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Viscosity of gruels for infants: a comparison of measurement procedures

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Numerous studies have been carried out to investigate energy density and consistency of gruels for infants in developing countries. However, starch-rich gruels have a complex rheological behavior and their consistency is difficult to characterize. Many published gruel viscosity data are available, but the lack of standardized viscosity measurement procedures makes comparisons and interpretations difficult. The influences of viscometer type and viscosity measurement conditions on gruels prepared with simple or multicomponent flours were assessed in this study. The results showed a drastic decrease in apparent viscosity when the shear rate increased. Other factors like shear time and gruel temperature also had a marked influence on apparent viscosity. For two types of gruel (maize or multicomponent flour) prepared at different concentrations, correspondences between a short qualitative description of the consistency and apparent viscosity values obtained with several viscometers in different measurement conditions are given. Finally, recommendations are put forward on techniques to obtain valid data on gruel consistency, adapted to each type of study (laboratory, field or large-scale surveys).

Introduction

The importance of increasing gruel energy density to improve the energy intake of young children in developing countries is now fully recognized (Brown, 1997; WHO, 1998). However, increasing the energy density of these generally starch-rich gruels simply by increasing the flour concentration leads to drastic changes in gruel consistency during cooking, i.e. especially substantial thickening.

Church (1979) postulated that gruel consistency had an influence on the energy intake of young children. Many studies have thus compared diets of low or high energy densities and low or high viscosities. Some of them reported a positive impact of viscosity reduction on the amount of gruel consumed (Gopaldas & John, 1992; Rahman *et al.*, 1994; Darling *et al.*, 1995; den Besten *et al.*, 1998; Bennett *et al.*, 1999) whereas others could not find any significant differences between high energy density–high viscosity versus high energy density–low viscosity diets (Marquis *et al.*, 1993; Stephenson *et al.*, 1994). This controversial issue has been reviewed by several authors. Ashworth and Draper (1992) concluded that the effectiveness of malting (process used to reduce the viscosity of high energy density gruels) to improve the energy intakes of young children

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

Number of classes	*Short descriptive term or expression*	*Qualitative definition*	*Viscosity range (Pa.s)*	*Viscometer type and measuring conditions*	*Ref.*
3	drinkable		<1	Haake VT500, measuring system	1
	spoonable	with the consistency of yoghurt	**1< <3**	SVDin, shear rate = 83 s^{-1}	
	thick		>3	gruel temperature = 45°C	
6	free-flowing liquid		<1		
	soup-like		1< <3		
	easily **spoonable**		**3< <6**	Brookfield LVT	2
	thick, batter-like		6< <10	measuring	
	very thick, non-spoonable		10< <40	conditions not reported	
	dough-like		>40		
4	liquid/semi-liquid	free-flowing state which could easily be poured from a tablespoon	<3		
	soft	could easily be poured in large drops from a tablespoon	3< <10	not reported	3
	semi-solid	is poured in one large lump from a tablespoon	10< <20		
	solid (stiff)	is stuck to the spoon and cannot be poured	>20		

[1] Trèche and Mbome Lapé (1999).
[2] Gopaldas *et al.* (1988).
[3] Svanberg (1987).

was not clearly demonstrated. More recently, Trèche (1996) and Brown (1997) pointed out the apparent inconsistency of all published results. According to Trèche (1996), imprecise viscosity determinations could be a key factor hindering comparisons between these different studies and definitive conclusions on the effects of gruel viscosity and energy density on infants' energy intake.

Gruel consistency is usually characterized into two ways:

- The first consists of measuring gruel viscosity. However, gruels are generally prepared with starch-rich raw materials and consequently have a complex rheological behavior. A specified gruel therefore cannot be only characterized by a constant viscosity value but raises several values that can vary markedly depending on measurement conditions, i.e. viscometer type, measurement spindle, shear rate, shear time and gruel temperature. 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 they can change between studies.
- The second way is based on sensory evaluation and involves describing the gruel consistency with qualitative adjectives. The descriptors used, however, are highly variable, e.g. the most diluted gruels are ranked as liquid, thin or fluid, while thick concentrated

gruels are classified as thick, stiff, sticky or semi-solid, etc. Moussa *et al.*, 1992; Marquis *et al.*, 1993; Rahman *et al.*, 1994). Other authors use more flamboyant expressions based on comparisons with other foods (yogurt, thin milkshake, soup, pour batter or drop batter, dough, mashed potatoes, etc.), or on the way the characterized food product has to be consumed due to its consistency (drinkable from a bottle or from a cup, spoonable), (Gopaldas *et al.*, 1988; Gopaldas & John, 1992; Marquis *et al.*, 1993). The main problem linked to these descriptive methods is that the choice of the descriptors is subjective and closely linked to the authors' culture and dietary habits. Consistency can thus be described by a wide variety of words or expressions and different consistencies are sometimes described by the same words.

Several authors have proposed different consistency classes, with correlations between descriptors and viscosity values (Table 1), but 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 (1999), but from 3 to 6 Pa.s for Gopaldas *et al.* (1988). These variations show that conditions for assessing gruel consistency need to be accurately standardized, with respect to both instrumental (measurement conditions) and sensorial methods (descriptors).

The aim of this article is to highlight the influence of viscometer type and measurement conditions on apparent viscosity values of starch-rich gruels and to put forward recommendations for the standardization of consistency characterization methods. Measurements were performed on several types of gruels to illustrate the apparent viscosity dependency on the measuring system. Results led us also to propose a set of measurement conditions corresponding to usual consumption conditions.

Materials and methods

Flour samples

Simple cassava, rice and maize flours were obtained from local commercial suppliers. A multicomponent infant flour prepared with millet (68%), soybean (17%), groundnut (5%), sugar (9%) and salt (1%) purchased in Ouagadougou (Burkina Faso) was also used.

Table 2. Composition of simple flour and multicomponent gruels

Type of gruel	*Composition (g/100 g dry matter)*
Simple flour gruel	
Gruel A	Maize 100%
Gruel B	Rice 100%
Gruel C	Cassava 100%
Multicomponent flour gruel	
Gruel D	Millet 68%, soybean 17%, groundnut 5%, sugar 9%, salt 1%

Preparation of gruels

Gruels at different concentrations were prepared in the following way. Flour was mixed with cold demineralized water into a slurry and cooked with continuous stirring over a hot plate for 5 min once the mixture started to boil. Then the gruel was allowed to cool to a desired temperature before viscosity measurements. The dry matter content of the gruel was determined by oven-drying at 105°C to constant weight.

Composition of the four types of gruel tested is given in Table 2. Attention has to be paid to the fact that those very simple gruels have been chosen to illustrate the complexity of the rheological behavior of such starch-rich gruels, and are not satisfying from a nutritional point of view.

Viscosity measurements

We performed measurements with three different systems selected from amongst those used in the literature: a Haake VT550 to control shear rate, a Brookfield RV which is the most commonly used, and a Rion VT04, which is very simple and can be used easily in the field. These three apparatuses are rotational viscometers but the 'fundamental' ones have to be distinguished from the empirical ones.

In fundamental viscometers, the measurement cells (coaxial cylinders or cone-plate systems) are characterized by narrow clearance between the rotating member and the fluid-

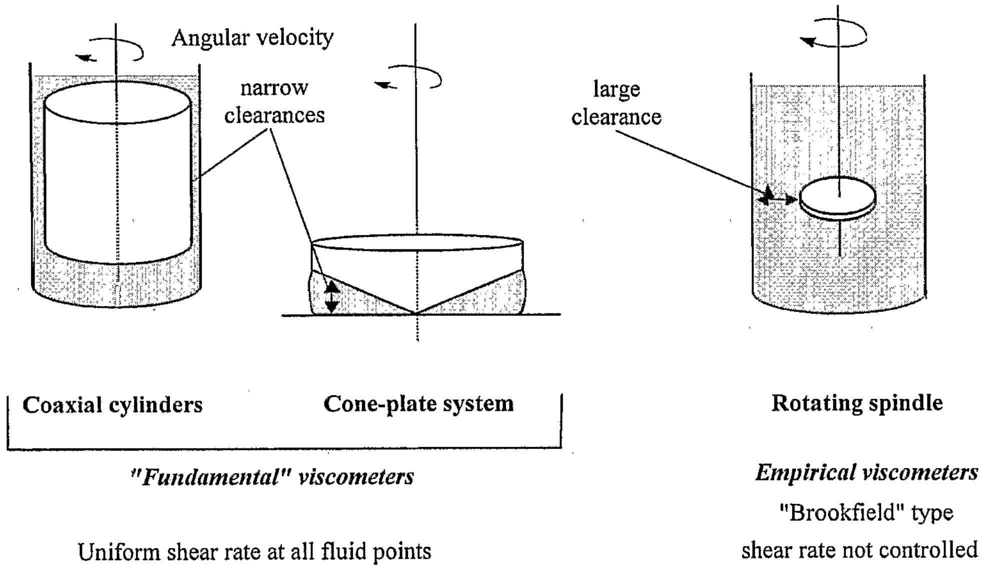

Figure 1. Measurement systems of rotational viscometers.

containing cup, thus the shear rate is controlled in all points of the product (Figure 1).

The fundamental viscometer we used was the Haake VT550 with SV-DIN coaxial cylinders driven by a PC computer with the Rheowin 2.67 software. The measuring procedure involves five steps: 10 min at 83 s^{-1}, 4 min at 8 s^{-1}, 4 min at 800 s^{-1} and a ramp-up from 0.01 to 900 s^{-1} followed by a ramp-down from 900 to 0.01 s^{-1}. The last values of the first three steps were kept as apparent viscosities at 8, 83 and 800 s^{-1}. The last step (ramp-down) was fitted with the very commonly used Ostwald de Waele (or power law) equation.

$$\sigma = K \cdot \dot{\gamma}^{n}$$

Ostwald de Waele equation (1)

where σ is the shear stress (Pa), and $\dot{\gamma}$ the shear rate (s^{-1}).

This equation can also be written:

$$\mu_{ap} = K \cdot \dot{\gamma}^{n-1}$$

Equation (2)

where μ_{ap} is the apparent viscosity (Pa.s).

The two constants of these equations, the consistency index K (Pa.s), and the exponent n (adimensional), also called flow behavior index (Launay, *et al.*, 1986) enables a description of the viscous behavior over the whole range of shear rates studied.

All equation parameters and determination coefficients were determined by ordinary least-squares regression. We used the modeling function of the Rheowin 2.67 software based on the Levenberg (1944) and Marquardt (1963) algorithm.

Empirical viscometers such as the well-known Brookfield type are based on torque measurements when a spindle of various sizes 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 the rotation speed of the spindle and not the true shear rate. For non-Newtonian fluids, the use of these viscometers allows measurements of 'Brookfield-type' viscosity, which is only useful for comparative purposes. We performed 'Brookfield-type' measurements with two apparatuses: one Brookfield RV model with spindles 4 and 6 at different rotation speeds and the Viscotester Rion VT04 with spindle 1 at the only rotation speed possible with this apparatus, i.e. 62.5 rpm.

All viscosity measurements were done in thermostated conditions, at 45 ± 0.5°C, except when the temperature influence was studied.

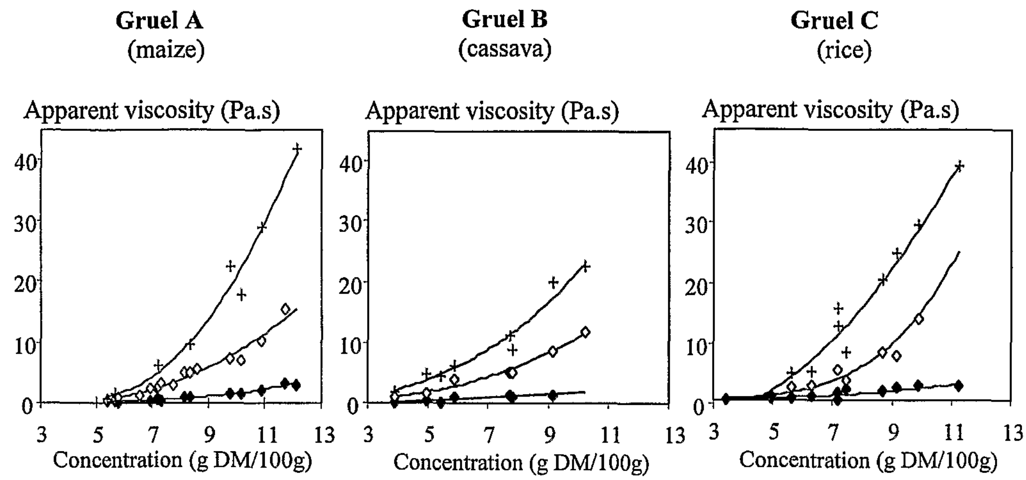

Figure 2. *Influence of the concentration on the apparent viscosity of gruels A, B and C (respectively maize, cassava or rice flour) measured with different viscometer types (shear time = 10 min; gruel temperature = 45°C).* ◆ Haake VT500, 83 s^{-1} ◇Rion VT04 spindle, 1, 62.5 rpm ◇ Brookfield RVT, spindle 6, 20 rpm

Measurement repeatability was evaluated by performing five measures on a maize gruel (7.82%) with each of the eight viscosity measurement systems used corresponding to the three apparatuses and the different conditions sets (shear rate or rotation speed and spindle number). In each case, the coefficient of variation was below 8%.

Results and discussion

Influence of gruel concentration
Measurements were done on gruels prepared with maize, rice or cassava flour at different concentrations (Figure 2).

Unsurprisingly, the results show a marked influence of the gruel dry matter content: the apparent viscosity values increased very rapidly with the dry matter content. But dry matter content is an intrinsic character of gruels that is difficult to control especially in field studies.

Influence of viscosity measurement system
Figure 2 also shows clearly that the apparent viscosity values of gruels are closely dependent on the viscosity measurement system used. This is due to the complex rheological behavior of these starch-rich gruels.

Shear rate
This non-Newtonian behavior is primarily due to a marked shear rate dependency called shear-thinning properties. The shear rate applied was 83 s^{-1} for the Haake system, and could not be determined, but the mean values were probably much lower for the two others.

Figure 3 illustrates the importance of shear rate on apparent viscosity values, under controlled shear rate conditions. Indeed, irrespective of the type of gruel (simple or multicomponent flour), the apparent viscosity drastically decreased as the shear rate increased and this trend was accentuated as the gruel dry matter content increased. This shear-thinning phenomenon is usually 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).

To more accurately describe the rheological properties of such shear-thinning products, it has often been proposed to fit the apparent viscosity curves over a wide range of shear rates with the Ostwald de Waele model (Evans & Haisman, 1979; Sopade & Filibus, 1995). Values of the two coefficients *K* and *n* of models

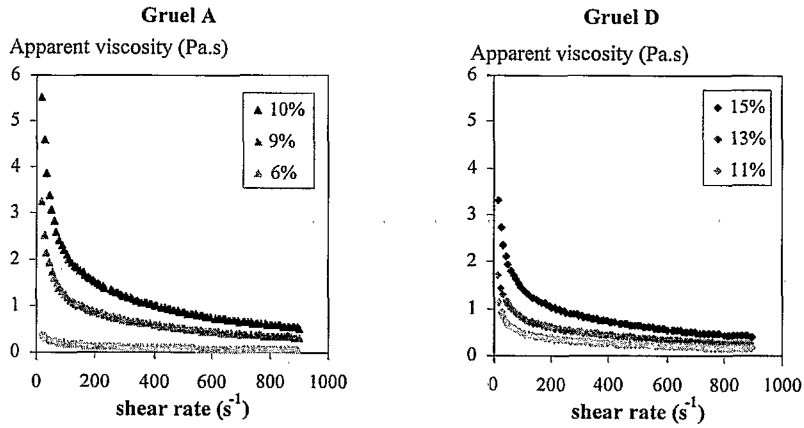

Figure 3. Influence of shear rate on apparent viscosity of gruels A (maize flour) and D (multicomponent flour) prepared at difference concentrations (shear time = 10 min; gruel temperature = 45°C).

obtained for two types of gruels (maize and multicomponent flours) prepared at different concentrations are presented in Table 3.

The determination coefficients (all higher than 0.99) indicated a close fit between the model and experimental results. As reported by Launay *et al.* (1986), the flow behavior index *n* was inferior to 1, thus indicating shear-thinning behavior and decreased when the gruel concentration increased. As expected, the consistency index *K* increased as the gruel concentration increased, but in a much more marked way than the apparent viscosity measured at 83 s^{-1}. From a practical point of view, although the quality of the fit was good, the results of the analysis of the model coefficients were similar to those obtained with a simple analysis of apparent viscosity at a defined shear rate (e.g. 83 s^{-1}). In many cases, the latter method (easier to carry out) could be sufficient.

Shear time

The shear time is another important factor modifying the apparent viscosity, which

Table 3. Ostwald de Waele parameters and determination coefficients obtained by fitting flow curves (between 0.05 and 850 s^{-1}) of gruels A (maize flour) and D (multicomponent flour) at various concentrations

Gruel concentration (g/100 g)	*Apparent viscosity at 83 s^{-1} Pa.s*	*Ostwald de Waele parameters*		*Determination coefficient R^2*
		K Pa.s	*n*	
Maize flour				
5.9	0.16	0.042	0.68	0.9985
6.8	0.21	0.578	0.68	0.9992
8.7	1.05	3.934	0.59	0.9982
9.1	1.37	5.686	0.57	0.9979
10.3	2.41	11.41	0.54	0.9973
Multicomponent flour				
9.1	0.16	0.428	0.69	0.9987
10.7	0.33	0.997	0.66	0.9989
11.4	0.54	2.378	0.59	0.9995
12.5	0.72	2.643	0.62	0.9995
13.4	0.89	3.631	0.60	0.9996
15.7	1.59	7.920	0.57	0.9996

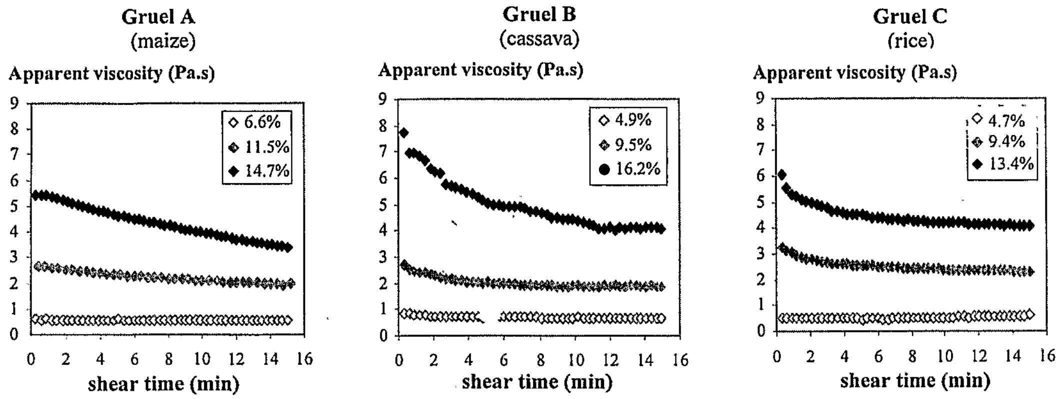

Figure 4. Influence of shear time on apparent viscosity of gruels A, B and C prepared respectively with rice, cassava or maize flours at different concentrations (shear rate = 83 s^{-1}; gruel temperature = 45°C).

decreases as shear time rises. The recording of apparent viscosity value of simple flour gruels during 15 min illustrates this property, called thixotropy (Figure 4). 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 behavior when prepared at high concentration. We can see in Figure 4 that, almost non-existent at concentrations below 7%, the thixotropic behaviour appears and becomes more and more pronounced for gruels of each type of simple flour tested when the gruel concentration increases. The practical consequence of this shear time dependency is that the shear time has to be set at a predetermined value before measurements. These results led us to take apparent viscosity readings after 10 min shear time since we found that the apparent viscosity

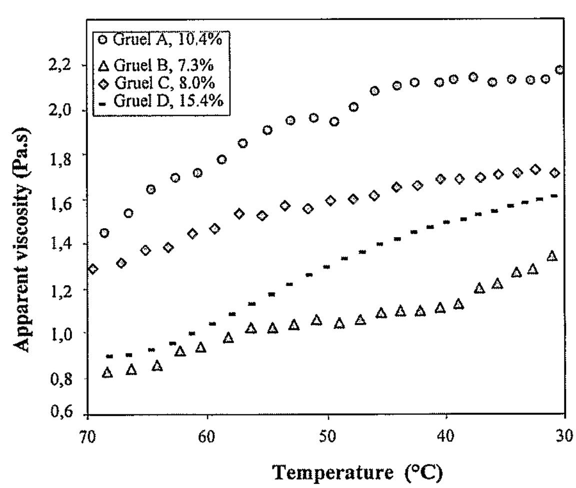

Figure 5. Variations in apparent viscosity of different types of gruels during cooling between 70 and 30°C (shear rate = 83 s^{1}).

values started to stabilize from this shear time for most of the gruels.

Gruel temperature
A third factor that could substantially modify viscosity is the gruel temperature, 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 5). It is therefore important to perform viscosity tests under thermostatically controlled conditions. The viscosity measurement temperature should be set 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 (Svanberg, 1987; Araya *et al.*, 1991; Wanink *et al.*, 1994) or 45°C (John & Gopaldas, 1988; Hayes *et al.*, 1995; Trèche & Mbome Lapé, 1999).

Comparison of viscosity measuring systems used in previously published studies
A wide variety of measuring systems have been used to evaluate the gruel consistency by different authors in different countries (Table 4). We noted that in the 35 published studies dealing with gruel consistency mentioned in Table 4, 78% used an empirical viscometer with a rotating spindle (Brookfield RV model, 42%; Brookfield LV model, 25%; other Brookfield, 8% and Rion VT04, 3%), and the other 22% used one viscometer with coaxial cylinders allowing shear rate control (Haake or Rheomat). The extremely variable measurement conditions applied (shear rate or spindle number and rotation speed, and gruel temperature, the shear time is generally not reported) explain the marked differences between measured viscosity ranges. In some cases, the measurement conditions and even the viscometer type are not reported.

In Table 5, we tried to establish, for maize and multicomponent gruels at several concentrations, correspondences between apparent viscosity values obtained with different measuring systems and qualitative descriptions of the gruel consistency consensually determined by our research team. The results clearly show that it is vain to compare apparent viscosity of gruels when they are measured with different apparatuses or in different measurement conditions.

It is interesting to note that the same viscosity value measured at 83 s^{-1} of 0.16 Pa.s corresponding to dry matter content of 5.9 and 9.1 (%, wt) for maize and multicomponent gruels respectively, corresponds to different apparent viscosity values when measured in other conditions, e.g. with a Brookfield RVT spindle 6 at 50 rpm (0.6 and 0.9 Pa.s, respectively). This can be explained by a shear-thinning behavior more marked for multicomponent gruels than for maize gruels and shows the limits of using single apparent viscosity measurements to describe gruel consistency.

Conclusion

All the results presented previously indicate that measurement conditions for assessing gruel consistency have not been sufficiently standardized. Because of this lack of standardization, 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).

Eventually, 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:

- to investigate the effects of a process on gruel consistency at a laboratory scale, the best approach would be to conduct viscosity analyses under standardized conditions, i.e. fixed shear rate (or measuring spindle number and spindle rotation speed), and controlled shear time and gruel temperature. The best is to use, when available, a viscometer that enables shear rate control. In our laboratory, we have been using a Haake VT500 viscometer for several years under the following conditions: shear rate = 83 s^{-1} (SVDIN coaxial cylinders; 64.5 rpm); gruel temperature = 45°C and shear time before readings = 10 min. These measurement conditions were chosen for the two main following reasons. First, they match conditions in which infants perceive gruel consistency: 45°C is close to the temperature at which gruels are consumed, and 83 s^{-1} is within the range of shear

Table 4. Comparison of measurement procedures used for gruel viscosity characterization in the literature

Viscometer type: Trade mark	Viscometer type: Model	*Measuring system or spindle*	Measurement conditions: *Shear rate (s^{-1}) or rotation speed (rpm)*	Measurement conditions: *Gruel temperature (°C)*	*Country*	*Approximate viscosity range*[1] *Pa.s*	*Bibliographic reference*
Brookfield	RV	2	20 rpm	28; 60	Tanzania	0.5–0.8	Darling *et al.* (1995)
		2; T-sp.	2.5 rpm	n.r.	Bangladesh	2–700	Wahed *et al.* (1994)
		2; T-sp.	2.5 rpm	n.r.	Bangladesh	1.7–503	Mahalanabis *et al.* (1993)
		3	20 rpm	ambient	USA	0.03–31	Likimani *et al.* (1991)
		4	20 rpm	40; 60	Peru	0.3–5	Marquis *et al.* (1993)
		5	50 rpm	45–50	USA	0–8	Jansen *et al.* (1981)
		6	20 rpm	n.r.	Tanzania	3–50	Mosha & Svanberg (1990)
		6	50 rpm	40	Chili	9	Alvina *et al.* (1990)
		6	50 rpm	40	Chili	3–9	Araya *et al.* (1991)
		5; 7	50 rpm	45–50	Zambia	0.001–75	Hayes *et al.* (1995)
		7	50 rpm	45	India	5–40	John & Gopaldas (1988)
		n.r.[2]	10,20,50,100 rpm	30,40,50,60,70	Nigeria	0–110	Sopade & Filibus (1995)
		n.r.	100 rpm	30	India	0.25–15	Malleshi & Desikachar (1988)
		n.r.	60 rpm	30	India	0.9–1.1	Krishna Kumari & Geervani (1996)
	LV	3	30 rpm	45	India	7–37	Gopaldas *et al.* (1986)
		1, 4	0.005–1 s^{-1}	25	India	5–65	Changala Reddy *et al.* (1989)
		4	6 rpm	40	Tanzania	1–70	Gimbi *et al.* (1997)
		various sp.	60 rpm	ambient	India	0–10	Malleshi & Desikachar (1982)
		n.r.	n.r.	40	Nigeria	0.1–10	Akpapunam *et al.* (1996)
		n.r.	n.r.	n.r.	India	0.005–0.015	Gopaldas *et al.* (1982)
		n.r.	n.r.	n.r.	India	0.01–9.5	Chandra Sekhar *et al.* (1988)
		n.r.	12 rpm	30	India	0.15–4	Kulkarni *et al.* (1991)
	HB	SC4–21	50 rpm	40	USA	0.7–5	Griffith *et al.* (1998)
	DVII	B,E	3 rpm	50	Peru	2.5–570	Bennett *et al.* (1999)
	n.r.	n.r.	n.r.	35–40	India	1.7–60	Gopaldas *et al.* (1988)
Rion	VT-04	1,3	62,5 rpm	55	Jamaica	0.28–4	Stephenson *et al.* (1994)
Haake	Rotovisco RV1	MV/MVI	42–571 s^{-1}	60	USA	0.1–1	Evans *et al.* (1986)
	Rotovisco	MV/MVII	1–10^3 s^{-1}; 59 s^{-1}	23; 60	USA	1–10	Bagley & Christianson (1982)
	Rotovisco	MV/MV3	1, 1 s^{-1}	40	Netherlands	10–80	Wanink *et al.* (1994)
	Rotovisco RV3	MV2, SV	22–135 s^{-1}	35	UK	0.1–2	Pavitt (1987)
	Rotovisco RV1	FK/SV2	54, 162 rpm	40	Tanzania/Sweden	0–2	Svanberg (1987)
	Rotovisco RV3	n.r.	256, 362, 512 rpm	30, 35, 40	Uganda	0–0.3	Kikafunda *et al.* (1997, 1998)
	VT500	SVDIN	83 s^{-1}	45	France	1–3	Trèche & Mbomé Lapé (1999)
Rheomat 30		MS-O/MS-DIN45	n.r.	n.r.	Sweden	0.1–0.4	Karlsson & Svanberg (1982)

[1] In the measurement conditions used.
[2] n.r. = not reported.

Table 5. Correspondences between short consistency descriptions and apparent viscosity values measured with the most common viscometers used in previously published studies for two types of gruels (maize flour and multicomponent flour) at different concentrations at 45°C

	Shear rate well defined			*Empirical measurements*					
	Haake VT550				*Brookfield RVT*				
				Rion VT04 spindle 1	*spindle 6*		*spindle 4*		
Gruel concentration (g/100 g)	*at 8 s⁻¹* Pa.s	*at 83 s⁻¹* Pa.s	at 800 s⁻¹ Pa.s	*at 62.5 rpm* Pa.s	*at 20 rpm* Pa.s	*at 50 rpm*	*at 5 rpm* Pa.s	*at 20 rpm* Pa.s	*Qualitative description of gruel consistency*
Maize flour									
5.91	0.46	0.16	0.04	1.2	1.4	0.6		2.0	drinkable
6.79	0.65	0.21	0.06	2.2	3.1	1.7	12.2	3.4	*limit between drinkable and spoonable*
8.72	2.63	1.05	0.20	8.5	11.2	5.9	36.1	–	spoonable
9.10	3.46	1.37	0.24	10.0	13.9	7.3	–	–	spoonable–thick
10.3	7.21	2.41	0.39	22.0	40.2	–	–	–	*limit between spoonable and too thick to be consumed by infants*
Multicomponent flour (millet, soyabean, groundnut, sugar, salt)									
9.10	0.37	0.16	0.05	1.1	1.7	0.9	5.3	2.0	drinkable
11.4	1.11	0.54	0.11	2.6	5.4	3.0	14.9	5.5	*limit between drinkable and spoonable*
12.5	1.71	0.72	0.15	3.4	8.2	4.5	25.8	8.7	spoonable
13.4	2.59	0.89	0.19	6.2	11.1	6.1	35.1	–	spoonable–thick
15.7	6.05	1.59	0.37	8.1	26.3	13.1	–	–	*limit between spoonable and too thick to be consumed by infants*

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 & Sherman, 1973). Secondly, they reduce the measurement variability associated with the non-Newtonian nature of gruels: preset shear rate and time (83 s^{-1} and 10 min) in order to take shear-thinning and thixotropic behavior into account.

- to carry out an experimental study in the field, a simple empirical viscometer in standardized conditions would be suitable. However, the results obtained will only be of comparative value for gruels with close compositions. Even in the field, measurement conditions (at least, spindle number, rotation speed, rotation time and gruel temperature) have to be standardized. In our laboratory, we have chosen to use the Rion VT04 which is sturdy and particularly easy to use. The measurement conditions we use are with spindle 1, 2 or 3 depending on the gruel viscosity range, the single rotation speed allowed by the apparatus (62.5 rpm) and shear time of 1 min.
- in large 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. In this case, it is essential to carry out studies in the field to take the mother perception into account for the determination of consistency classes and to use vocabulary that will be fully understood by the survey population. It could also be useful to determine correspondences between sensorial descriptors and apparent viscosity values obtained in standardized conditions.

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