity of 3 Pa.s, there is a twofold increase in the energy density (from 41 to 82 kcal/100 g gruel) when comparing gruels made with simple rice flour and with multi-component flours (pearl millet/cowpea/groundnut). However, according to the latest WHO recommendations (WHO, 1998), the minimal complementary food energy density required for breastfed 6-8 month-old infants receiving two gruel meals a day (*i.e.* a very common pattern in many African countries) is 128 kcal/100 g of gruel. Hence, even if multi-component flours are used, it is not possible to prepare gruels with energy density levels that would be high enough to meet energy needs of young infants.

1.2. Effects of adding oil or sugar

Many techniques have been proposed to enhance the energy density of gruels while retaining a suitable consistency, *e.g.* the addition of oil (or a lipid-rich ingredient such as groundnut paste) and sugar (Kikafunda *et al.*, 1997; Onofiok and Nnanyelugo, 1998; Sopade, 1995; WHO, 1998).

There are two potential ways of incorporating ingredients in a gruel: first, gruels with equivalent dry matter contents could be compared, with ingredients added (generally sugar or

oil) as a replacement for an equivalent quantity of flour dry matter; secondly, gruels with equivalent flour concentrations could be compared, with ingredients simply added. The first method, which has been used by Kikafunda *et al.* (1997), shows a considerable decrease in viscosity, mainly due to a relative decrease in the gruel starch content. These authors also suggested the possible formation of starch-lipid complexes or of an effect of starch grain coatings with a fat layer, which would decrease the water absorption capacity of the starch, thus reducing the thickening process during gruel cooking.
The consistency effects of adding oil or sugar to liquid (5.4%) or thick (7.8%) rice gruels were studied. For the liquid gruel, adding oil did not have a significant effect on the flow distance. For the thicker gruel, as shown in Figure 16, there was a slight increase in the flow distance when oil or sugar were added, but this minor increase in fluidity was barely perceptible from a sensorial viewpoint, despite the high quantities of ingredient added.
The energy density of gruels could therefore be increased by adding oil or sugar, without significant modifications in gruel consistency. However, added quantities should be kept reasonable to avoid upsetting the nutrient balance in the gruel. According to recent WHO data (1998), lipid-based energy inputs in complementary foods should be comprised between 30 and 45%. Energy densities of rice gruels prepared in these conditions are much lower than the recommended minimum value of 128 kcal/100 g of gruel (Figure 16).

Adding "non-starchy" ingredients to gruels increases lipid and protein intake, thus partially enhancing the energy density. However, there are two limitations: (1) the respect of the macronutrient balance, and (2) the availability of ingredients supplying these nutrients: starchy, cereal and tuber raw materials are often staple foods in developing countries, and generally more economically accessible than other ingredients (protein and oilseed products).
Hence, processes enabling partial hydrolysis of starch are necessary to help obtain gruels with suitable consistency and energy density.

II.2. Modifying the functional properties of starches

Starches are large-molecule polymers that can include several thousands of glucose residues bound in α 1-4. Starch molecules are organized as insoluble grains in raw materials prior to processing. During hydrothermic treatment, these grains open, become hydrated, and the starch molecules unfold, thus increasing the viscosity of the medium - these are gelatinization-swelling phenomena (Figure 17). When starch molecules are large, the viscosity they produce in the medium during cooking will generally be high. This viscosity can be substantially reduced through a reduction in their molecular size obtained by disrupting a few bonds in the middle of the chain.
The processes most commonly used for partial hydrolysis of starch, thus reducing the viscosity of gruels, are enzymatic hydrolysis and extrusion cooking.

2.1. Enzymatic hydrolysis

Processes based on enzymatic hydrolysis of starch have been fully described in the literature (Gopaldas *et al.*, 1986; Trèche, 1995). Three enzyme sources can be used: an industrially-produced bacterial amylase, a vegetal amylase contained in malt flours, or a bacterial amylase produced during fermentation induced by amylolytic lactic bacteria. This latter source, however, should be the focus of studies to assess its feasibility and efficacy.

Figure 18 shows the effect of the added quantity of amylase on the viscosity of multi-component flour-based gruels (millet/soybean/groundnut/sugar) prepared at 30% concentration, which corresponds to an energy density of 127 kcal/100 g. Without amylase, it is very difficult to prepare such a concentrated gruel: there would be so much thickening during cooking that the gruel would stick to the saucepan. A gruel of any desired consistency could be prepared with 30% DM by simply adjusting the quantity of BAN amylase added.

The consistency of these gruels modified by an amylase supplement remains closely dependent on the concentration. Figure 19 shows that the viscosity of gruels rises quickly with the concentration, irrespective of the type of flour used, and regardless of whether or not amylase is added. This figure also highlights the different sensitivities to enzymatic hydrolysis of various flours: maize flour appears to be more resistant to hydrolysis than rice or cassava flours. This could be explained by differences in gelatinization temperatures. The enzyme is actually only active on gelatinized starch (whose granular structure is broken down) and is denatured when the temperature rises above 85°C. The intensity of starch hydrolysis is therefore related to the time it takes for the temperature to rise between gelatinization and enzyme denaturation. The lower the gelatinization temperature is, the longer is the gelatinization-denaturation time and more pronounced is the hydrolysis.

For small-scale or family preparations, malt flour can be used instead of BAN amylase. The amylolytic potential of these malt flours, which can vary according to the malting conditions (type of grains, germination time and drying intensity), is much lower than that of the purified BAN enzyme. When malt flours are added at about 10%, they prompt a spectacular increase in the concentrations (*i.e.* energy densities) at which gruels can be prepared (Figure 20). However, women who manage meals for the household might hesitate to prepare malt flours with optimal amylolytic properties as it is a very delicate and time-consuming procedure.

2.2. Extrusion cooking

It has always been considered that extrusion cooking is a sophisticated and expensive technology. Nevertheless, extension of this technique could be promoted by carrying out studies designed to develop small-scale inexpensive equipment that could be produced locally. Extrusion cooking is a process by which a product is very briefly submitted to intense mechanical treatment at high temperature and pressure. These severe processing conditions cause many physicochemical modifications in the food product. Gelatinization and dextrinization are two phenomena responsible for modifying the functional properties of starches (Figure 17). Gelatinization, which breaks down the granular structure of raw starch, acts as a precooking stage and gives infant flours their "instant" character, *i.e.* hot water just has to be added to prepare gruels with these flours.

Dextrinization is prompted by starch chain disruption, which occurs randomly as a result of shear stress. This process leads to the formation of maltodextrins and reduces the viscosity of gruels.

Note also that extrusion cooking leads to denaturing of some antinutritional factors. However, in cases of over-heating, losses of some essential nutrients such as available lysine can occur.

Figure 21 shows viscosity variations of gruels prepared with raw and extruded rice and multicomponent flours as a function of their dry matter contents. As noted with enzymatic hydrolysis, there is a shift in the viscosity curve for extruded rice flours towards higher concentrations. However, with simplified extrusion cookers, the efficiency of extrusion cooking can be reduced for multi-component flours, especially since they have high lipid contents. Starch gelatinization and dextrinization are not sufficient to produce instant flours that could be used to prepare gruels with adequate consistency and energy density levels. As shown in Figure 21, for the raw and extruded multicomponent flour (rice/soybean/green-bean/sesame), extrusion cooking actually increases gruel concentrations, but not yet to a suitable extent. Studies are currently under way to investigate the many different variables involved in the processes (initial water content, type of extruder, temperature, shear intensity, etc.) - the results should help optimize the process for producing infant flours with a high enough nutritional value to meet young infants' needs.

Conclusion

The results presented in this paper clearly highlight the interest of using standardized methods for the instrumental assessment of gruel consistency. Measurement conditions should also be uniformized in order to be able to compare the results of studies conducted by different research teams on enhancing the energy density/consistency relationship in gruels.
However, a consistency parameter should be selected that would accurately express what mothers and infants sensorially perceive with respect to gruel consistency. Studies on correlating instrumental and sensorial methods should thus be carried out in the field under various conditions. Considering the complexity of perceived sensations and the rheological behaviour of gruels, one parameter might not be enough to be able to match gruel consistency with young infants' and mothers' preferences.

Apart from these results, it seems that the main limiting factor for the preparation of gruels with high energy density and suitable consistency is their starch content. The energy density of prepared gruels can be enhanced by various methods, but processes that prompt partial starch hydrolysis will have to be developed in order to be able to easily achieve currently recommended energy density levels. Enzymatic hydrolysis and extrusion cooking, for instance, offer interesting solutions but they should be optimized through further studies.

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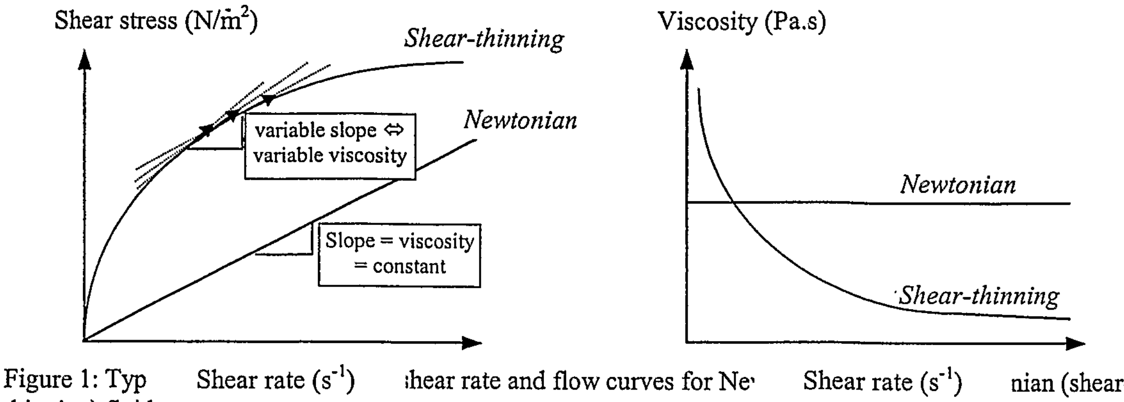

Figure 1: Typ... ...hear rate and flow curves for Ne... ...nian (shear-thinning) fluids.

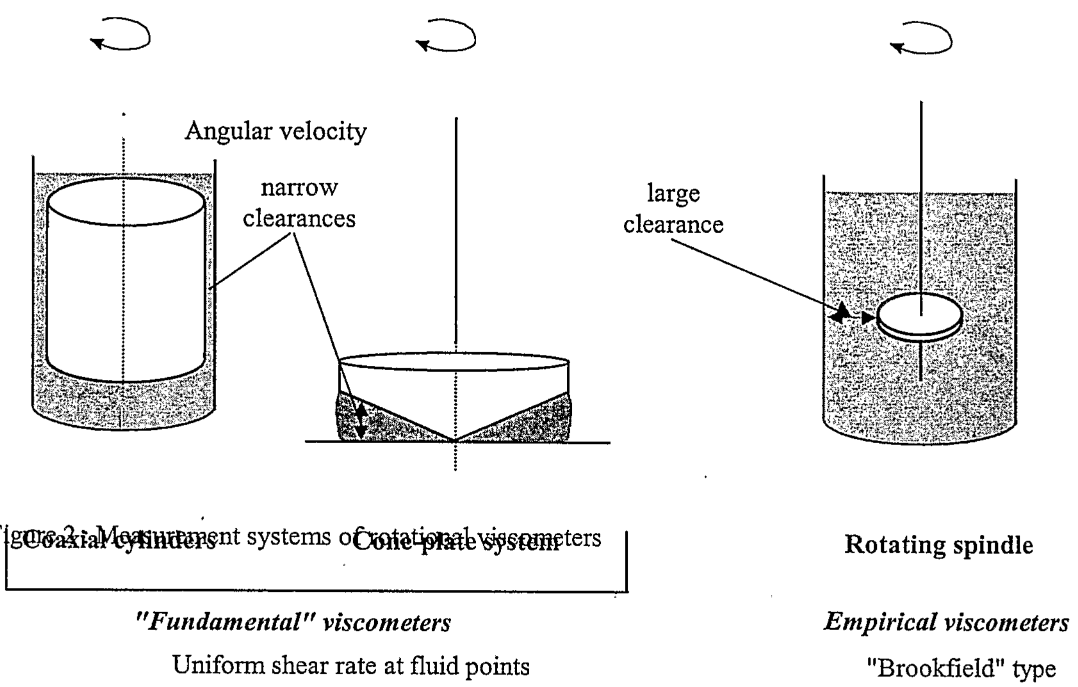

Figure 2: Measurement systems of rotational viscometers

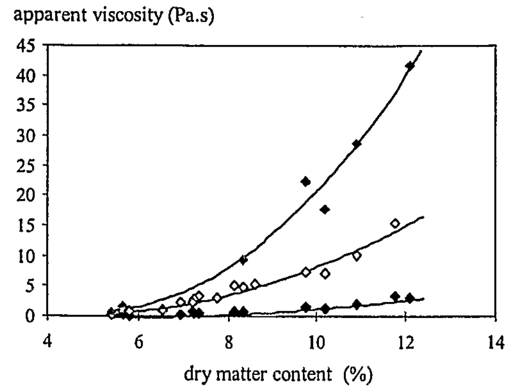

Figure 3 : Effect of the concentration on maize gruel measured at 45°C with three different viscometers : υ Haake VT500, 83 s^{-1}; Γ Rion VT04 - spindle 1, 62.5 rpm; υ Brookfield RV-spindle 6, 20 rpm.

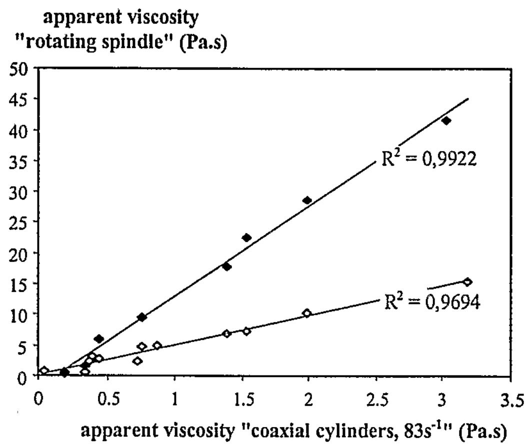

Figure 4 :The relationship between apparent viscosity measured on maize gruels with empirical viscometer with rotating spindle and fundamental viscometer with coaxial cylinders (Haake VT500, 83 s^{-1}): υ Brookfield RV, spindle 6, 20 rpm; Γ Rion VT04, spindle 1, 62.5 rpm.

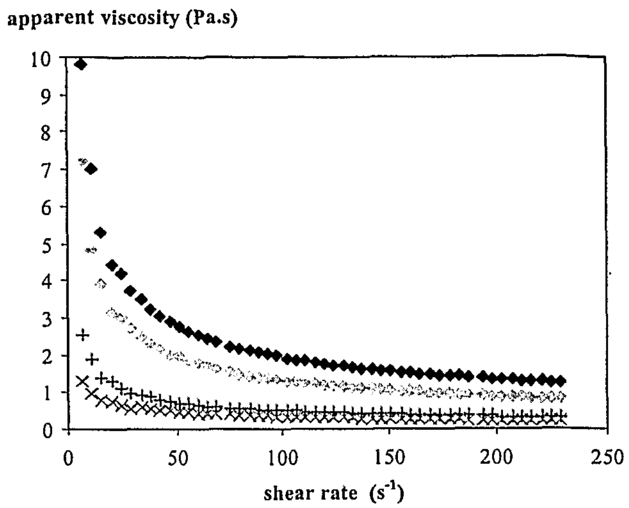

Figure 5 : Effect of shear rate on apparent viscosity (Haake VT500) of simple flour and multicomponent gruels of various concentrations. υ millet/soybean/groundnut/sugar, 15 %; + millet/soybean/groundnut/sugar, 10 %; υ rice, 7 %; 5 rice, 5 %.

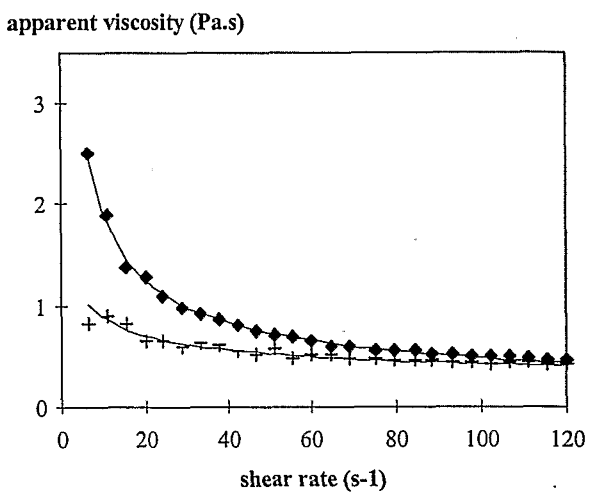

Figure 6 : Shear-thinning behaviour of various gruel types; υ gruel A, prepared with crude multicomponent flour (10 %); + gruel B, prepared with extruded flour rice (16 %)

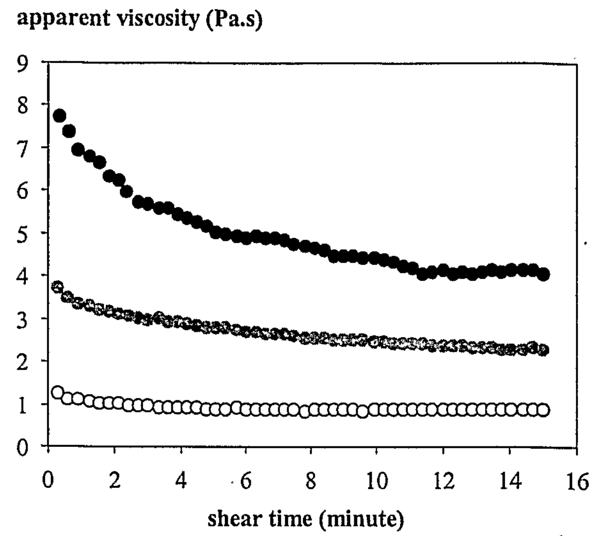

Figure 7 : Effect of shear time on apparent viscosity (Haake, VT500, 83 s^{-1}) of cassava gruels of various concentrations (w/w, dry matter). λ 16.2 %; λ 9.5 %;O 4.9 %.

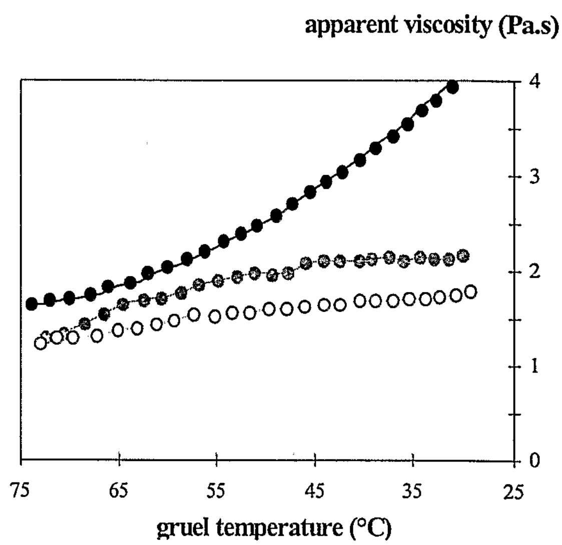

Figure 8 : Effect of measurement temperature on apparent viscosity (Haake, VT500, 83 s^{-1}) of simple flour gruels. λ cassava, 15.0 %; λ maize 10.4 %;O rice 8.0 %.

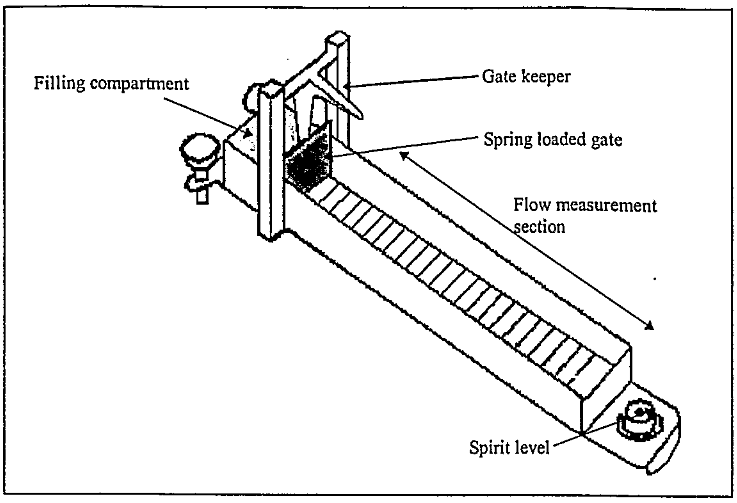

Figure 9: Schematic representation of the Bostwick consistometer

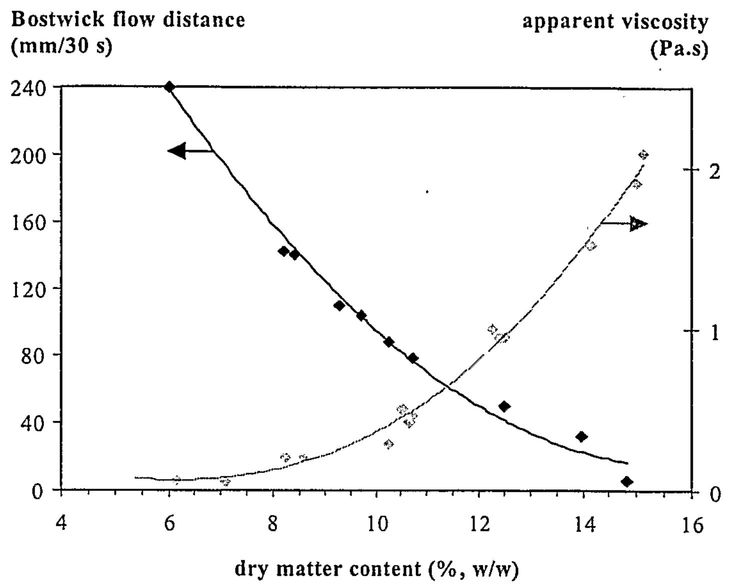

Figure 10 : Effect of concentration on Bostwick flow distance (υ) and apparent viscosity (Haake, VT500, 83 s^{-1}) (υ) of multicomponent gruel (millet/soybean/groundnut/sugar).

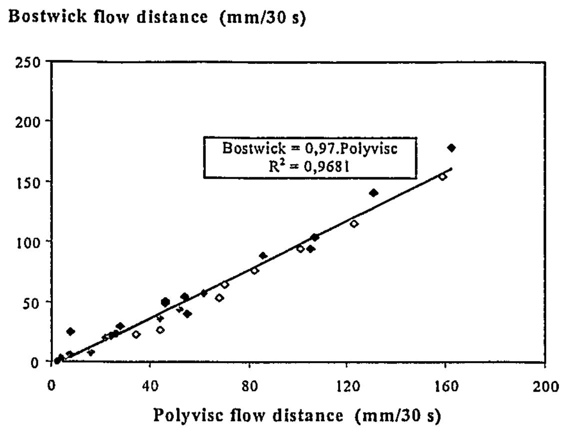

Figure 11 : The relationship between Bostwick and Polyvisc flow distances of maize (υ), rice (υ) and cassava (Γ) gruels at various concentrations.

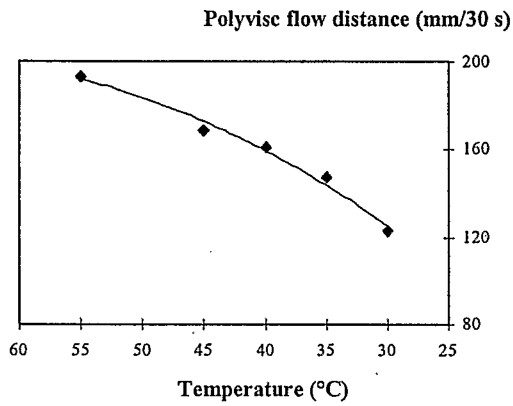

Figure 12 : Effect of measurement temperature on Polyvisc flow distance: example of a multicomponent gruel (25 %, w/w, dry matter) liquefied with amylase.

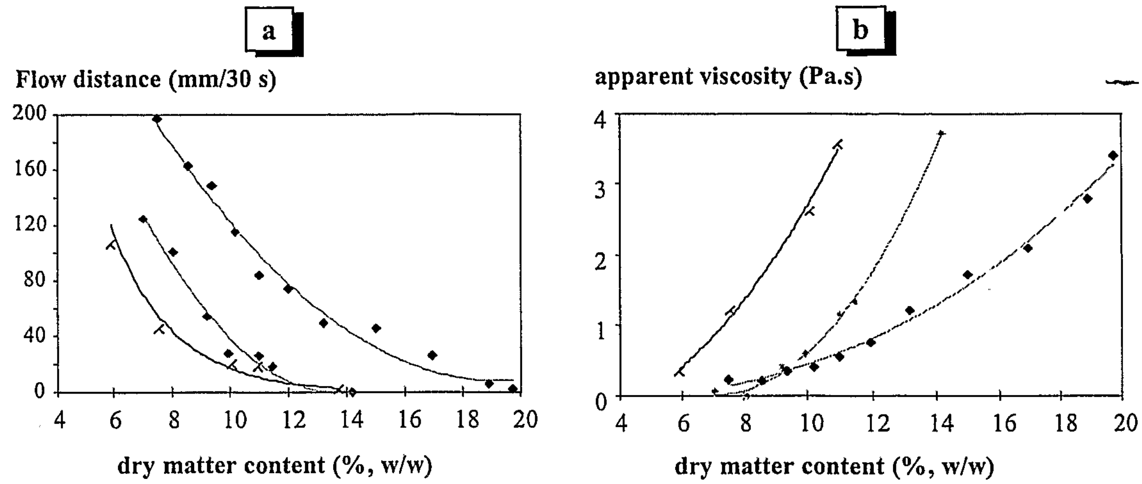

Figure 13 : Effect of concentration (%, w/w dry matter) on flow distance (**a**), and apparent viscosity (**b**) of three different gruels: x rice; ✦ rice/soybean/green bean/sesame ♦ millet/cowpea/groundnut/sugar.

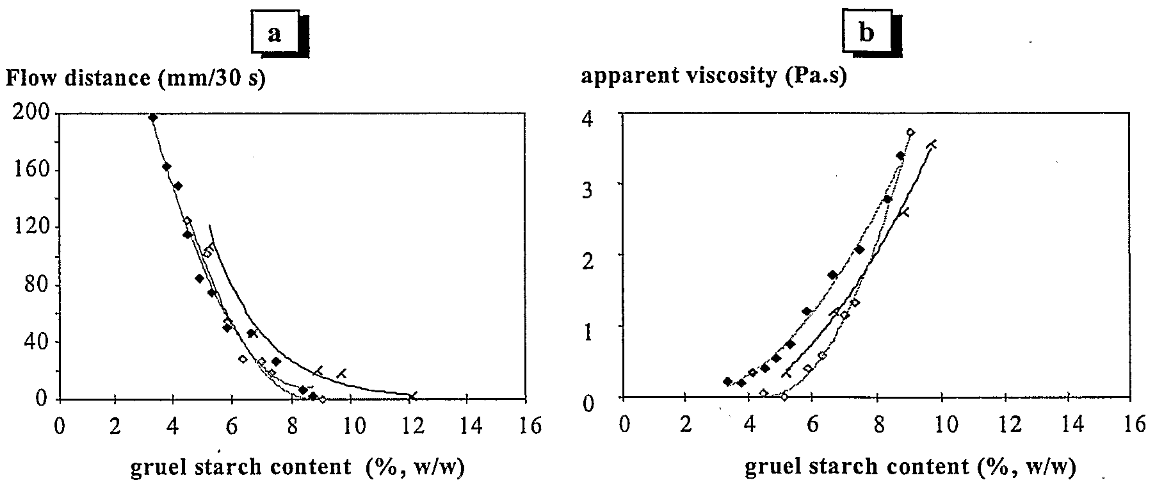

Figure 14 : Effect of starch content (%, w/w dry matter) on flow distance (**a**), and apparent viscosity (**b**) of three different gruels: x rice; ◊ rice/soybean/green bean/sesame ♦ millet/cowpea/groundnut/sugar.

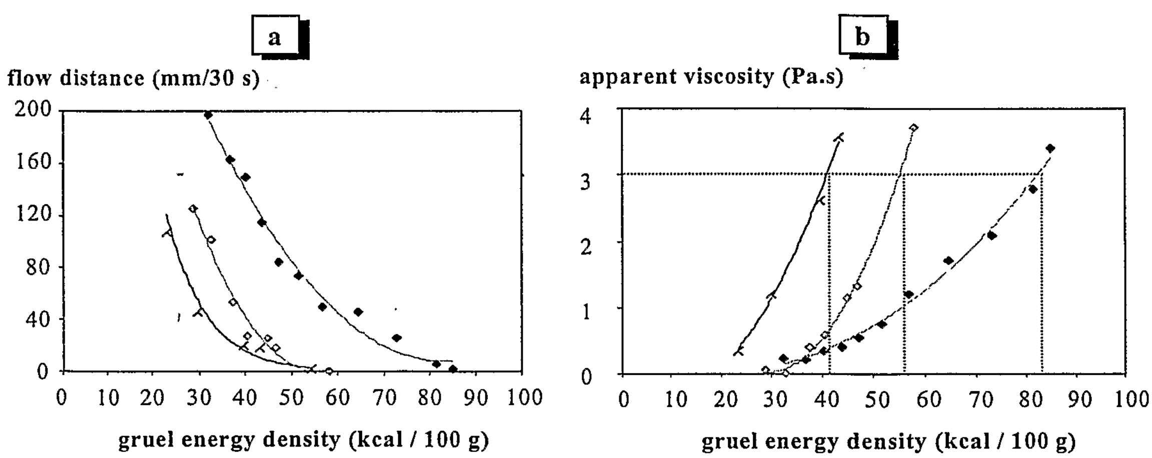

Figure 15 : The relationship between gruel energy density (kcal/100g dry matter) and flow distance (**a**) or apparent viscosity (**b**) of three different gruels: x rice; ✦ rice/soybean/green bean/sesame, ♦ millet/cowpea/groundnut/sugar.

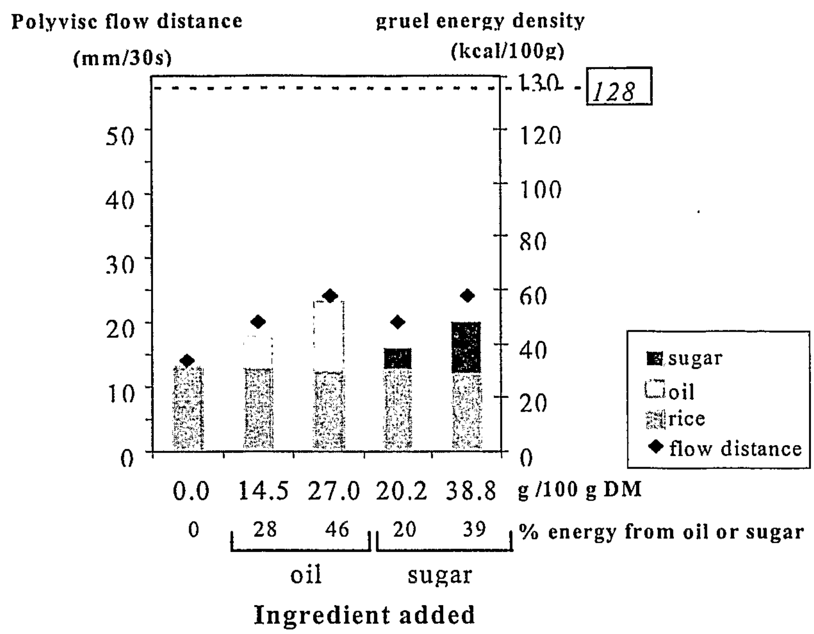

Figure 16 : Effect of oil or sugar addition (g of oil or sugar / 100 g DM) on Polyvisc flow distance and energy density of rice gruel (7.8 % w/w dry matter).

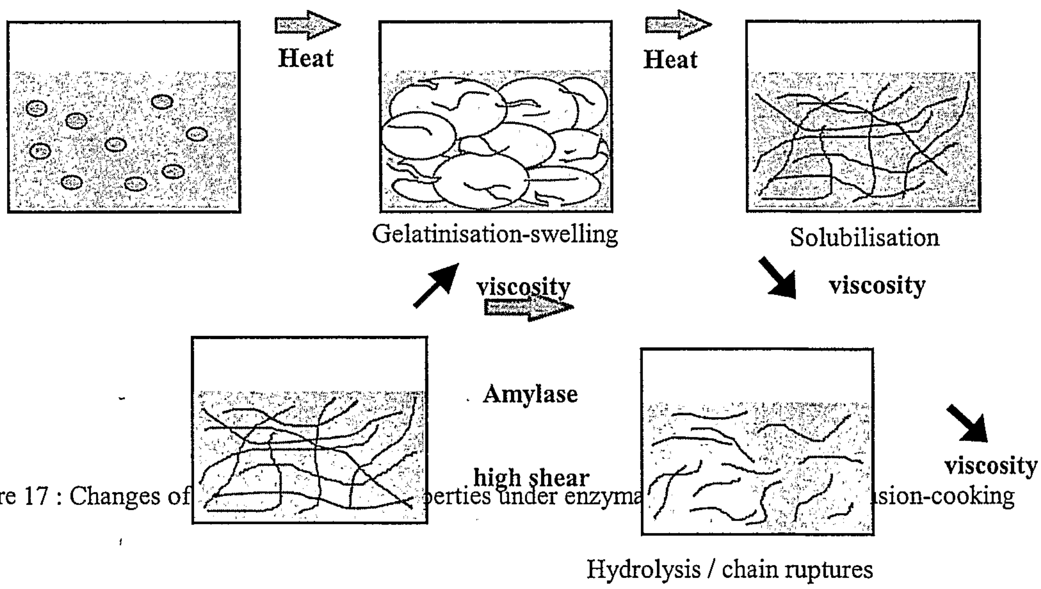

Figure 17 : Changes of ... erties under enzyma ... sion-cooking

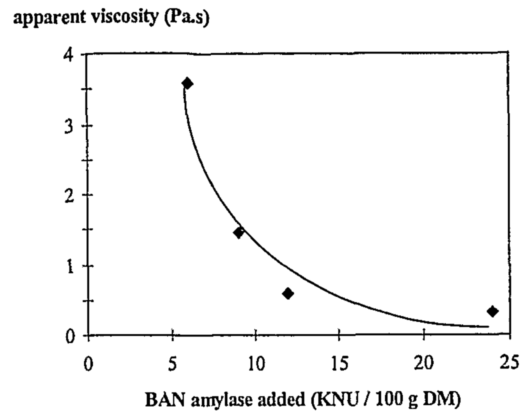

Figure 18 : Effect of amylase addition on apparent viscosity of a multicomponent gruel (millet/soybean/groundnut/sugar) of 30 % dry matter content

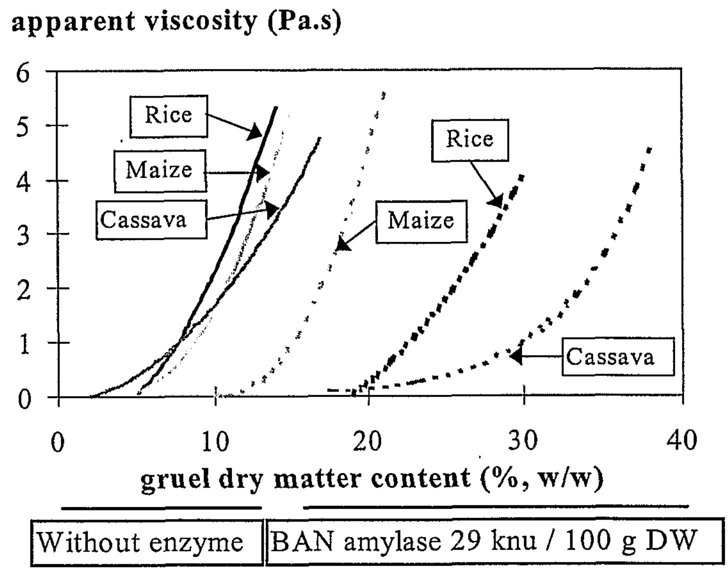

Figure 19 : Effect of the addition of BAN amylase on apparent viscosity of various simple flour gruels (reproduced from Trèche, 1995)

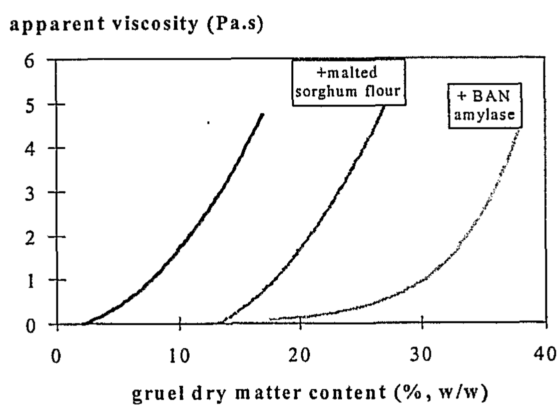

Figure 20: Relationships between concentration and apparent viscosity of cassava gruels ( ); cassava gruels added with malted sorghum flour (10% DW) ( ); and cassava gruels added with BAN amylase (29 KNU/100g DW) ( ).

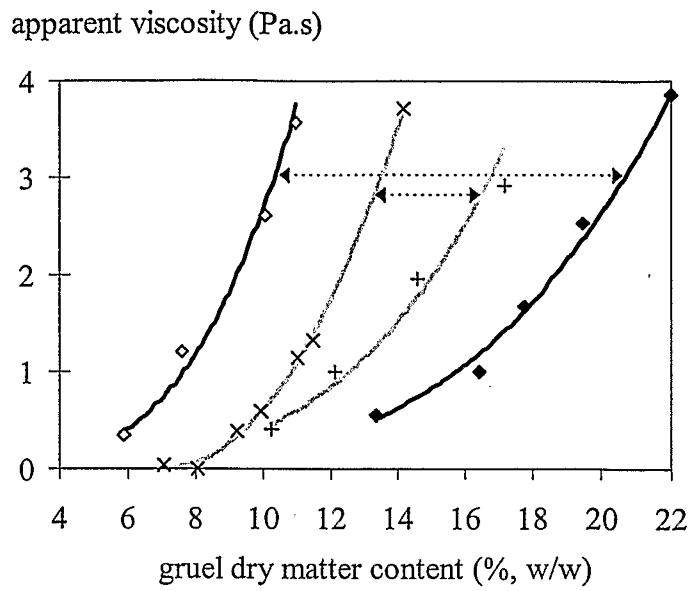

Figure 21: Effect of extrusion-cooking on apparent viscosity of simple flour and multicomponent flour gruels of various concentrations: Γ crude rice flour; υ extruded rice flour; 5 crude rice/soybean/green bean/sesame flour; + extruded rice/soybean/green bean/sesame flour.