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Pasting properties of expanded extrudate and pellets from corn flour and rice flour

Propriedades de pasta de extrudados expandidos de pellets de milho e arroz

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Resumo

A extrusão termoplástica é um dos processos industriais que tem se mostrado eficiente na obtenção de produtos alimentícios. Este processo possibilita a obtenção de uma variedade de produtos, como *snacks* e farinha de arroz, entre outros. Dentre as propriedades importantes dos produtos extrudados, figuram a expansão e a viscosidade de pasta. A elaboração de produtos por meio do processo de extrusão tem crescido notavelmente nos últimos anos. O processo de extrusão promove modificações físico-químicas, estruturais e bioquímicas do amido, da proteína e dos componentes menores, visando melhorar as suas propriedades tecnológicas, funcionais e nutricionais para as mais diversas aplicações na indústria de alimentos. A determinação da viscosidade de pasta permite verificar o grau de modificação relativa quando os amidos ou as farinhas são submetidos a tratamento térmico em meio aquoso. Essas modificações são drásticas, no caso da extrusão, quando as forças de cisalhamento são altas. No caso de expandidos, essa força é muito superior quando comparada àquela do processamento de farinhas para *pellets* (*snacks* de terceira geração). O objetivo deste trabalho foi comparar as propriedades de pasta de extrudados expandidos e *pellets* elaborados de farinha de milho e arroz, através da extrusão utilizando o *Rapid Visco Analyser* (RVA). Os resultados indicaram uma alta viscosidade no ciclo de aquecimento (até 90 °C) para o expandido de milho e viscosidade intermediária para o expandido de arroz. Quanto às viscosidades dos *pellets* de milho e arroz, foi observada baixa viscosidade se comparada à encontrada nos expandidos. Outra diferença importante nos *pellets* de milho foi o seu alto grau de retrogradação, alcançando cerca 1600 cP; já o *pellets* de arroz teve um valor de 350 cP. Isto implica que a fabricação de expandidos e de *pellets* requer cuidados nos parâmetros de processamento. Com relação à degradação, os produtos expandidos estão sujeitos a uma maior degradação, pois se utiliza maior taxa de cisalhamento quando comparada à dos *pellets*, que são processados a altas umidades. Com base nos resultados obtidos, pode-se concluir que a farinha de milho é mais indicada para os expandidos, provavelmente pela sua estrutura granular e pela matriz proteica, e a farinha de arroz, indicada para os *pellets*; neste caso, talvez pelo tamanho dos grânulos de amido, que são de aproximadamente três micras.

Palavras-chave: *Extrusão; Viscosidade de pasta; Milho; Arroz; Viscoamilógrafo.*

Summary

Thermoplastic extrusion is one of the most efficient industrial processes for obtaining nutritious products. This process makes it possible to obtain a variety of products such as snacks and precooked rice flour, amongst others. Some of the most important properties of extruded products are their expansion and paste viscosity. The elaboration of products using the extrusion process has grown notably in the last few years. The extrusion process promotes physiochemical, structural and biochemical modifications of the starch, protein and smaller components, seeking to improve their technological, functional and nutritional properties for the most varied applications in the food industry. The pasting viscosity allows one to determine the degree of modification of the starches or flours when subjected to heat treatment under moist conditions. These changes are dramatic in the case of extrusion, since the shear forces are high. In the case of expanded products, this force is much higher than that involved in the flour pelleting process (third generation snacks -3G). The objective of this study was to compare the pasting properties of expanded extrudates and pellets obtained from corn and rice flours, using the *Rapid Visco Analyser* (RVA). The results indicated a high viscosity in the heating cycle (up to 90 °C) for the expanded corn flour and intermediate viscosity for the expanded rice flour. The pasting viscosity of the pellets was low as compared to that of the expanded extrudates. Another important difference between the pellets from corn flour and those from rice flour was the high degree of retrogradation in the former, reaching about 1600 cP, whereas for the rice pellets this value was only 350 cP. This implies that the manufacture of expanded extrudates and pellets requires care with respect to the processing parameters. Based on these results, it was concluded that the corn flour was more indicated for the manufacture of expanded extrudates, probably due to its granular structure and protein matrix, whereas the rice flour was more indicated for pellet manufacture, possibly due to the size of its starch granules, which were approximately three micra.

Key words: *Extrusion; Pasting viscosity; Corn; Rice; Visco analyzer.*

1 Introduction

Extruded products are usually prepared from flours and starches (such as corn and rice), or roots and tubers, such as cassava and potatoes (BALAGOPALAN, 2002; CHEYNE et al., 2005; CHUANG and YEH, 2004; DING et al., 2005). Extrusion is defined as an HTST (high temperature in short time) process, in which the mechanical energy is combined with heating to gelatinize the starch and denature the proteins, plasticizing and reorganizing the material to create new shapes and textures, and it also has the ability to inactivate enzymes, destroy some toxic substances and reduce the microbial activity. Extruders with different designs are used in the production of pre-cooked foods, textured vegetable protein, powdered instant drinks, instant soups, baby food, snacks, etc. (SGARBIERI, 1998).

Extrusion is a continuous process, which is versatile and widely used in food processing. During food extrusion, chemical modifications and structural changes occur, such as starch gelatinization (AKDOGAN, 1999, VAN DEN EINDE et al., 2005), protein denaturation (GUY, 2001b; IWE et al., 2004), pigment and vitamin degradation, (ILO and BERGHOFER, 1999), the loss of volatile compounds (BHANDARI et al., 2001) and others. Extrusion cooking is a technology with high versatility and efficiency, low cost, high yield and short reaction time, with no waste generation (NABESHIMA and GROSSMANN, 2001).

The starch pasting properties of these materials are very important when studied in warm, moist or semi-moist systems.

According to Ascheri (1997) raw starch absorbs practically no water at room temperature and its contribution to the increase in viscosity is practically nil. However, when extruded, it rapidly absorbs water, forming a paste at room temperature with no further heating. This paste is formed by macromolecules suspended in an aqueous medium which also includes water-swollen particles (gel).

According to Yacu (1995), the extrusion process variables which directly control the food quality attributes are designated as independent variables. These include the food composition, moisture content, particle size, feeding speed, screw and die configuration, temperature, pressure and residence time of the food in the extruder barrel.

The dependent variables or responses change as a result of the independent variables and are used to evaluate the physical, chemical and functional properties of the extrudates. They include the density, specific volume, moisture, expansion, sensory attributes such as appearance, flavour, crispness and texture, the degree of cooking as evaluated by enzyme susceptibility, the viscosity, the rate of water absorption and solubility, X-ray diffraction and calorimetry (YACU, 1995).

The production of extruded foods has been considered a global trend with an innovative market, and is one of the most versatile tools in processing. The development of expanded products through the extrusion process has grown significantly in Brazil (FERNANDES; BATISTUTI, 2000), with the promotion of an increasingly thermoplastic extrusion process resulting in innovative food products of high nutritional value and/or digestibility (FERNANDES et al., 2002). The objective of this study was to compare the extruded pasting properties of expanded products and pellets obtained from corn flour and rice flours, using the *Rapid Visco Analyser* (RVA). Moisture is a critical factor for both expanded and non-expanded products. In this experiment, the moisture content of the expanded samples was 15% and of the pelletted samples, 28%. Expanded products require higher shear in the extruder barrel to cause the greater transformation of the starch structure. The moisture content of the pellets is higher than that of the expanded products and the shear is smaller, resulting in no expansion and a compact laminar product (WHALEN, 2001; SILVA, 2007).

2 Material and methods

2.1 Sample preparation and conditioning

Corn flour (*Zea mays*) and rice grains (*Oryza sativa L.*), both acquired from local shops, were used to obtain pellets and expanded products. Milling was carried out in a TREU hammer mill TREU (mod. 1188, São Paulo, Brazil), with a mesh of 1.5 mm.

The sample moisture contents (conditioning) used for processing the expanded and pelletted products were 15 and 28%, respectively. The samples were packed into plastic bags and stored at room temperature for 24 h. A SIAM UTIL S.A. industrial mixer with a capacity of 10 kg was used to condition the raw materials. The initial moisture content of the corn flour (12.12%) was determined according to the AACC method 44-16 A (1995), using an oven at 105 °C to constant weight. The amount of water to be added was calculated using the following Equation (1):

$$Y = \frac{(M_f - M_i) * W_e}{100 - M_f} \quad \textbf{(1)}$$

where: Y = amount of water to be added (mL); Mf = final moisture content of the sample; Mi = initial moisture of the sample; We = sample weight (g).

After homogenization the samples were placed in plastic bags and stored refrigerated for 24 h, to obtain more uniform water distribution and absorption (ASCHERI, 2010).

2.2.1 Particle size

One hundred gram samples were used in the particle size determination of the raw materials, with 10 min of vibration through a set of seven rounded USA STANDARD sieves in a model RO-TAP RX-29-10 vibrator, using the 420, 300, 250, 180, 150 and 75 micra sieves for the unbleached rice flour, and the 300, 425, 500, 710, 850, 1180 and 1400 micra sieves for the corn flour. The amounts retained on each sieve were weighed and expressed in percentages.

2.2 Proximate composition of the raw materials

The moisture content was determined in triplicate according to method 44-15A of the American Association of Cereal Chemists - AACC (1995) using the semi-automatic - Brabender Moisture Tester (Duisburg, Germany). This determination is based on evaporation of the water from the sample in an oven with air circulation at 130 °C for 1 h, the reading being made on the appliance itself. The moisture tester determination was used for the extruded samples, since it gives the result in a shorter time.

The ash content was determined by incineration of the material in an oven at 550 °C, according to method 923.03 of the Association of Official Analytical Chemists - AOAC (FERNANDES; BATISTUTI, 2000), and represents the total content of inorganic substances in the sample.

The total nitrogen content of the sample was determined by the traditional Kjeldahl procedure, according to the methodology of the American Association of Cereal Chemists - AACC (1995), method 46-13. To calculate the crude protein content from the nitrogen content, a factor of 6.25 was used.

The ether extract was determined using the Soxhlet apparatus, according to method 945.38 of the Association of Official Analytical Chemists - AOAC (HOROWITZ, 2000). In this method, the lipid content is obtained by extraction with petroleum ether, followed by evaporation off of the solvent.

2.3 Determination of the crude fibre and carbohydrates

The crude fibre was determined by boiling 5 g raw material with 100 mL of 1.25% H_2SO_4 in a beaker on a block digester for 30 min, and then filtering and washing the residue. The residue was transferred back to the beaker, 100 mL of 1.25% NaOH added, and boiled for a further 30 min on the block digester. The beaker was also washed with hot water to remove any residue of the sample and NaOH. The crucible containing the fibres and waste was heated in an oven at 105 °C for 3-4 h and then placed in a desiccator for 30 min to 1 h. After weighing the crucible (crude fibre + mineral), it was transferred to an oven at 550 °C for 2 h and 30 min (destruction of organic matter). After cooling in a desiccator, it was weighed again. The difference between the first and second weights was the weight of the crude fibre (SILVA and QUEIROZ, 2004)

The total carbohydrates were determined by difference.

2.4 Processing of the expanded product

A single-screw BRABENDER model 20DN extruder was used in the extrusion process. The fixed parameters were: die diameter (3 mm), screw with a compression ratio of 3:1, screw diameter 19 mm, Screw length L : D 20; feed rate 16 rpm (throughput 2.5 kg.h^{-1}).

The temperatures were: 80 °C in zone 1, 100 °C in zone 2 and 130 °C in zone 3. The screw rotation speed was constant throughout the process (180 rpm) and the extruded product was dried in an oven at 50 °C for 12 h, with a final moisture content of 7 to 10%.

2.5 Processing of the extruded pellets

A single-screw BRABENDER model 20DN extruder was used in the extrusion process. The fixed parameters were: 1 mm laminar die, screw compression ratio of 4:1, feed rate 16 rpm, (capacity 2.5 kg.h^{-1}). The temperatures were: 60 °C in zone 1, 70 °C in zone 2 and 80 °C in zone 3. The screw rotation speed was constant throughout the process (150 rpm).

The extruded product was dried in an oven at 40 °C for 12 h, with the air circulation and relative humidity controlled to prevent rupture of the material.

After reaching ambient temperature, both types of sample, expanded and pelletted products, were placed in plastic bags, sealed and kept at room temperature until used. To obtain a sample suitable for testing the pasting viscosity (PV), the materials were ground to pass through sieves of 106 and 212 μm.

2.6 Pasting properties

The pasting viscosity was determined for use as a parameter to evaluate the changes occurring in the starch during the extrusion process. It was determined using the model 3D+ *Rapid Visco Analyzer* (RVA) from *Newport Scientific*, according to Becker et al. (2001), using the Standard 1 method.

For the pasting properties, a concentration of 3 g sample/25 mL distilled water was used, corrected for a basis of 14% moisture (ASCHERI et al., 2006).

The initial temperature, 25 °C, was increased gradually to 95 °C, remaining constant for 3 min. The cooling phase was also carried out gradually to a final temperature of 25 °C.

- Viscosity profile analysis:

a) Initial Pasting Viscosity (VI) at 25 °C ("cold") refers to the maximum viscosity of the suspension in centipoises (cP) at the start of heating. The cold viscosity depends mainly on the degree of gelatinization of the starch granules and the magnitude of molecular breakage during the extrusion process;

b) Maximum viscosity (VMAX) at 95 °C is the value of the viscosity in cP at the peak of the curve obtained during the heating cycle;

c) Final viscosity (VFIN) at 25 °C (cooling cycle) involves the molecular element present in the phenomenon of retrogradation with the beginning of molecular re-association, increasing the viscosity.

3 Results and discussion

3.1 Classification of the particle size of the corn and rice flours

The particle size of the raw materials can significantly affect the texture and uniformity of the final product. For this reason it is desirable for the particles to have a uniform size and density to prevent segregation during mixing and transport before the extrusion process. The importance of uniformity in the conditioning step is based on the water diffusivity principle, in which the smaller particles will absorb the water quicker than the others, so particle size uniformity of the ingredients before cooking affects the uniformity of the properties during the extrusion process, preventing hardness or partial cooking of the final product.

Figures 1 (a and b) show the results for the particle size distribution of the samples of raw rice and corn flours. It can be seen that the highest percentage of the rice flour (24.1%) was retained on the 150 micra sieve and the highest percentage of the corn flour (24%) on the 300 micra sieve. The remaining percentages were distributed on the other sieves, with pores ranging from 420 to 75 micra.

3.2 Proximate composition

Table 1 shows the results obtained for the proximate composition of the raw materials. The protein content of the rice flour was close to 10% and of the corn flour 7%. On the other hand, in a typical process, the raw material containing to the order of 60 to 80% expandable starch base, is moistened with water or steam. Such a composition results in an adequate structure for compacting and melting in a screw extruder revolving inside a barrel, using a heating system according to the parameters required for each raw material and final product desired. In this case, the starch composition is very important for obtaining the required effects during extrusion. The corn and rice flours showed little differences in their proximate compositions, but sufficient to promote changes in the extrudates (CHUANG and YEH, 2004).

Table 1. Proximate composition of the rice and corn flours (g.100 g^{-1}, on a dry weight basis and kcal.100 g^{-1}).

Composition (%)	Rice flour (%)	Corn flour (%)
Protein	9.81	7.00
Ether extract	0.62	2.30
Ash	0.78	0.20
Crude fibre	0.74	0.10
Carbohydrates*	88.79	90.4

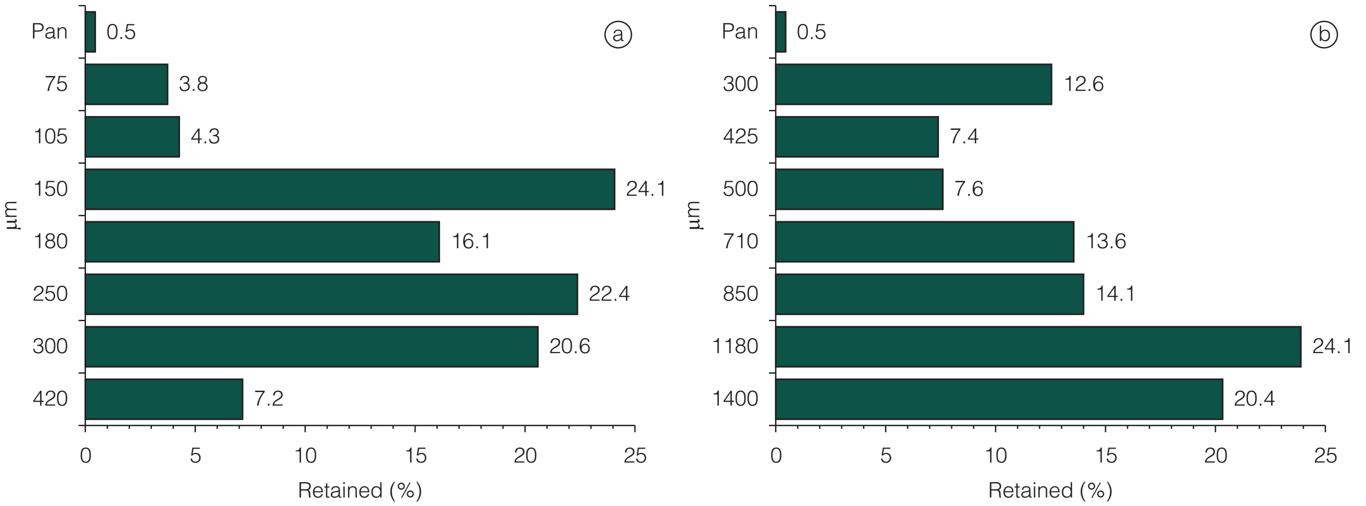

Figure 1. Particle size distributions for the raw rice (a) and corn (b) flours.

3.3 Determination of crude fibre and carbohydrates

Normally the extruded products must have a determined composition. Corn chips, for example, can have no more than 1% of fat, no more than 10% of protein and the carbohydrate content in the form of starch must be over 70%, with the total fibre content no more than 1.5%. Exceeding these limits, the material will not expand as expected. (ROKEY, 1996). The samples studied were within the expected limits with respect to composition, 0.74% crude fibre for rice flour and 0.1% for corn flour. Such values suggest that the samples are suitable for pellets (PROSKY et al, 1988).

3.4 Viscosity

The viscosity curves evaluated the pasting characteristics of the samples during heating as a result of the structural changes in the starch molecules, soon after the setback during cooling. The pasting properties determine the functional properties of the starch in the raw material and in the different industrial applications. These applications may vary according to their behaviour, either cold or hot, depending on the product required by the consumer. Amongst other characteristics of the paste viscosity, the viscogram can provide its performance during cooling. Table 2 summarizes the results of the pasting properties of the raw materials and extruded flours. Considering the raw materials as described in Table 2, it can be seen that the initial viscosity was lower than normal for this condition and the maximum viscosity in the heating cycle for the corn and rice flours was considerably higher than that for the processed materials. High values can also be observed for the final viscosities of both flours. These values help in analyzing the differences between the extruded and unprocessed materials.

3.5 Initial viscosity at 25 °C

The initial viscosity of the flour in water at 25 °C is called the cold viscosity. In the preparation of instant foods this property indicates the capacity of the flour to absorb water at room temperature to form a paste, gel or viscous liquid.

The processing of corn flour for the production of expanded products by extrusion-cooking is done at a temperature above that of starch gelatinization, which results in characteristic curves for each starch source. In the case of rice flour (Figure 2a), during the first two minutes, the paste viscosity was 100 cP, and then rose to 210 cP during the heating cycle. This implies that several starch granules could still absorb more water, as seen from the integrity (or partial integrity) of their granules. In Figure 2b, it can be seen that the initial viscosity of the corn flour was about 350 cP, and that a few minutes of heating and agitation caused a decrease in these values. Two samples expanded by extrusion using the same process will have different curves. The rice sample, although having smaller starch granules (average of 3.5 micra), showed greater shear resistance, showing that the granules could resist the heating cycle.

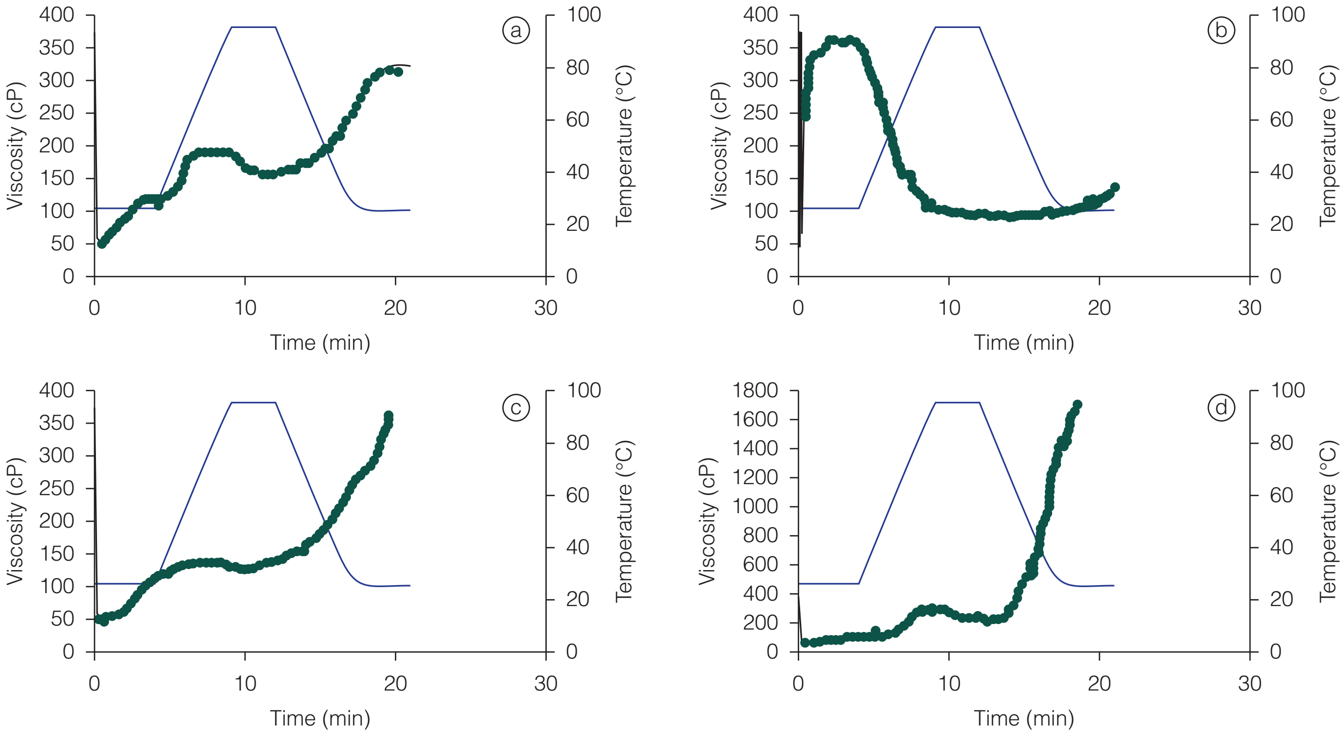

Figure 2. Viscosity profiles: a) expanded rice, b) expanded corn, c) rice pellet and d) corn pellet.

Table 2. Pasting viscosity results for the raw materials and extruded flours.

Flour from	*Initial viscosity (cP) (25 °C)	*Maximum viscosity (cP) (95 °C)	*Final viscosity (cP) (25 °C)
Expanded rice	53 ± 0.75^{d}	190 ± 0.81^{c}	310 ± 0^{c}
Expanded corn flour	300 ± 0.25^{a}	355 ± 0.31^{d}	130 ± 0.6^{d}
Rice pellet	52 ± 0.1^{c}	140 ± 0.72^{a}	350 ± 0.12^{a}
Corn pellet	10 ± 0.28^{b}	180 ± 1.03^{b}	1700 ± 0^{b}
Corn flour (non-processed)	5	1485	5384
Rice Flour (non-processed)	3	2632	4000

* Means with different letters in the same column differ significantly by the Tukey test ($p < 0.05$).

In the case of the corn flour samples (average 10.5), these results imply they could be used directly in the preparation of baby foods with water or cold milk, since they are pasty and hence show good ability to absorb water. In the case of the rice samples, the addition of hot water to the masses will show the typical response of progressive absorption, according to the typical pasting properties.

Interesting behaviour was also shown by the two expanded materials. In the case of the rice flour, retrogradation was observed to reach about 300 cP, but in the case of corn flour, the setback was smaller, about 100 cP. For rice (Figure 2c) and corn (Figure 2d) pellets, the parameters of moisture and temperature did not dramatically affect the values for the initial viscosity at 25 °C, whilst for the expanded corn and rice samples, the temperature and mechanical energy of the extrusion system was more severe, with greater disruption of the starch structure, resulting in a higher initial viscosity peak at room temperature, being comparable with extruded instant meal products.

Lower values for the initial viscosity at 25 °C can be explained by the conditions imposed on the system before and during the extrusion process, such as milder temperatures of up to 100 °C for the rice and corn pellet samples (Figures 2c and 2d), and the lower screw speed (leading to lower shear). The very low initial viscosity of the extruded materials can be explained by the protein content and the presence of fibres, such as in the case of the rice flour. Thus a high initial viscosity is typical of gelatinized starch products and low moisture content processing, which indicates a high level of polymer breakage.

3.6 Maximum and final pasting viscosities

The pasting viscosity at 95 °C is a parameter that measures the resistance of the starch granules to collapse resulting from the action of temperature and mechanical stress in the RVA. During the heating cycle up to 95 °C, the starch granules swell and gelatinize, reaching a peak at this stage for the pellets. In the extrusion process, depending on the process conditions, the heat treatment can destroy the crystalline starch structure, so that during the heating cycle, the viscosity profile has no peak and very low viscosity. If the treatments are not so severe, a certain percentage of the starch granules may preserve their structure, presenting relatively high values for paste viscosity since the majority of the starch granules are in the swollen condition.

According to the results obtained, the expanded rice and corn (Figure 2a and 2b) showed a high capacity to absorb water at room temperature to form a cold paste or viscous liquid, which makes rapid hydration at room temperature possible. This is important in products requiring higher viscosity under cold conditions. There was no peak viscosity during the heating cycle up to 95 °C. This indicates degradation of the crystalline starch structure during extrusion, due to its very low value. The results also show greater pasting stability for the expanded rice and corn (Figures 2a and 2b).

The viscosity is related to the level of degradation suffered by the starch granules. Higher values for maximum viscosity at 95 °C indicate a less severe treatment and higher moisture content, thus maintaining a higher percentage of the starch granules intact. This phenomenon is of great importance for extruded products, since it shows a higher capacity to absorb water and predict the type of product.

According to the results, the final values for viscosity varied, and the lowest value was for the expanded corn flour (Figure 2 b) and the highest for the rice pellet (Figure 2 c), showing that the rice starch had a greater tendency to retrograde as compared to the corn pellet (Figure 2b).

The highest value for initial viscosity at 25 °C (Table 2 and Figure 2b) was obtained for the expanded corn flour. On the other hand, the low values for initial viscosity were justified by the low water absorption capacity of the starch granules present in their natural state. The temperature and rotational speed promote friction and homogenize the starch in the water inside the tube of the RVA, thus forming a gel. The expanded rice (Table 2 and Figure 2a) showed a low initial viscosity compared to the other extruded products.

According to Table 2 and Figure 2c, the maximum final viscosity was obtained for the rice pellet. The high value for maximum viscosity was attributed to the high proportion of intact starch granules, since they were not subjected to any treatment that would involve modification of the starch structure and consequently of their technological characteristics.

According to the pasting characteristics both the expanded and non-expanded products, or pellets, showed different behaviours for viscosity in the different cycles of the amylograph. Since there were two different processes and two different raw materials, the variation was remarkable and could predict their possible uses in food production. The maximum viscosity, or hot viscosity, indicates the potential uses of the extruded flour.

4 Conclusions

Based on these results, it was concluded that the corn flour was more suitable for use in expanded products and the rice flour for pellets. In both cases, they could be used for either expanded products or pellets, probably due to their granular structure and protein matrix. It was evident that using the same parameters and different raw materials, the pasting viscosity properties showed different behaviours in the profiles studied.

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