Techniques for increasing the energy density of gruel

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1. INTRODUCTION

Nicol (1971) in Nigeria, and Rutishauser (1974) in Uganda were the first to mention "dietary bulk" as a possible cause of protein-energy malnutrition in young children. But the need to increase the energy density of complementary foods, because of children's limited gastric capacity, especially when daily feeding frequency is low, was recognized only in the 80s following the publication of several papers by a team of Swedish researchers (Ljungqvist et al., 1981; Hellstrom et al., 1981; Brandtzaeg et al., 1981; Karlsson and Svanberg, 1982) and the work of Desikachar (1980; 1982), Gopaldas (1984) and Golpadas et al. (1986) in India. More recently, the literature on the relationship among complementary feeding, the level of energy intake and protein-energy malnutrition, emphasized that it was important to identify and promote ways of increasing the energy density of foods based on locally produced staples (Walker, 1990; Creed de Kanashiro et al., 1990; Brown, 1991; Ashworth and Draper, 1992).

2. WHEN IS IT APPROPRIATE TO INCREASE THE ENERGY DENSITY OF GRUEL?

Studies on infant feeding practices and on the nutritional value of traditional gruels in various African countries have demonstrated the benefits, and sometimes the necessity of improving the energy density of gruels.

To clarify our point, we will use an example, in Congo. In this country, surveys of infant feeding practices have shown that among children consuming gruel regularly, only 22% in the rural sector and 21% in Brazzaville received gruel more than twice a day (Cornu et al., 1993).

In more than 80% of cases, gruel is prepared from locally grown products, fermented maize paste *poto-poto*, or cassava flour (Trèche et al., 1992; 1993). The dry matter content of gruel taken at the time of consumption was determined in more than 300 samples; the mean dry matter content was for maize and cassava gruel, 14 and 16 g of dry matter (DM) per 100 g of gruel respectively. Given that 1 g of DM provides 4 kcal, approximately 50% of the gruels had an energy density of less than 60 kcal/100 ml (Figure 1).

During the period of gruel consumption, most Congolese children consume a gruel with an energy density of often less than 60 kcal/100 ml once or twice a day. If Central African mothers' mean breast milk output is 540 ml/day or 380 kcal, as estimated by Vis et al. (1981) in Zaïre, complementary feeding must provide a 6 month-old boy with an additional 385 kcal to meet his estimated energy needs of 765 kcal.

In order to obtain 385 kcal, children should consume 640 ml of gruel with an energy density of 60 kcal/100 ml. In fact, at this age, children cannot eat more than 150 to 200 ml of gruel per meal because of their limited gastric capacity. If the mean intake per meal is 170 ml it implies that (Figure 2):

- If children receive two meals per day, the energy density of gruel must be 120 kcal/100 ml to satisfy their energy needs.
- If the energy density of gruel does not exceed 60 kcal/100 ml, four meals per day are needed.

In a situation where breast milk intake is limited, the frequency of gruel distribution is low, and where complementary foods are made of cereals or tubers that have not been appropriately processed, gruel cannot adequately complement breast milk to cover children's energy needs. The most straightforward solution to this problem is to increase the frequency of distribution of gruel; four meals of gruel with an energy density of 60 kcal/100 ml would satisfy energy requirements. Unfortunately, studies have shown that this is not feasible for mothers who work in agriculture or as vendors.

An alternative is to increase the amount of flour, i.e. to incorporate more flour or paste in a given quantity of gruel. But measures of the viscosity of gruel used traditionally in Congo (Trèche and Giamarchi, unpublished), have shown that younger infants prefer a more liquid gruel (Figure 3). The viscosity of gruel — measured with a rotating viscosimeter, expressed in Pascal.second (Pa.s) — increases sharply with concentration, irrespective of the nature of the basic ingredient. The viscosity of gruel should not exceed 1.5 Pa.s to be acceptable to the younger children. In fact, it is impossible to prepare maize, cassava, or rice gruel with, at the same time, a concentration of more than 10 g DM/100 ml and a viscosity near 1.5 Pa.s, without special processing of the basic ingredient (Figure 4).

Other approaches can be proposed:

- reducing mothers' workload and/or improving their food consumption in order to increase their breast milk production;
- incorporating energy-dense ingredients in gruel, particularly oil, or ingredients that do not alter the consistency such as sugar.

However, experience shows that these solutions are not well accepted, either because they are not in accord with the local lifestyle or because they are too expensive.

Several studies, carried out among children over one year of age consuming two meals per day, have shown that the amount of dry matter ingested increases with the energy density of the gruel (Brown et al., 1989; Alvina et al., 1990; Sanchez-Grinan et al, 1992; Mujibur Rahman et al., 1994). Indeed increasing the energy density of gruel appears to be the most efficient way of increasing children's energy intake. This can be achieved by processing foods to alter the physicochemical properties of starch, in order to reduce the viscosity of gruel to a level that is acceptable to young children when the gruel is prepared with adequate concentrations of dry matter.

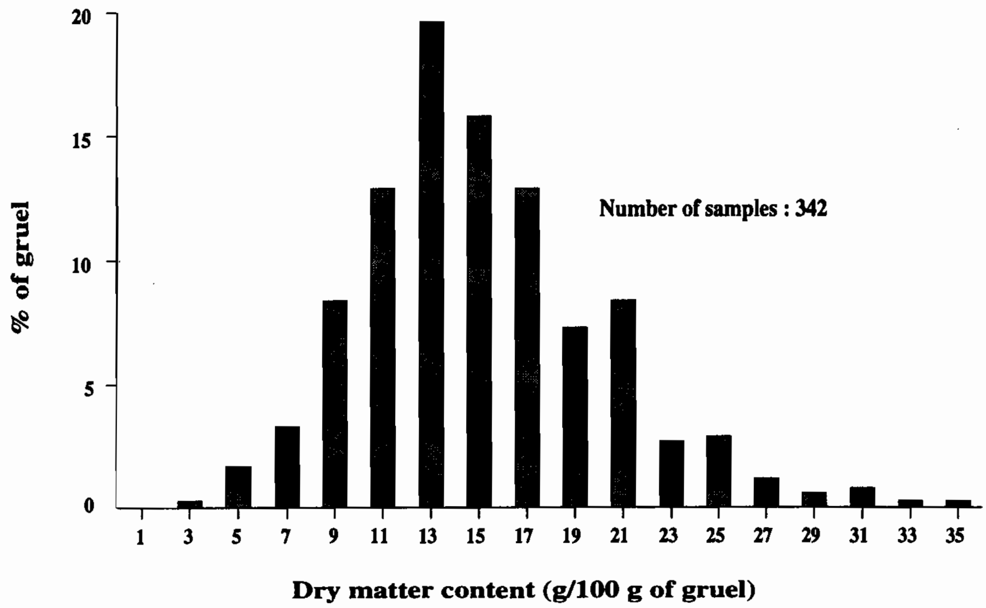

Figure 1
Distribution of dry matter content of gruels consumed in rural areas of Congo

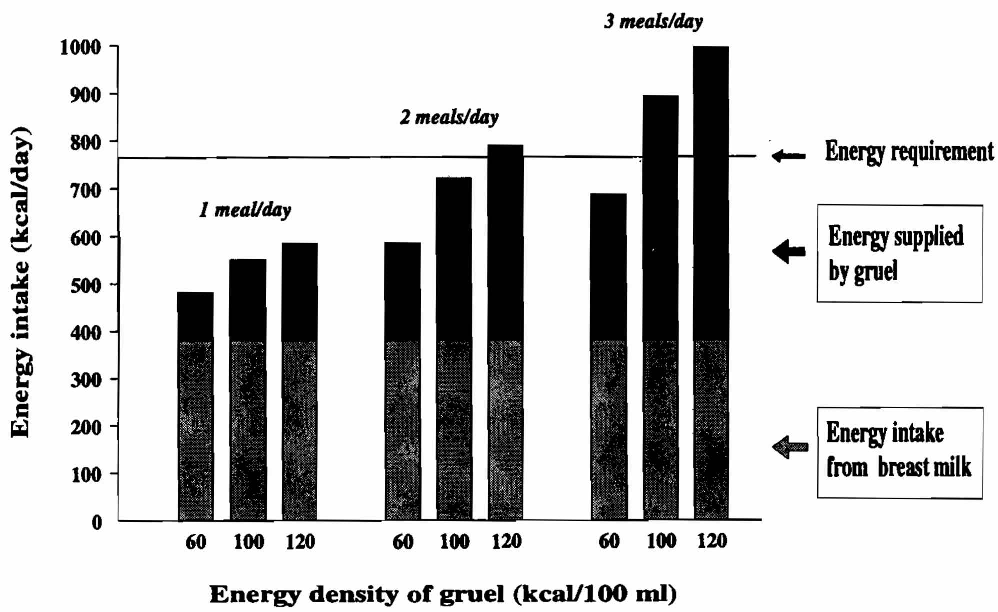

Figure 2
Level of satisfaction of energy requirements of a 6-month-old boy, according to frequency of distribution and energy density of gruel

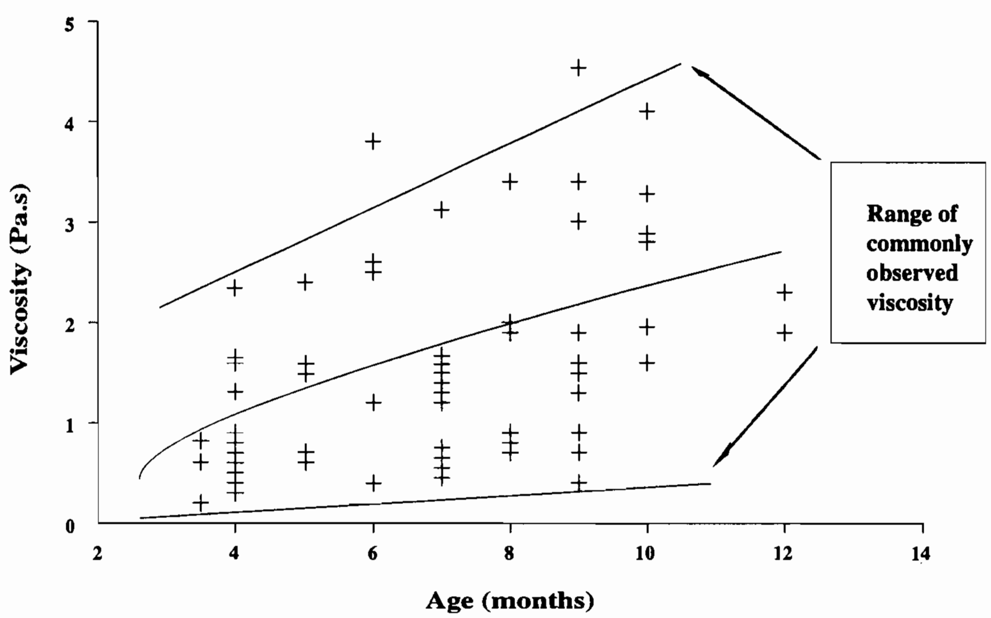

Figure 3
Variation of observed viscosity of gruel according to child's age in Congo

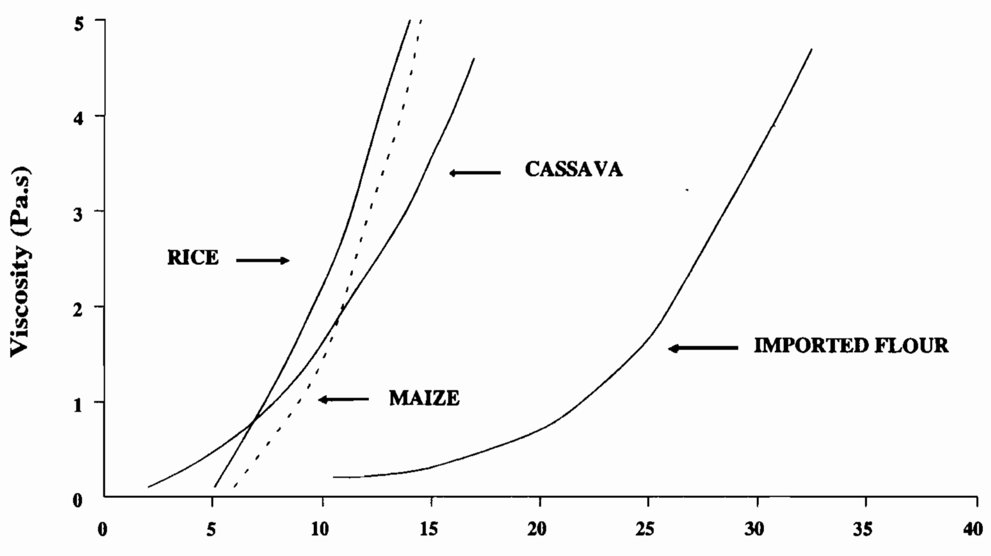

Figure 4
Variation of viscosity of gruel made from various starchy foods according to dry matter content

3. PROCESSES TO REDUCE THE VISCOSITY OF GRUEL

3.1 The options

Theoretically, there are two approaches for modifying the viscosity of preparations of starch in an aqueous medium. The first method is reticulation, which demands the addition of polar organic molecules, such as monoglycerides and fatty acids, to transform amylose from an amorphous to a compact helicoïdal form, thereby preventing the penetration of water in the molecule. The second method is depolymerisation which shortens the non-branched fragments of structural starch chains, thereby reducing their swelling capacity.

There are several techniques for obtaining depolymerisation:

- drastic hydro-thermic treatment, such as drum-drying or extrusion-cooking, which causes the starch granules to burst, and the structural chains to unfold and break;
- acid hydrolysis that dissolves preferentially the amorphous parts of starch granules by splitting the $\alpha(1\text{–}4)$ hemiacetal bonds of the amylopectin and amylose chains, thereby shortening them;
- enzymatic hydrolysis using alpha-amylase; the enzymes attack randomly non-terminal $\alpha(1\text{–}4)$ bonds, producing ramified or unramified dextrins with a degree of polymerisation that depends on the state of the substrate and hydrolysis conditions, particularly duration, pH and temperature.

Given the price of the first two methods of depolymerisation, the impossibility of implementing them at household level, and legal difficulties entailed in the use of acid hydrolysis, the most interesting option is enzymatic hydrolysis.

Several natural sources of alpha-amylase could be used:

- animal alpha-amylase: pancreas decoction, human saliva, breast milk;
- bacterial alpha-amylase produced industrially or by non-pathogenic strains developing on the substrate;
- plant alpha-amylase which are naturally present in certain plants or are produced during germination of seeds or tubers.

In most cases, to improve the energy density of gruel prepared from tropical staple foods, authors have chosen the preliminary fermentation of starch components (Tomkins et al., 1989), and the use of germinated cereal, or the addition of small amounts of amylase-rich flour made from germinated cereal (Desikachar, 1980; Brandtzaeg et al., 1981; Desikachar, 1982; Mosha and Svanberg, 1983; Gopaldas et al., 1988; Malleshi and Amla, 1989; Mosha and Lorri, 1989). The studies we have conducted show that, in addition to these sources, industrially-produced amylase can be used, particularly for incorporation into flour produced by small-scale production units (Trèche and Giamarchi, 1991; Sanogo, 1994; Trèche and Legros, 1994).

3.2 Effect of fermentation

In many countries, fermented cereal is used traditionally for the preparation of gruel for infants (Tomkins et al., 1989; Cornu et al., 1993): the Nigerian *ogi*; the Congolese *poto-poto*; the South-African *mahewu*; the Kenyan *uji*; the Ghanaian *kenkey*; *bogobe* from Botswana;

nasha in Sudan; *obusera* in Uganda; *njera* in Ethiopia; *motoho* and *leshele-shele* in Lesotho, etc. In Tanzania, the viscosity of gruel is reduced when *udaga*, a flour made from aerial fermentation of cassava roots is used, but the fermentation process is difficult to control (Hakimjee and Lindgren, 1989; Mlingi, 1989).

There are numerous advantages to fermentation; fermented products have a good acceptability and the risk of microbial contamination is reduced (Mensah et al., 1991; Svanberg et al., 1992; Lorri and Svanberg, 1994). Moreover fermentation can reduce the viscosity of gruel of low or medium dry matter content, but it has not yet been possible to obtain gruel with an energy density of more than 100 kcal/100 ml by simple fermentation.

3.3 Use of germinated cereals

Incorporation of increasing amounts of germinated cereal flour can drastically reduce the viscosity of gruel prepared with an adequate concentration (Figure 5); however, the amount of germinated flour that must be incorporated varies considerably according to the type of substrate: to obtain a gruel with a concentration of 30 g of DM/100 g and a viscosity of 1 Pa.s, the relative amount of germinated maize flour that must be added to rice, maize, or millet gruel is respectively 3 times, 2.5 and 2 times the amount needed in cassava gruel (Figure 6). Thus, for a given viscosity, the increase in dry matter content, and consequently in energy density, obtained with the addition of a given amount of germinated flour, is much higher for cassava gruel than for cereal-based gruels such as maize gruel (Figure 7).

Optimal conditions for the germination of sorghum and maize are the following:

- Grains are dehusked by hand, to eliminate glumes and glumellae; grains are removed from kernels.
- Grains are soaked in water at room temperature for 24 hours.
- Grains are spread on a damp fabric, protected from the direct sun, for approximately 48 hours, until 2-inch sprouts develop.
- Germinated grains are dried in the sun for 2 or 3 days.
- Sprouts are eliminated by hand.
- Desprouted grains are ground with a mortar or in a hammer-mill.

The effectiveness of germinated flour in reducing the viscosity of gruel can be evaluated by measuring the amylolytic activity (Bernfeld, 1955). There is a large inter- and intra-specific variation of this activity. For a given variety, the activity will vary depending on the treatment previously applied to the grains, in particular storage time.

The preparation of gruel with improved energy density from germinated cereal flour is theoretically possible at household level, because the basic ingredients are generally available in households. The choice of the processing methods must take into account the nature and characteristics of available foodstuffs. In Figure 8, an example is given of what was feasible in a Central African setting where the only available staple foods were cassava, groundnut and pumpkin-seed paste, and small amounts of maize (Trèche, 1994); the objective was to

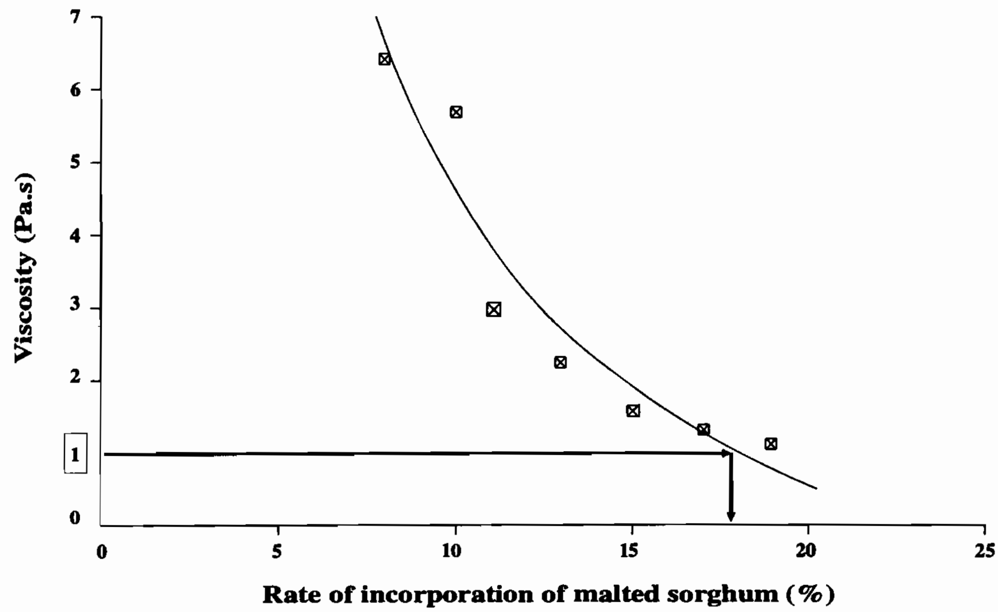

Figure 5
Effect of the addition of malted sorghum on the viscosity of cassava-based gruel prepared with a dry matter content of 30 g per 100 g of gruel

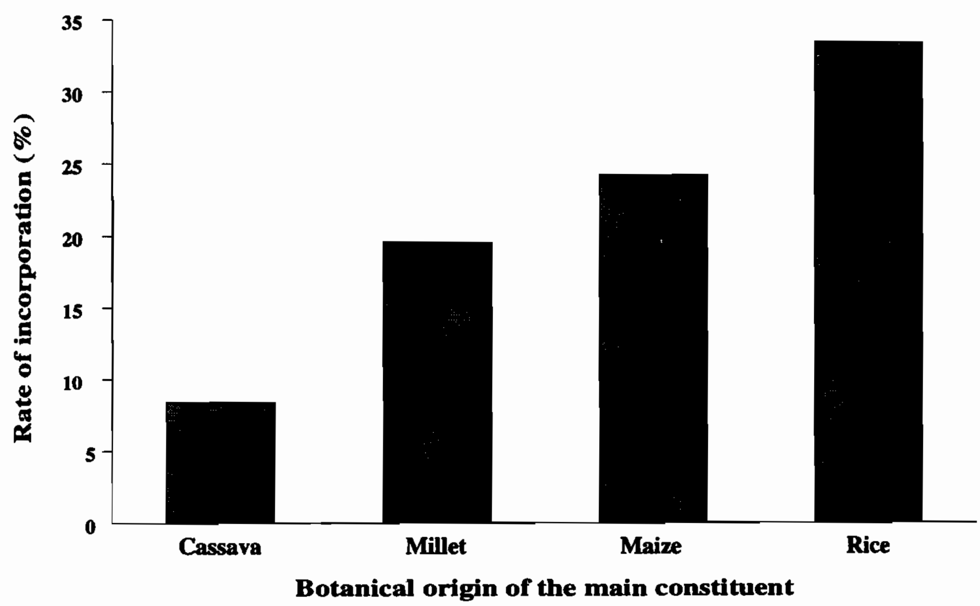

Figure 6
Rate of incorporation of germinated maize flour needed to obtain gruel viscosity of 1 Pa.s with a dry matter content of 30 g per 100 g, according to botanical origin of the main constituent

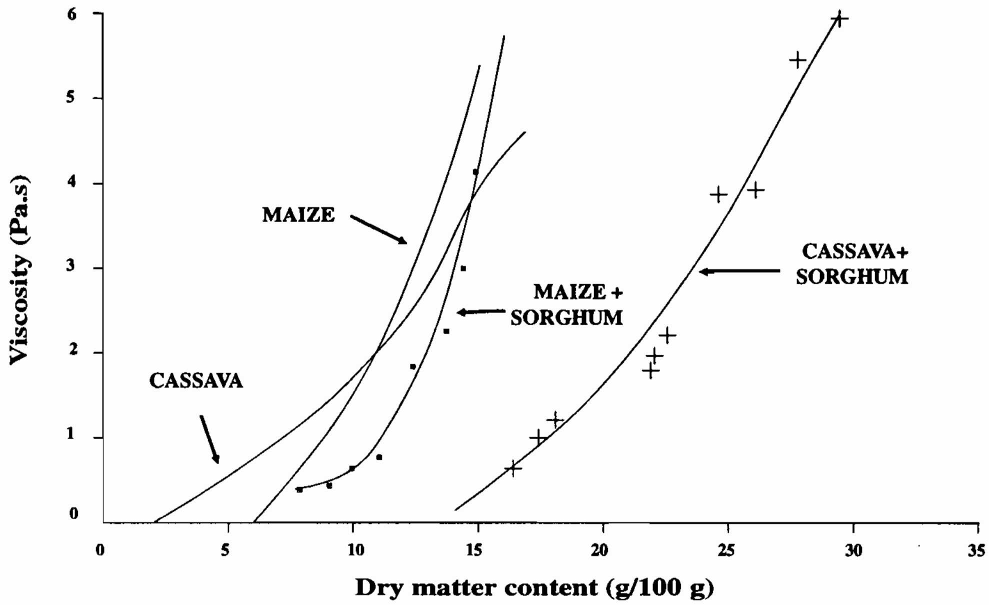

Figure 7
Effect of the addition of 10% of malted sorghum flour on the viscosity of cassava and maize gruel

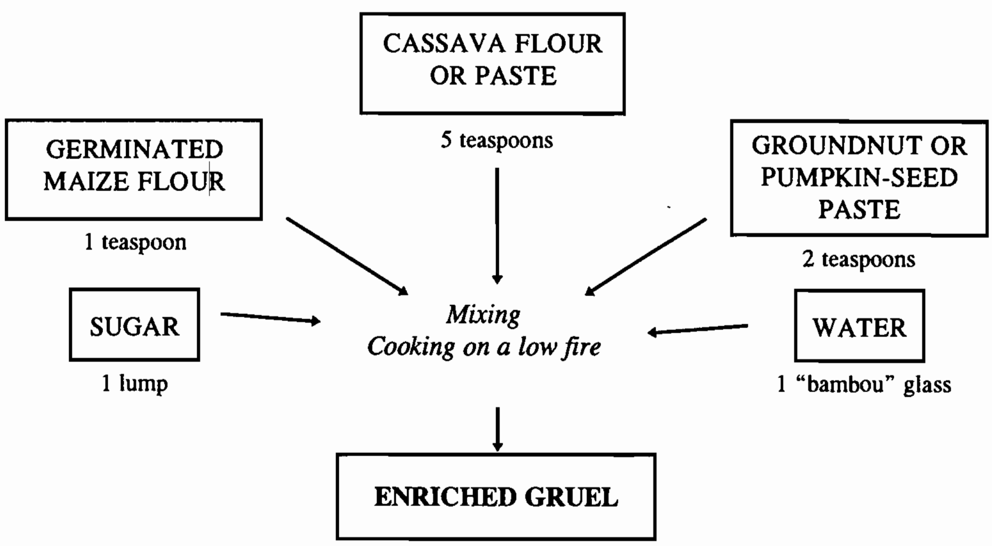

Figure 8
Example of flow-sheet for preparation of an energy-dense gruel in a Central African setting

obtain a gruel with a protein content of 10 g/100 g of DM, and a dry matter content of approximately 30 g/100 ml of gruel: the formulation is 65% of cassava paste, 32% of groundnut paste and 3% of germinated maize flour.

The preparation method is very simple: the ingredients are mixed into cold water, and heated on a low fire while stirring, boiled for 5 minutes and left to cool.

Several pilot trials have shown that these processes can be disseminated at household level. The preparation of germinated cereal flour, however, is long and households may be reluctant to prepare it. To overcome this difficulty, we have proposed other enzyme sources when flour for infants and young children is produced in small scale units.

3.4 Use of industrially-produced enzymes

Since imported industrial enzymes are inexpensive, we have proposed to incorporate them in flour for infants produced in small-scale units. BAN (NOVO Industries A/S), an enzyme adequate for incorporation into food, was selected after laboratory testing; the characteristics of BAN, described in Table 1, enable it to act upon structural starch molecules during the preparation of gruel by mothers. The temperature for optimal activity of the enzyme is 72°C. It is higher than the temperature of gelatinization of starch granules; they are therefore particularly susceptible to the enzyme. Moreover, boiling the gruel for a few minutes destroys the enzyme, preventing the gruel from becoming more liquid after cooling.

Table 1
Characteristics of the industrial enzyme used in the Vitafort production unit

Name	BAN 800 MG (Novo Industries A/S)
Nature and source	Bacterial endo-amylase (Bacillus subtilis)
Form	Microgranule
Packaging	40 Kg barrel
Shelf-life	6 months at 25°C; more than a year at 5°C
Price	60 US $/kg delivered in Congo
Absence of toxicity	Conforming with specifications recommended by FAO/WHO/JEFCA and FCC for use in food
Amylase activity	800 KNU*/g
Optimal pH	6.0
Optimal temperature	72°C (between 42 and 85°C activity is more than 2/3 of optimal activity)
Products of degradation	Dextrins with various levels of polymerisation; oligosaccharides

* *KNU (Kilo-Unit Alpha-amylase Novo) : amount of enzyme needed to breakdown 5.26 g of soluble starch (Merck, Erg B6) per hour, using the standard Novo method.*

The viscosity of gruel can be reduced drastically with very small amounts of enzyme (Figure 9). As with germinated cereal flour, the amount of BAN needed depends on the nature of the gruel staple (Figure 10): the increase in dry matter content, and consequently in energy density resulting from the incorporation of BAN, is much higher, for a given viscosity, with cassava than with cereals such as maize.

An example of a production scheme to obtain improved energy dense flour for infants using industrial enzymes is presented in Figure 11 (Sanogo, 1994; Trèche and Legros, 1994; Trèche et al., 1995).

4. FACTORS INFLUENCING THE EFFICIENCY OF ENZYME-BASED PROCESSES

The efficiency of processes based on the incorporation of enzymes depends on the level of amylolytic activity of the enzyme source, the botanical origin of the gruel staple, and on other factors which must be taken into account in the development of technologies at household or cottage industry level.

4.1 pH of gruel

The optimal pH for alpha-amylase is slightly acid: 4.7 to 5.4 for barley malt; 6.0 for BAN. We have verified that the ability of BAN to reduce the viscosity of gruel prepared with an optimal amount of dry matter is stable at pH 5.5 to 9.0 (Figure 12). Alpha-amylase cannot be used in fermented foods whose pH is usually under 4.0.

4.2 Nature of other constituents of gruel

The examples described above were simple mixtures of one starch-rich flour with the enzyme source. Flours for infants usually also comprise a protein source, sugar and vitamin and mineral supplements. Depending on their nature and the amounts added, these constituents may have a variety of effects on the gruel: for example, vitamin and mineral supplements have a negligible effect on viscosity. Some ingredients increase the energy density without affecting viscosity significantly (sugar, fat), while others, such as bean flour, increase viscosity (Figure 13). Therefore, all ingredients must be taken into account when determining the amount of enzyme source that must be added to gruel.

4.3 Methods for preparing gruel

Preparation techniques are very important because starch is only sensitive to enzymes beyond its gelatinization temperature, i.e. above 55 to 65°C. However, beyond a certain temperature — which is source-specific — enzymes are inactivated. The efficiency of the process depends on the time active enzymes are in contact with the gelatinized starch, i.e. the time during which the flour mixed in water is maintained at a temperature between 60 and 80°C approximately, depending on the enzyme source. This time depends on the preparation technique.

The simplest technique, which we have used in the aforementioned tests under standardized heating conditions, is to mix the ingredients in cold water and heat gradually until bubbles appear on the surface, and to maintain the boil for a certain time (preparation technique A). The viscosity of gruels prepared using this technique varies slightly with the intensity of heating, i.e. how quickly the gruel is heated (Figure 14).

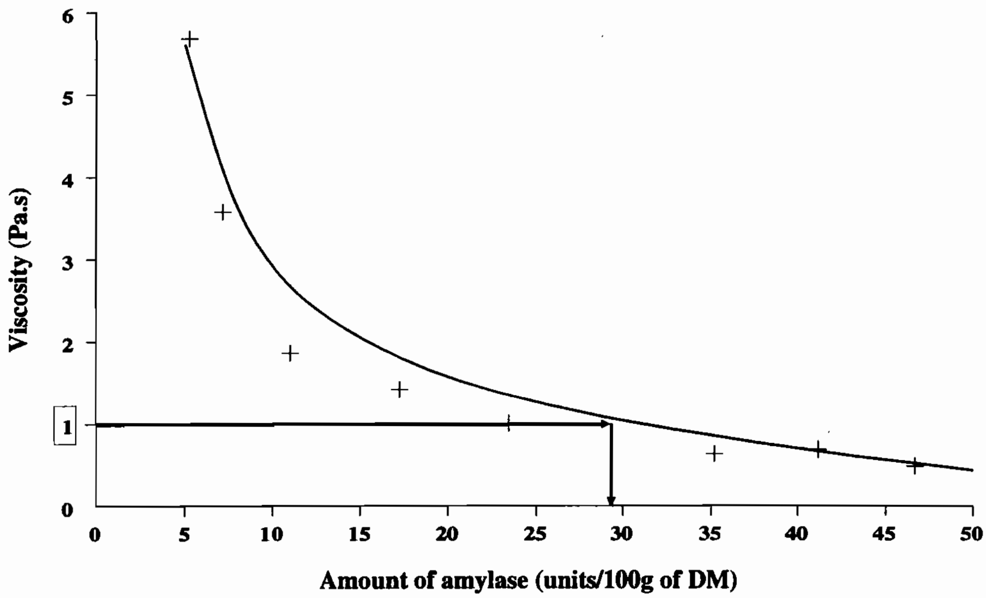

Figure 9
Effect of the addition of BAN on the viscosity of cassava gruel prepared with a dry matter content of 30 g/100 g

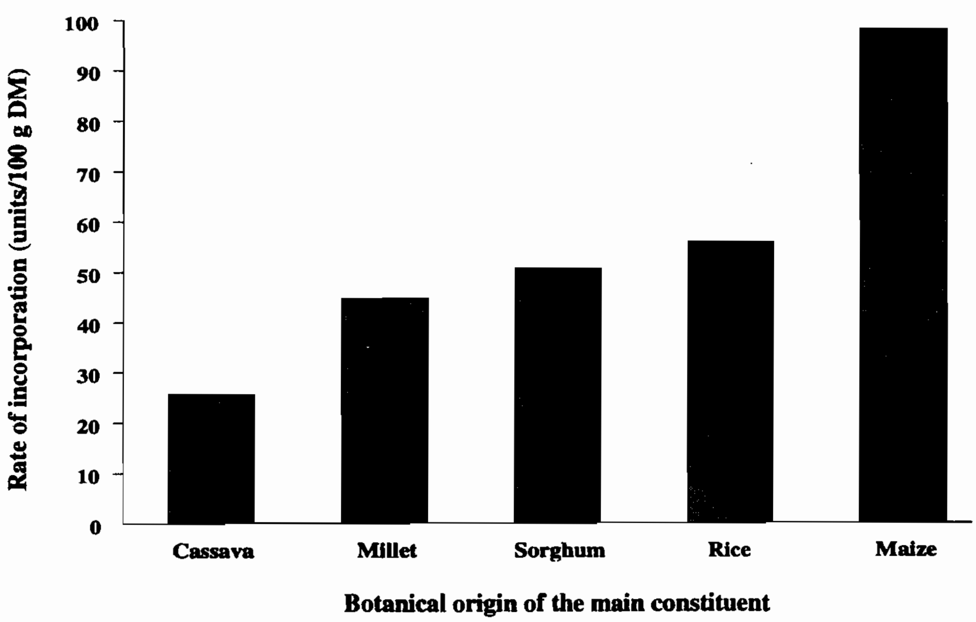

Figure 10
Effect of botanical origin of the main constituent of gruel on the amount of BAN needed to limit gruel viscosity to 1 Pa.s when prepared with a dry matter content of 30 g/100 g

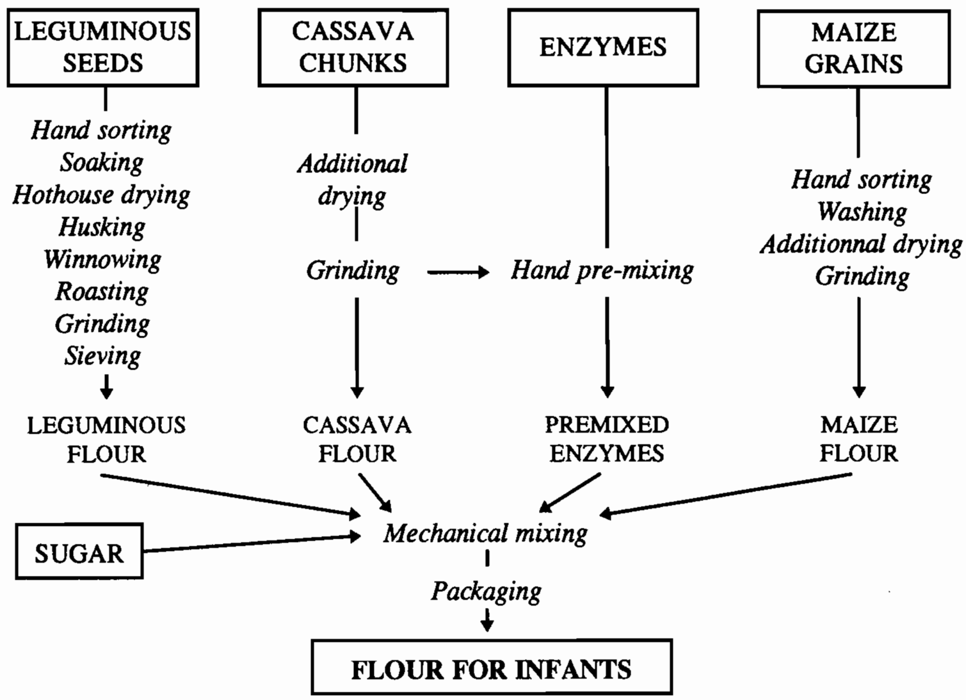

Figure 11
Flow-sheet for production of maize and cassava-based flour for infants for the preparation of gruel with an improved energy density

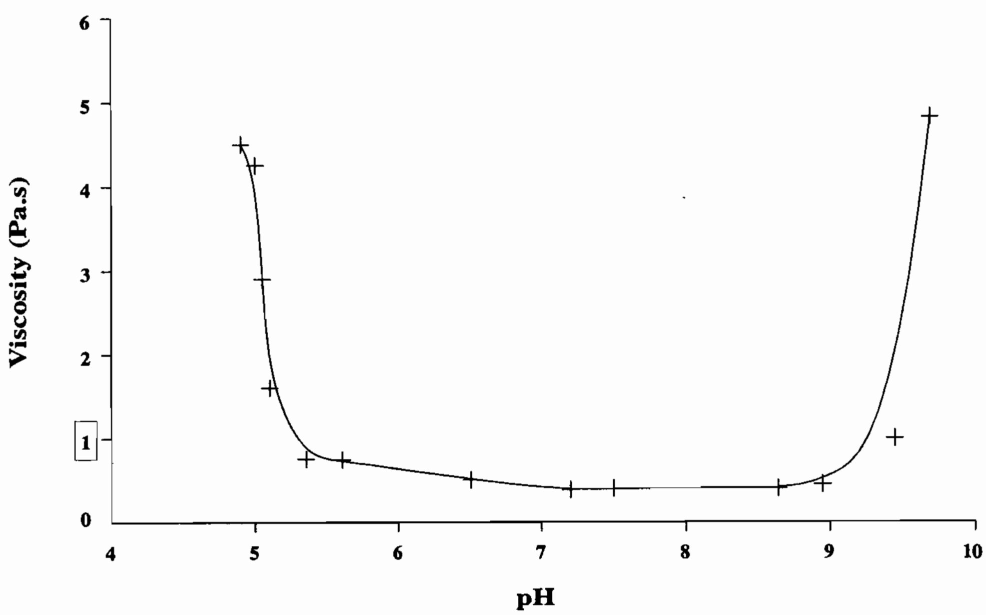

Figure 12
Effect of gruel pH on the efficiency of BAN in reducing the viscosity of cassava gruel prepared with a dry matter content of 27 g/100 g

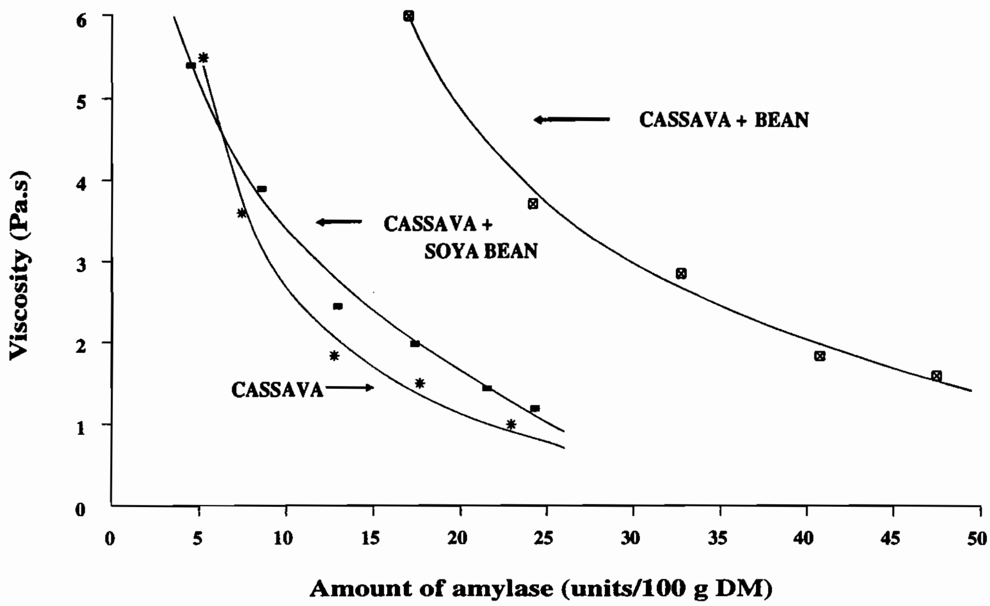

Figure 13
Effect of incorporation of BAN on the viscosity of gruel prepared with a dry matter content of 30 g/100 g, according to the nature of ingredients

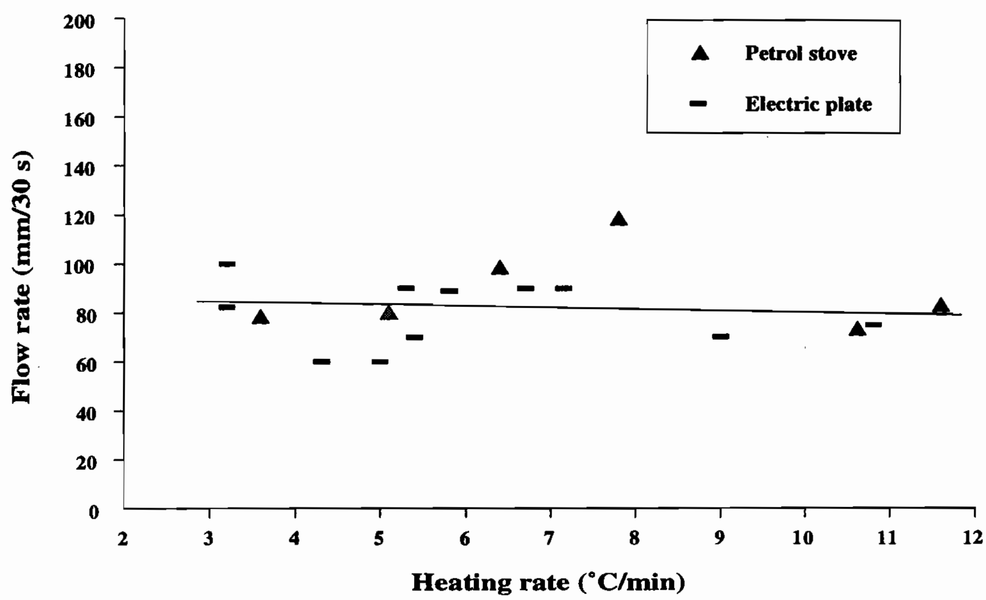

Figure 14
Effect of heating rate on the efficiency of BAN (12 units/100 g of DM) in reducing the viscosity of cassava gruel prepared with a dry matter content of 30 g/100 g

We have compared preparation technique A with two others; B consists in taking the pot off the heat source, during cooking, so that the enzymes will be active for a longer period of time; C is somewhat similar to the traditional Congolese recipe: the ingredients are mixed in a small quantity of cold water, then poured into a pot of boiling water; the pot is then left to stand off the fire for 5 minutes before cooking, so that active enzymes are in contact with the ingredients for a sufficient amount of time. Technique C is the most efficient for reducing the viscosity of the cassava-malted sorghum gruel (Table 2).

Other combinations, with other preparation techniques, could be more efficient. The choice of the enzyme source, and of the amount used, must not be separated from that of the preparation technique.

Table 2
Variation of the viscosity of cassava/sorghum gruel (90/10; m/m) prepared with 30 g DM for 100 g of gruel according to preparation technique

	Preparation techniques	Viscosity
A	- Mix flour in cold water - Heat progressively until bubbles appear (85°C) - Maintain the boil for 5 mn	5.38 Pa.s
B	- Mix flour in cold water - Heat to 65°C and boil; leave to stand off the fire for 5 mn - Heat progressively until bubbles appear (85°C) - Maintain the boil for 5 mn	2.47 Pa.s
C	- Mix flour in a small quantity of cold water, then pour into boiling water, and leave to stand off the fire for 5 mn - Heat progressively until bubbles appear (85°C) - Maintain the boil for 5 mn	1.10 Pa.s

4.4 Previous treatment of starch sources

Several studies have shown that particle size of cereal or tuber flour has little effect on the efficiency of the process as long as particle size is less than 0.8 mm. On the contrary, thermic treatment, such as roasting maize grains before milling, or additional drying of cassava chips on heated metallic sheets, can notably increase or decrease the susceptibility of starch to the enzyme.

5. PROCEDURE FOR THE DEVELOPMENT OF AN ENZYME PROCESS

The steps for the choice of an enzyme source and for the development of the process are the following, in chronological order:

- The first step is to collect data on the nutritional status and the feeding practices for infants and young children (under 2 years of age), to determine whether the energy density of gruel should be improved. Two factors are important for decision making: the nature of and frequency with which gruel is distributed.

- The second step is to formulate a gruel using locally available staple foods. The composition, when energy needs are covered, should also meet infants' and young children's nutrient requirements.
- The third step is to decide whether classic hydro-thermic processes such as extrusion-cooking and drum-drying are adequate, or whether enzymatic treatment is necessary to improve the energy density of gruel. The latter is often easier to develop and less expensive in the technological context of developing countries.
- Step four is to evaluate, at household or cottage industry level, whether the production of the flour is feasible technologically, and whether the product meets the required nutritional quality and is acceptable from an organoleptic, cultural, and economic perspective.
- The final step is to choose the most appropriate enzyme source and to determine the amount that must be incorporated.

The choice of the enzyme source will differ if the food is prepared at household level or if it is to be produced by the cottage industry.

At the cottage industry level, major constraints are the cost and the need for a constant level of quality. The cheapest source, with the most stable quality, is industrially-produced enzymes. Their only disadvantage, in developing countries, is that they must be imported, although the quantity needed is very small. Other sources can be used, such as malted barley from breweries, provided it is available at low-cost. An alternative can be the local production of germinated cereal flour, if a stable amylolytic activity can be obtained.

At household and community level, the use of malted cereal flour is the best option. Its main disadvantage is the time required for preparation. Other options could be the addition of breast milk or saliva to gruel with a high dry matter content so that amylase will reduce viscosity, or the use of other natural sources of amylase (germinated tuber flour, certain tree-barks etc).

At this stage, the amount of amylase that is needed for the type of preparation chosen can be determined: the procedure is to make gruel with the desired energy density and add increasing amounts of amylase until the desired viscosity is obtained.

The standardized measurement of viscosity is done with a rotating viscosimeter, which is an expensive device. Alternatively a flow-box can be used ("Polyvisc", Kinematica Inc.); the principle is to measure the distance covered by the flow of gruel within a given time. For a given gruel, there is a high correlation between viscosity and flow rate measured with the Polyvisc (Figure 15). Thus, this simple device can be used to measure viscosity with an acceptable reproducibility. Nevertheless, viscosity of gruel can also be estimated empirically without any special equipment in order to determine the adequate amount of enzyme source needed.

6. CONCLUSION

In some settings in developing countries, particularly in Africa, increasing the energy density of gruel could be an efficient and feasible way to increase infants' and young children's intake of energy and key nutrients during the period of complementary feeding. Various techniques based on natural amylase have been experimented with, although often, only at pilot-project level (e.g. in East Africa).

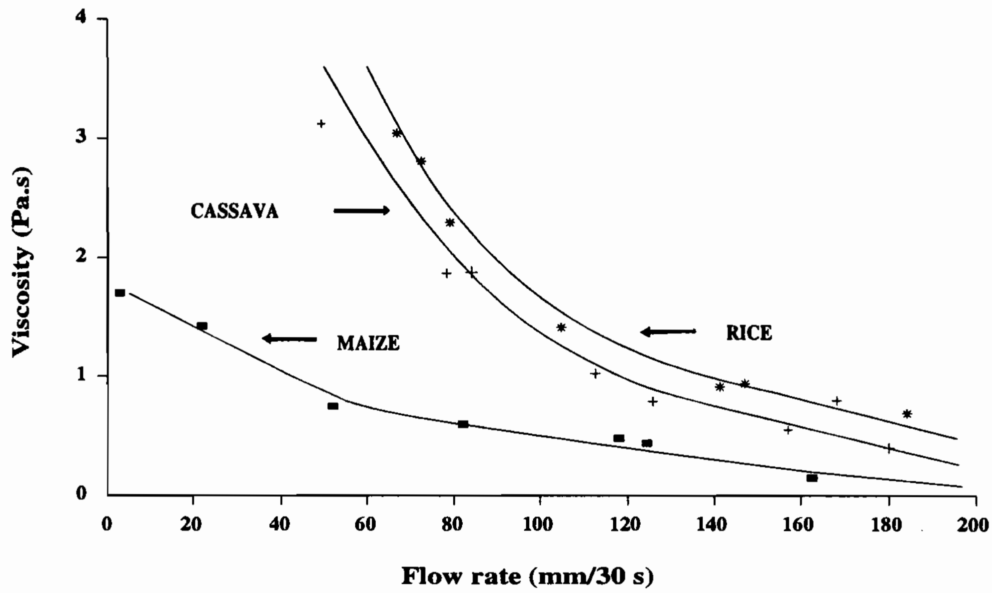

Figure 15
Relationship between flow rate and viscosity of gruel prepared with a dry matter content of 30 g/100 g, after enzymatic treatment, according to the nature of the main constituent

The preparation of malted cereal flour is time-consuming, but it is nevertheless an efficient process at the household and cottage industry levels. At the household level it is the sole feasible approach. At the level of small-scale production units, the use of industrial amylase is an efficient alternative that is both easy to implement and inexpensive.

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WHO/NHD/99.3
WHO/AFRO/NUT/99.4
Distr.: General
Original: English

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IRD
Institut de recherche pour le développement

World Health Organization
Geneva

COMPLEMENTARY FEEDING OF YOUNG CHILDREN IN AFRICA AND THE MIDDLE EAST

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Part of this document was published in French as "L'alimentation de complément du jeune enfant" by Orstom Editions, 1995 (ISBN 2-7099-1289-9). The English translation is published with the permission of Orstom.