ELSEVIER

Food Chemistry 82 (2003) 249–255

Food Chemistry

www.elsevier.com/locate/foodchem

Ability of a “very low-cost extruder” to produce instant infant flours at a small scale in Vietnam

C. Mouquet[a,*], B. Salvignol[b], N. Van Hoan[b], J. Monvois[c], S. Trèche[d]

[a] *UR106, Nutrition, limentation Sociétes, IRD, BP 182, Ouagadougou 01, Burkina Faso*
[b] *GRET, 269 Kim Ma Street, Hanoi, Viet Nam*
[c] *GRET, 213 rue La Fayette, 75010 Paris, France*
[d] *UR106, IRD, BP64501, F34 394 Montpellier cedex France*

Received 25 July 2002; received in revised form 18 November 2002; accepted 21 November 2002

Abstract

Extrusion cooking is a useful process for the production of instant infant flours, as it allows gelatinisation and partial dextrinisation of starch, as well as reduction of the activity of some antinutritional factors. But existing extrusion equipment is not suited to the context of developing countries as it requires considerable financial investment and the production capacity (minimum 300 kg/h) is too high. The aim of our study was to improve traditional extruders with low production capacity (about 30 kg/h) manufactured in Vietnam and to test their performance in the production of infant flours. Several blends made with rice, sesame and/or soybean have been extruded with the modified equipment that we name “very low-cost extruder”. In the case of blends containing soybean, starch gelatinisation was not complete, and decreased with an increase in the lipid content of the blend. The rate of trypsin inhibitor destruction evolved in a similar way. Adding water before extrusion, or extruding the blends twice was not effective in increasing the rates of starch gelatinisation or trypsin inhibitor destruction. However, the “very low-cost extruder” proved its ability to process the rice–sesame blend that had a lipid content of less than 6 g/100 g DM, and low initial water content [around 10%, wet basis (wb)]. In this case, extrusion led to total starch gelatinisation and the extent of starch dextrinisation, which was measured by comparing the viscosity of gruels prepared from crude and corresponding extruded blends, was sufficient to prepare gruels with substantially increased energy density. With the addition of roasted soybean flour, sugar, milk powder, vitamins and minerals, this blend could provide a nutritious instant flour usable as complementary food for infants and young children.

Keywords: Extrusion cooking; Instant flour; Complementary food; Gelatinisation; Dextrinisation; Trypsin inhibitor destruction

1. Introduction

Extrusion cooking is one of several different processes used to produce infant flours. This particular process has many advantages that have been extensively reviewed (Björck & Asp, 1983; Camire, Camire, & Krumhar, 1990; Harper & Jansen, 1985). From a nutritional point of view, extrusion cooking allows inactivation of certain antinutritional factors like trypsin inhibitor factors thus increasing protein digestibility. The high temperature generated during processing ensures satisfactory hygienic quality, and in general results in starch gelatinisation, thus leading to an instant flour. If not truly instant, the flour is at least pre-cooked, and the subsequent time required to cook the gruel is considerably reduced. During extrusion cooking, raw materials also undergo high shear, thus allowing partial starch hydrolysis (Colonna, Doublier, Melcion, De Monredon, & Mercier, 1984). The extent of hydrolysis determines the energy density at which it will be possible to prepare a gruel of semi-liquid consistency that is acceptable to infants. At a given consistency, the more important the starch is hydrolyzed, the higher the gruel energy density will be.

In spite of these advantages, the adoption of extrusion cooking processing for the production of infant flour in developing countries is still limited. Only a few industrial units produce extruded flour at a large scale mainly in response to the need of international or non-govern-

---

* Tel.: +226-30-67-37; fax: +226-31-03-85.
E-mail address: claire.mouquet@ird.bf (C. Mouquet).

0308-8146/03/$ - see front matter
doi:10.1016/S0308-8146(02)00545-9

mental organisations for emergency supplies. The main reason for this is that most extruders are designed for large-scale production, thus requiring very high investment and technical knowledge. Even the so-called low-cost extruders, or dry extruders that were developed for the production of complementary foods at the beginning of the 1980s by the university of Colorado (Harper, 1995; Harper & Jansen, 1985; Said, 2000), are too costly and their production capacity is too high (about 55,000 dollars for a machine with a production capacity of 1 ton per hour), and are thus not affordable for developing countries. The development of a small simple machine, with a small production capacity (about 30 kg/h) is therefore of great potential interest.

The Vietnamese context is particularly well suited for the development of the production of infant flour by extrusion cooking for several reasons.

1. In rural areas and particularly in the plains, mothers prepare a thermos of boiled hot water each morning in order to have a supply of safe drinking water available during the day, and this water could easily be used for the preparation of a gruel with an instant flour
2. A rudimentary extrusion cooking process has been used for many years in the countryside; simple extruders with very small production capacity already exist and are used for the production of snacks or cassava noodles sold in the street. These machines were probably originally designed in the United States at the end of the nineteenth century for the extrusion of plastic.
3. These small extruders are now manufactured locally in small mechanical workshops, and it is also easy and cheap to construct spare parts locally for the maintenance of the machines.

Occasional attempts have been made to produce instant infant flours using these rudimentary local extruders but these efforts have not continued, firstly because their impact on nutritional quality of infant flours was not satisfactory, and secondly because the machines were not sturdy and often broke down during production.

Taking the features of this specific context into account, we modified the rudimentary type of local extruder to improve their ability to produce infant flour, as well as their sturdiness. These improved extruders with limited production capacity were named "very low-cost extruders" in reference to the low-cost extruders that Harper and Jansen already developed for the production of nutritious precooked foods for developing countries (Harper & Jansen, 1985).

The objective of this study was to test the performance of these improved "very low-cost extruders" and, in particular, to evaluate the instant character of the flour, the extent of starch dextrinisation and the residual trypsin inhibitor activity of extruded blends.

2. Materials and methods

2.1. Extrusion cooking equipment

The "very low-cost extruder" we used is a simple single-screw autogenous extruder manufactured in Vietnam by a small enterprise named "Mechanical Workshop no. 147″, (Phan Chu Trinh Street, Da nang City) according plans that we furnished (see photo in Fig. 1). The drive motor has a power of 10.5 kW. The barrel length is 200 mm with a length/diameter ratio of 5 and has a central cylindrical die of 5 mm in diameter and 9 mm in length. The rotating speed of the screw is high (500 rpm), thus allowing high shear. The design of the screw was modified (constant pitch and gradual decrease in the flight depth), to allow a progressive increase in friction forces and consequently in the temperature inside the barrel. The screw diameter is 40 mm and the root diameter increases gradually from 33 to 38 mm (see photo in Fig. 2) The extruder barrel wall has reverse helical grooves to enhance forward conveyance of the product.

To ensure a regular feeding rate, the extruder is equipped with a motorised feeding screw that allows feeding rates from 5 to 39 kg/h. Residence time is between 4 and 20 s, which is very short in comparison to other extruders but longer than the residence time observed in rudimentary Vietnamese extruders.

2.2. Raw materials

The raw materials used to prepare composite flours were the cheapest and the most easily available on the Vietnamese market. The basic cereal was polished rice. Soybean and sesame were added to increase lipid and protein contents. All raw materials were bought locally. Soybean was dried in an oven to reach a dry matter content above 92%, wet basis (wb), before being dehulled in an abrasive disk huller equipped with a cyclone to remove hulls and straws. After dehulling, the abrasive disks were brought closer and the soybean passed a second time in the machine to be roughly ground to a size of about 2 mm.

Different infant flour formulas (flours A, B, C and D) were calculated to achieve the minimum protein and lipid contents of respectively, 12 and 8 g/100 g DM required for complementary foods, after addition of a premix to the extruded blends (Table 1). The premix

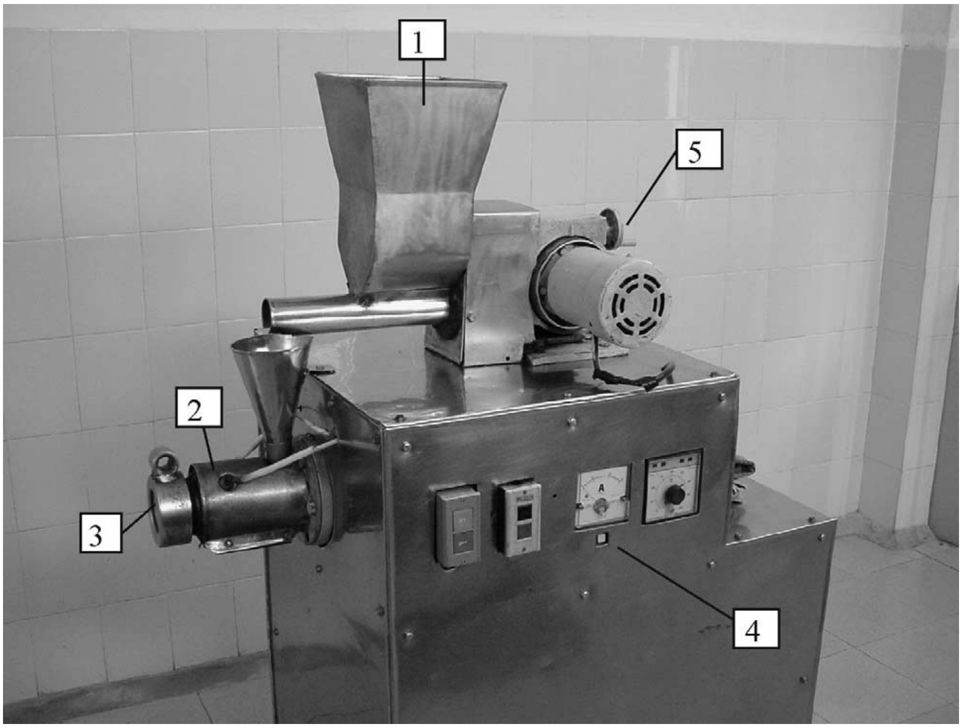

Fig. 1. The “very low-cost extrusion-cooker” used for experiments (designed and manufactured in Vietnam). 1. Feeding hopper; 2. screw and barrel; 3. central cylindrical die; 4. control panel (amperage, temperature, feeding screw On/Off, extruder On/Off); 5. feeding screw speed variator.

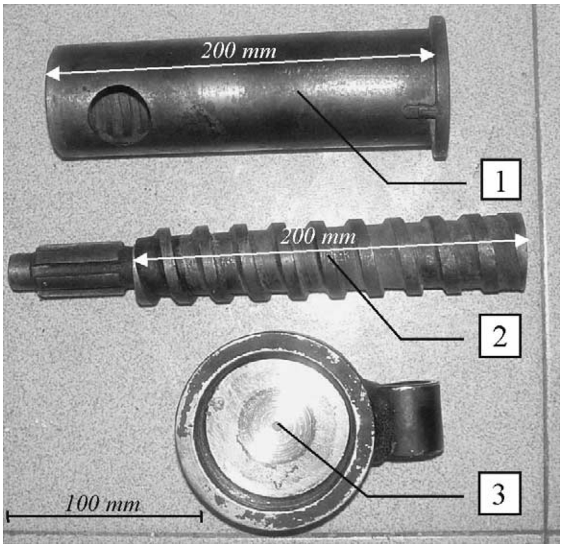

Fig. 2. Main spare parts of the “very low-cost extrusion-cooker”. 1. Barrel; 2. screw with gradual decrease in the flight depth and constant pitch; 3. cylindrical die of 5 mm in diameter and 9 mm in length.

Table 1
Formulas and calculated protein and lipid contents of final composite flours

	Composition (g/100 g dry matter)					Nutrient content[a] of final flour (g/100 g DM)	
	Ingredients blended before extrusion			Ingredients added after extrusion		Lipid	Protein[c]
	Rice	Soybean	Sesame	Roasted soybean	Premix[b]		
Flour A	49.9	21.7	5.7	0.0	22.7	10.03	15.45
Flour B	50.2	27.1	0.0	0.0	22.7	8.05	16.63
Flour C	50.2	24.7	2.3	0.0	22.7	8.82	16.70
Flour D	52.4	0.0	4.9	20.0	22.7	10.12	16.33

[a] Calculated from Souci et al. (2000).

[b] Premix prepared by blending sugar (66%), milk powder (22%), salt (4%), vitamins and minerals (7%) and vanilla aroma (1%).

[c] Total N content multiplied by 5.80, 5.30, 5.71 and 6.38 for rice, soybean, sesame and milk powder, respectively.

(sugar 66%, milk powder 22%, salt 4%, aroma 1%, vitamins and minerals 7%, wt.) was added in order to meet recommendations for vitamin and mineral contents and confer suitable organoleptic characteristics to the flours. For blend D, the formula was calculated taking into account the addition of roasted soybean flour bought on the local market after extrusion to achieve required protein and lipid contents. The formula calculations were made with data from food composition tables (Souci, Fachman, & Kraut, 2000).

Extrusion cooking experiments were performed on rice alone and on the different blends of rice, soybean and/or sesame used for the preparation of flours A, B, C and D (Table 2). After extrusion, all extrudates were ground (particle size <500 μm) before biochemical analysis.

Table 2
Composition and calculated lipid and protein contents of rice and blends before extrusion

	Composition (g/100 g DM)			Nutrient content[a] (g/100 g DM)	
	Rice	Soybean	Sesame	Lipid	Protein[b]
Rice	100.0	0.0	0.0	0.71	7.84
Blend A	64.5	28.1	7.4	11.18	18.25
Blend B	65.0	35.0	0.0	8.61	19.78
Blend C	65.0	32.0	3.0	9.60	19.09
Blend D	91.4	0.0	8.6	5.47	8.82

[a] Calculated from Souci et al. (2000).

[b] Total N content multiplied by 5.80, 5.30 and 5.71 for rice, soybean and sesame, respectively.

2.3. Starch gelatinisation rate

Total starch content of composite flours was determined by the enzymatic method of Batey (1982). Analyses were made in duplicate and both values are given. The extent of starch gelatinisation during extrusion cooking was determined in duplicate by a method based on the evaluation of amyloglucosidase hydrolysis susceptibility (Chiang & Johnson, 1977; Kainuma, Matsunaga, Itagawa, & Kobayashi, 1981). The gelatinisation rate is the ratio of starch fraction susceptible to amyloglucosidase hydrolysis and total starch (minimum, maximum and mean values are given).

2.4. Preparation of gruels

Crude and extruded blend were ground and the flours obtained were used for the preparation of gruels with different dry matter contents using:

1. A “cooking procedure” comprising mixing flour with cold demineralised water into a slurry and cooking on a hot plate (300 °C) with continuous stirring for 5 min once the mixture started to boil.
2. An “instant procedure” comprising adding demineralised water heated to 75 °C to the flour and stirring vigorously.

After preparation, gruels were allowed to cool to 45 °C before viscosity measurements. Dry matter contents of the gruels were determined by oven drying at 105 °C to constant weight.

2.5. Apparent viscosity measurements

Apparent viscosity measurements were performed on gruels with a Haake viscometer VT550 with SV-DIN coaxial cylinders driven by a PC computer with the Rheowin 2.67 software. We applied the measurement procedure proposed by Mouquet and Trèche (2001), i.e. shear rate of 83 s^{-1}, shear time of 10 min and measurement temperature of 45.0 ± 0.5 °C.

2.6. Procedure used to check the instant character of extruded blends

To our knowledge, the term “instant”, which usually describes dehydrated precooked food usable after the simple addition of hot water, is not accurately defined from a biochemical point of view. As starch becomes easier to digest when it is completely gelatinised and swollen, we chose to evaluate the instant character by comparing apparent viscosity of gruels prepared by the “instant” and the “cooking” procedures with the same dry matter content. Two scenarios can be expected: if the apparent viscosity of the gruel prepared with the “instant procedure” is equal or slightly higher than the viscosity of the gruel prepared with the “cooking procedure”, then the flour can be considered as “instant”. If it is lower, it implies that part of the flour starch is not totally precooked during the extrusion cooking stage and will continue to swell during the cooking of the gruel, thus leading to an increase in viscosity.

2.7. Trypsin inhibitor activity

Trypsin inhibitor activity (TIA) was determined in duplicate by the method of Kakade, Rackis, MacGhee, and Puski (1974), modified by Smith, Van Megen, Twaalfhoven, and Hitchcock (1980), and both values, expressed in trypsin inhibitor units (TIU) per 100 g DM, are given. The percentage of trypsin inhibitor destroyed during extrusion cooking were calculated from the ratio between TIA before and after extrusion, and mean, minimum and maximum values are given.

3. Results and discussion

3.1. Effect of very low-cost extruder on starch gelatinisation rate

The main characteristics of the different extruded blends are given in Table 3. In all cases, we observed an increase in dry matter content after extrusion cooking. This increase is due to water loss by instant vaporisation at the exit of the die.

For extruded rice and blend D only, the gelatinisation rate exceeded 90%, from which we estimated that gelatinisation rate had reached a satisfactory level. For extruded blends A, B and C, the gelatinisation rate after extrusion cooking ranged from 56 to 83%. The remaining native and, thus, non-digestible starch content was non negligible, and we consequently considered that the corresponding flours could not be used as “instant” flours, even though they appeared to be precooked.

Table 3
Effects of processing with the "very low-cost extruder" on the starch gelatinisation rate and the trypsin inhibitor activity of rice and different blends

Blend used for extrusion cooking		Dry matter content (g/100g, wb)[a]	Total starch content[a,b] (g/100g DM)	Gelatinised starch content (g/100g DM)[a,b]	Gelatinisation rate (%)[c]		Trypsin inhibitor activity		TI destroyed (%)[c]
							TIU[a]/g DM	TIU/g DM of soybean	
Rice	Before EC[a]	86.0	91.9–93.9	10.8–11.5	12	(11–12)	–	–	–
eRice[a]	After EC	90.5		85.0–87.8	93	(91–96)			
A	Before EC	88.9	55.5–57.3	9.4–10.9	18	(16–20)	12,213–12,246	44,250–44,490	
eA	After EC	90.4		30.3–33.3	57	(53–60)	5766–6091	20,890–22,066	52 (50–53)
B	Before EC	90.1	61.2–65.9	10.6–12.7	18	(16–21)	13,518–13,900	37,655–38,719	
eB	After EC	95.5		51.1–53.8	83	(78–87)	3140–3491	9548–9924	76 (74–78)
C	Before EC	90.6	56.3–58.5	10.5–11.3	19	(18–20)	13,394–13,774	40,836–41,994	
eC	After EC	95.4		44.0–46.6	79	(75–83)	2380–2574	6777–8327	82 (81–83)
$\mathrm{eC_a}$[d]	After EC	89.9		35.6–39.0	65	(61–69)	6041–6625	18,418–20,198	53 (51–56)
$\mathrm{eC_b}$[e]	After EC	92.0		45.8–46.0	80	(78–82)	1972–2112	6014–6438	85 (84–86)
$\mathrm{eC_c}$[f]	After EC	90.8		44.3–44.4	77	(76–79)	2167–2292	6608–6990	84 (83–84)
D	Before EC	88.7	84.4–86.3	19.3–21.7	24	(23–25)	–	–	–
eD	After EC	92.7		82.3–84.9	98	(95–100)			

[a] wb, wet basis; DM, dry matter; TIU, trypsin inhibitor units; TI, trypsin inhibitor; EC, extrusion cooking; eRice, extruded rice; eA, extruded blend A,….

[b] Analyses were made in duplicate and both values are given.

[c] For ratios, mean values calculated from analyses results are given (minimum and maximum values in parentheses).

[d] $\mathrm{eC_a}$, the blend C was added with water (10ml/100g) before extrusion cooking, lowering the initial dry matter content of the blend to 81.8 g/100 g DM.

[e] $\mathrm{eC_b}$, the blend B was extruded a first time, then sesame and water (10 ml/100 g, wb) were added and the blend extruded a second time.

[f] $\mathrm{eC_c}$, the blend C was extruded twice, with addition of water (15 ml/100 g, wb) between the two treatments.

To check this, the apparent viscosity of gruels prepared at different concentrations with the flours obtained from extruded blends according to the two different procedures ("instant" and "cooking") were compared. The viscous behaviour of gruels prepared with the flour of the crude blend was also determined. Results obtained with rice, and with blends A and D are presented in Fig. 3.

The curves of apparent viscosity of gruels obtained with the flour of the extruded blend D (Fig. 3c) were almost superimposed for the two gruel preparation procedures indicating that this procedure had no major effect on its consistency. This confirms that flour D can be sold and used as instant flour. However, in the case of the flour of the extruded blend A (Fig. 3b), the viscosity curve of gruels prepared by the "instant" procedure was very far from those of gruels prepared by boiling for 5 min, indicating that a starch fraction that had not gelatinised during the extrusion cooking treatment, gelatinised and swelled during gruel preparation, leading to a much more viscous gruel at the same concentration. The viscous behaviour of those gruels was very close to that of gruels prepared with the corresponding flour of crude blend and we concluded that the extrusion cooking treatment had had very little effect on starch in this case.

In the case of the extruded rice flour (Fig. 3a) surprisingly, gruels cooked by boiling for 5 min were thinner at the same concentration, than those prepared by the addition of hot water. This can be explained by a partial solubilisation of swollen granules of starch during the cooking of the gruel that resulted in reduced viscosity.

Thus, while extruded rice or blend D resulted in flours that can be considered instant, the persistence of a non gelatinised fraction of starch in blend A after extrusion cooking led us to conclude that the processing with "very low-cost extruders" was not appropriate for this blend.

3.2. Effect of "very low-cost extruder" on starch dextrinisation

The results presented in Fig. 3 can also be used to evaluate the intensity of starch dextrinisation during the extrusion cooking process. Partial starch dextrinisation is desirable because it reduces swelling during gruel preparation, thus allowing an appropriate semi-fluid consistency to be maintained at a higher concentration, i.e. higher energy density. To achieve this, we measured the gain in dry matter content between gruels prepared at the same apparent viscosity with crude flours according to the "cooking" procedure and with flours of extruded blends according to the "instant" procedure when starch gelatinisation was complete (extruded rice and blend D), or according to the "cooking" procedure when starch gelatinisation was only partial (extruded blend A). At the apparent viscosity value of 1.5 Pa.s, which corresponds to a thick but spoonable gruel (Mouquet & Trèche, 2001), the increases in dry matter content of gruels due to the extrusion cooking treatment for rice and blend D were 5.7 and 4.3 g/100 g of gruel, respectively (Fig. 3a and c). This increase was limited to 1.2 g/100 g of gruel for extruded blend A, demonstrat-

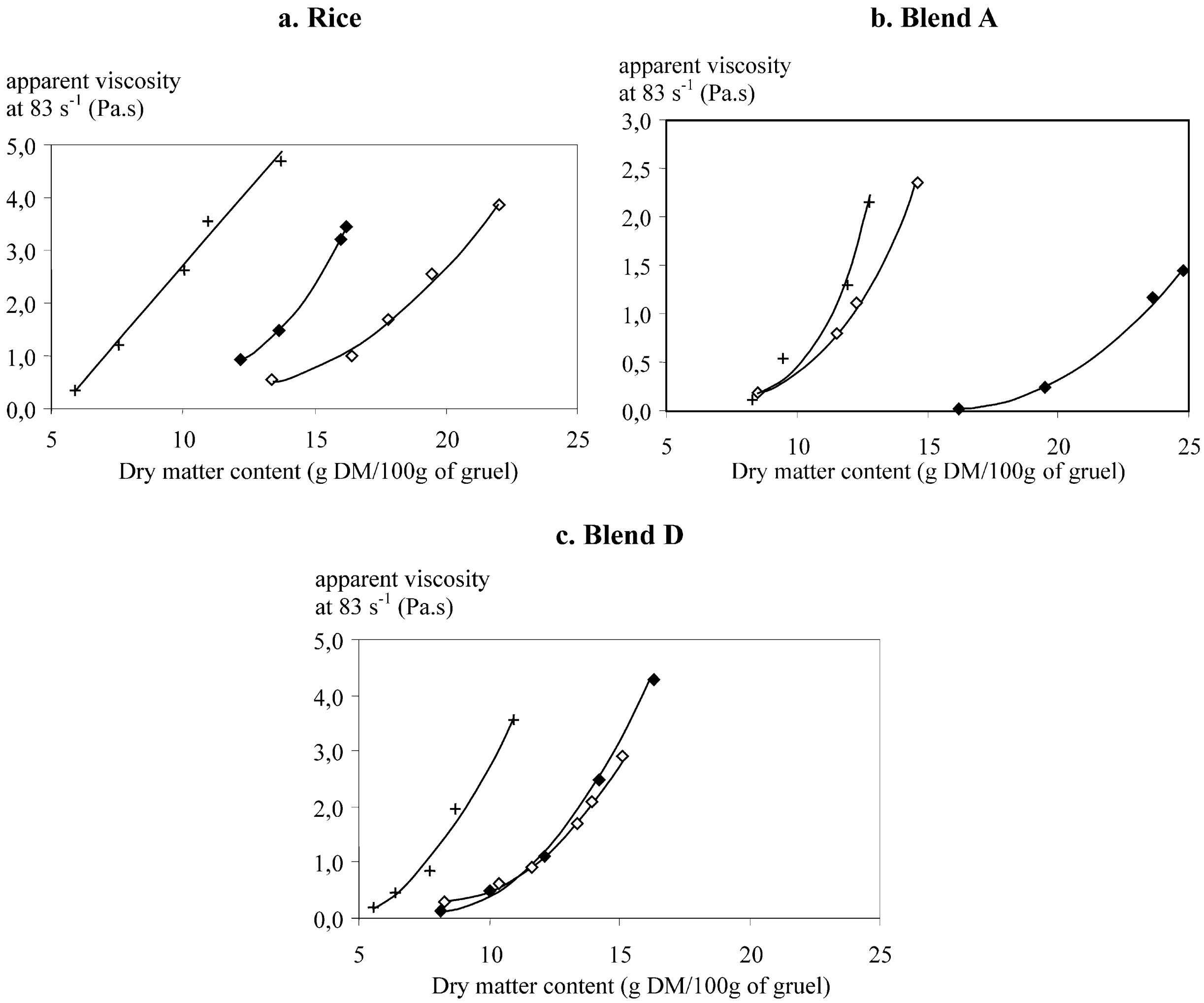

Fig. 3. Effect of the concentration on the apparent viscosity of gruels prepared with rice and experimental blends according to different procedures. + Crude flour, boiling 5 min; ◆ extruded flour, addition of water at 75 °C; ◇ extruded flour, boiling 5 min.

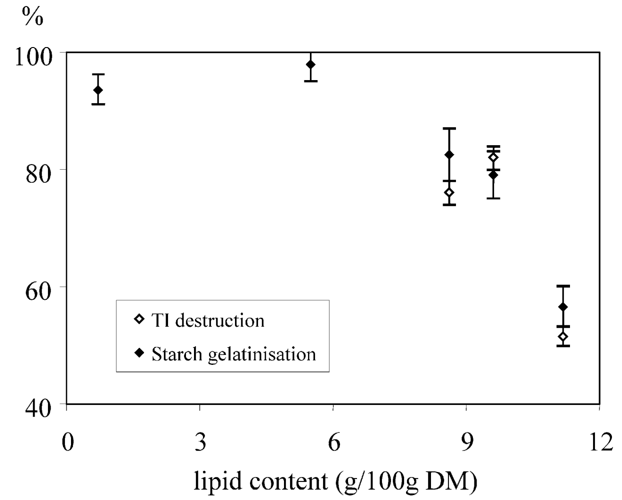

Fig. 4. Influence of the initial lipid content of the blend on the percentages of trypsin inhibitor destruction and starch gelatinisation during processing in very low-cost extruder (mean, minimum and maximum values).

ing once again the less drastic effect of the extrusion cooking treatment (Fig. 3b).

3.3. Effect of "very low-cost extruder" on the reduction of trypsin inhibitor activity

The TIA of crude grains of soybean bought on the local market is very high, about 40,000 TIU/g DM of soybean (Table 3). After extrusion cooking, we observed a reduction in TIA that took place in a similar way to the gelatinisation rate as a function of the composition of the blend (Fig. 4). The lipid content of the blends seemed to be one of the main factors affecting the severity of the extrusion cooking treatment. It is indeed well known that lipids, by lubricating the screw and the internal surface of the barrel, decrease friction forces and thus reduce the maximum temperature inside the extruder. In our experiments, until it reached 6 g/100 g DM, the lipid content of the blends appeared to have no effect on starch gelatinisation. Beyond this value, the starch gelatinisation rate started to decrease, resulting in reduced efficiency of the extrusion cooking treatment. We also observed a simultaneous decrease in trypsin inhibitor destruction rates, as lipid content increased. These results are consistent with the threshold value of 7 g/100 g DM previously mentioned for lipid content under which it becomes difficult to transform mechanical energy into heat with a single-screw extruder and without steam injection (Huber, 2000).

To increase the efficiency of the extrusion cooking process, we tried several combinations of treatment:

1. We increased the initial water content of blend C (trial C_a) from 9.5 to 18.2 by water spraying to favour starch gelatinisation assuming that the gelatinisation temperature decreases with increasing initial water content of the blend (Lelièvre, 1973),
2. We attempted to amplify the effects of extrusion cooking by repeating the treatment: in trial C_b, we first extruded blend B (rice and soybean) and then added sesame to obtain blend C for the second extrusion. In trial C_c, we twice extruded the complete blend C (rice, soybean and sesame). We had to add water to the blends between the two extrusion cooking treatments, because after the first extrusion cooking treatment, the dry matter content was more than 95%, and there was a risk of damage to the extruder. The quantity of water added was calculated to reach an initial dry matter content of about 90%, close to the values of initial blends.

The effects of these combined or modified treatments on starch gelatinisation and trypsin inhibitor destruction rates are given in Table 3.

The results of trial C_a show that the addition of water to the initial blend had a strong negative effect on the efficiency of the extrusion cooking treatment probably due to a marked decrease in the maximum temperature reached inside the barrel (maximum temperature measured on the external side of the barrel near the die was 156 °C without water addition, and decreased to 108 °C when water was added before extrusion). The percentages of gelatinised starch and destroyed trypsin inhibitor fell from 79 and 82% respectively, without the addition of water, to 65 and 53%. The "very low-cost extruder" is not equipped with a steam injection system to balance the reduction of the friction forces due to the smoothing effect of the water. For trials C_b and C_c, the second extrusion cooking treatment had no beneficial effects on the gelatinisation rate and allowed an increase of only a few percent in the trypsin inhibitor destruction rate, which was not sufficient to justify performing the second extrusion cooking operation in commercial production.

4. Conclusion

The results of our experiments showed that the kind of "very low-cost extruders" with a small production capacity that we improved in Vietnam is suitable to process blends with low water content (around 10%, wb) and low lipid content (below 6%, db). In these conditions, the rice–sesame blend extruded with this equipment resulted in total starch gelatinisation, which is required if the flour is to be sold as instant flour. Starch was also partially dextrinised during the treatment, thus allowing the preparation of gruels of higher energy density. After extrusion, the addition of roasted soybean flour and premix allowed the appropriate macro and micronutrient balance required for a complete infant flour to be achieved.

References

Batey, I. L. (1982). Starch analysis using thermostable α-amylase. *Starch*, *4*, 125–128.

Björck, I., & Asp, N. (1983). The effects of extrusion cooking on nutritional value—a literature review. *Journal of Food Engineering*, *2*, 281–308.

Camire, M., Camire, A., & Krumhar, K. (1990). Chemical and nutritional changes in foods during extrusion. *Critical Reviews in Food Science and Nutrition*, *29*(1), 35–56.

Chiang, C. J., & Johnson, J. A. (1977). Measurement of total and gelatinized starch by glucoamylase and o-toluidine reagent. *Cereal Chemistry*, *54*(3), 429–435.

Colonna, P., Doublier, J. L., Melcion, J. P., De Monredon, F., & Mercier, C. (1984). Extrusion cooking and drum drying of wheat starch. I. Physical and macromolecular modifications. *Cereal Chemistry*, *61*(6), 538–544.

Harper, J. (1995). Low-cost extrusion: possibilities for Africa. *The South-African Journal of Food Science and Nutrition*, *7*, 142–147.

Harper, J., & Jansen, G. (1985). Production of nutritious precooked foods in developing countries by low-cost extrusion technology. *Food Reviews International*, *1*(1), 27–97.

Huber, G. R. (2000). Twin-screw extruders. In M. N. Riaz (Ed.), *Extruders in food applications* (pp. 81–114). Texas: Technomic publishing Co.

Kainuma, K., Matsunaga, F., Itagawa, M., & Kobayashi, S. (1981). New enzyme system β-amylase–pullulanase to determine the degree of gelatinization and retrogradation of starch or starch products. *Journal of Japanese Society on Starch Science*, *28*(4), 235–240.

Kakade, M. L., Rackis, J. J., MacGhee, J. E., & Puski, G. (1974). Determination of trypsin inhibitor activity of soy products: a collaborative analysis of an improved procedure. *Cereal Chemistry*, *51*, 376–382.

Lelièvre, J. (1973). Starch gelatinization. *Journal of Applied Polymer Science*, *18*, 293–296.

Mouquet, C., & Trèche, S. (2001). Viscosity of gruels for infants: a comparison of measurement procedures. *International Journal of Food Sciences and Nutrition*, *52*, 389–400.

Said, N. W. (2000). Dry extruders. In M. N. Riaz (Ed.), *Extruders in food applications* (pp. 51–62). Texas: Technomic publishing Co.

Smith, C., Van-Megen, W., Twaalfhoven, L., & Hitchcock, C. (1980). The determination of trypsin inhibitor levels in foodstuffs. *Journal of the Science of Food and Agriculture*, *31*, 341–350.

Souci, S., Fachman, W., & Kraut, H. (2000). *Food composition and nutrition tables* (6th ed). London: Medpharm Scientific Publisher & CRC Press.