Preparation of High-Quality Protein-Based Extruded Pellets Expanded by Microwave Oven

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ABSTRACT

Cereal Chem. 83(4):363–369

The aim of this work was to study the effects of extrusion barrel temperature (75–140°C) and feed moisture (16–30%) on the production of third-generation snacks expanded by microwave heating. A blend of potato starch (50%), quality protein maize (QPM) (35%), and soybean meal (SM) (15%) was used in the preparation of the snacks. A laboratory single extruder with a 1.5 × 20.0 × 100 mm die-nozzle and a central composite routable experimental design were used. Expansion index (EI) and bulk density (BD) were measured in expanded pellets, viscosity at 83°C (V_{83}), thermal properties, and relative crystallinity were measured in extruded pellets. EI increased and BD decreased when the barrel temperature was increased, while the feed moisture effect was not significant. V_{83} increased when feed moisture increased. Extrusion modified the crystalline structures of the pellets and the X-ray data suggests the formation of new structures, probably due to the development of amylose-lipid complexes. The maximum expansion of pellets was found at barrel temperatures of 123–140°C, and feed moisture of 24.5–30%. It is possible to obtain a functional third-generation snack with good expansion characteristics using a microwave oven, and this snack has health benefits due to the addition of QPM and SM.

Third-generation snacks have become an important part of the American diet (Suknark et al 1999; Ernoult et al 2002). Corn starch is commonly used as a raw material for preparing nonexpanded pellets (Lee et al 2000; Ernoult et al 2002), although rice (Chen and Yeh 2000), tapioca with catfish, and tapioca starch with partially defatted peanut flour have been used (Suknark et al 1999). The nonexpanded pellets are formed by extruding these materials at high moisture content (30–35%), moderate shear and barrel temperatures, and die temperatures <100°C (Suknark et al 1999; Ernoult et al 2002). After cooling and drying to 10–11% moisture, the extruded pellets become glassy and very stable (Sprat et al 1988; Osman et al 2000) and can be expanded by baking (Chen and Yeh 2000), deep fat frying (Osman et al 2000), or microwave heating (Van Hulle et al 1981, 1983; Spratt et al 1988; Ernoult et al 2002). Extrusion is a large-scale food processing technique and a standard procedure for manufacturing many snacks (Colonna et al 1989), including nonexpanded pellets or third-generation pellets for snacks. In addition to being relatively cheap and easy to produce, pellets are easily expanded in the home by frying or microwaving. Compared with hot-oil frying expansion, pellets expanded by microwave heating do not contain fat. Nonexpanded pellets are very stable when stored and have a high density. This facilitates handling because large amounts of the product occupy small storage volumes (Hollingsworth 2001).

In general, snacks are not considered to be a staple food due to their low nutritional contribution to health, and so they have been called “junk food”, as being more detrimental than helpful in a balanced diet. According to Cheftel (1989), Camire et al (1990), and Zazueta-Morales et al (2002), snacks can be used as a vehicle for incorporating nutrients that have health benefits. The effects of extrusion on native starches have been well studied. Extrusion of native starches has been reported to cause decreases in crystallinity (Mercier et al 1979) and paste viscosity (Mason and Hoseney 1986).

The objective of this research was to study the effects of the extrusion process on different functional and technological characteristics of third-generation snacks prepared with blends of potato starch, high-quality protein maize, and soybean flours, and expanded by microwave heating.

MATERIALS AND METHODS

Materials

Potato starch (PS) was purchased from the National Starch Co. (Bridgewater, NJ). Soybean meal (SM) (S-100 OGDEN, grown in Illinois in 2002) was donated by Cargill of Mexico. Quality protein maize (QPM) grown in Mexico in 2002 was donated by INIFAP (Celaya, Mexico).

Chemical Composition

Official methods (AOAC 1999) were used to analyze moisture (925.09), protein (979.09), lipid (923.05), fiber (962.09), and ash (923.03) contents. The amylose content was determined by the iodine affinity method (Knutson 1986).

Preparation of Samples

QPM maize grains were decorticated according to the methodology of San Martín-Martinez et al (2003). Clean maize grain (5 kg) was steeped in water (1:0.8 w/w) with intermittent agitation at a steeping temperature of 25°C and 8 min of steeping time. The steeped grain was fed into a continuous decorticating device, keeping the residence time constant at 1 min with a screw speed of 800 rpm. The separation of the fractions was done using pneumatic equipment. The fraction that went through a 1.19-mm mesh sieve was separated out and the fraction retained was milled using a hammer mill (Pulvex, model 200, Mexico) with a 0.8-mm sieve. The blend was prepared by mixing 50% potato starch (PS), 35% quality protein maize (QPM), and 15% soybean meal (SM). The feed moisture varied from 16 to 30%. Extrusion experiments were performed using a laboratory single-screw extruder (model GNF 1014/2, Brabender, Duisburg, Germany) with an extruder barrel 380 mm long and 19 mm in diameter and a compression ratio of 2:1. A rectangular die with internal measurements of 20 mm × 1.5 mm × 100 mm long was used. Barrel temperature in the cooking zone (zone 2) was varied according to the experimental design from 75 to 140°C. The feed rate was kept constant at 47.3 ± 2.36 g/min and the screw speed was 103 rpm. Extruded pellets were equilibrated and dried to the desired moisture content (9.5–10.5%) in a convection oven (40°C) for 18 hr.

Expansion Index (EI)

Dried and equilibrated pellets were cut into pieces 2 cm long and expanded by heating for 25 sec in a conventional microwave

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DOI: 10.1094/CC-83-0363

oven (Samsung, model MW843WA, 1200W and 60 Hz). Each assay was the mean of 15 repetitions. Expansion index (EI) was calculated by dividing average transversal area of the expanded products by average transversal area of the nonexpanded products

Bulk Density

The bulk density (BD) was determined in expanded pellets. BD (kg.m^{-3}) was calculated by dividing the extrudate piece weight by its apparent volume (Gujska and Khan 1991). The average of 15 samples for each assay was measured and the apparent volume (V, m^3) was calculated as $V = t \times w \times l$, where t (m) is the average thickness, w (m) is the average width, and l (m) is the length of the extruded product.

Viscosity Profiles

The viscosity of the samples was determined at 83°C (V_{83}) according to the method of Zeng et al (1997) using a 3C Rapid Visco Analyzer (Newport Scientific, Sydney, Australia).

X-ray Diffraction Patterns

Ground samples with a 9.5–10.5% moisture content that had passed through a 2.50-mm mesh sieve were packed onto a glass sample plate (0.5 mm deep) and mounted on a diffractometer (Siemens D500). Scans were made with a Bragg angle of 5–30° on a 2θ scale with a step-size of 0.02, operating at 30 kV and 16 mA with CuKμ radiation wavelength $\lambda = 1.5406$ Å. Relative crystallinity was calculated using Herman's method, as described by Nara et al (1978) and Gomez et al (1989). The percentage of relative crystallinity of the starch was measured by separating the crystalline and amorphous areas in the X-ray diffractograms. The percentage of relative crystallinity was calculated as crystalline area/total area × 100.

Thermal Properties

Differential scanning calorimetry (DSC 822e, Birefrigerated, Mettler Toledo Lab Plant, Huddersfild, England) was used to heat the samples from 40 to 100°C at a rate of 10°C/min.

TABLE I
Experimental Design for Two Factors

	Independent Variables			
	Codified		Decodified	
Assay	X_1	X_2	Barrel Temp (°C)	Feed Moisture (%)
1	–1	–1	85	18
2	1	–1	130	18
3	–1	1	85	28
4	1	1	130	28
5	–1.414	0	75	23
6	1.414	0	140	23
7	0	–1.414	107.5	16
8	0	1.414	107.5	30
9	0	0	107.5	23
10	0	0	107.5	23
11	0	0	107.5	23
12	0	0	107.5	23
13	0	0	107.5	23

TABLE II
Analysis of Variance for Responses of EI, BD of Expanded Pellets, and V_{83} of Extruded Pellets Using Microwave Oven[a]

Response	R^2 Adjusted	CV (%)	F Value	P of F (model)	Lack-of-Fit
EI	0.77	6.39	9.26	0.005	0.131
BD	0.92	9.01	52.90	< 0.001	0.635
V_{83}	0.87	34.75	33.47	<0.001	0.99

[a] EI, expansion index; BD, bulk density; V_{83}, viscosity at 83°C; CV, coefficient of variation.

Experimental Design and Data Analysis

A central composite routable model with two variables with $\alpha = 1.414$ was used. All assays were performed randomly (Table I) and the data was analyzed using response surface methodology (Desing-expert v. 6.0.5, Stat-Ease, Minneapolis, MN).

The significance of the models was tested using variance analysis (F test), and the effects of the variables were registered with surface graphs. The second-order polynomial used to predict the experimental behavior was $y_i = b_0 + b_1X_1 + b_2X_2 + b_{11}X_1^2 + b_{22}X_2^2 + b_{12}X_1X_2$, where y_i = generic response; $b_{1...12}$ = regression coefficients; X_1 = barrel temperature; and X_2 = feed moisture.

RESULTS AND DISCUSSION

Chemical Composition

The chemical composition (wb%, means of two repetitions) of the potato starch, soybean meal, and quality protein maize, respectively, was moisture 12.96, 5.85, 4.80; proteins (N × 6.25) 0.17, 51.24, 7.90; lipids 0.11, 1.69, 3.64; fiber 0.085, 3.57, 1.87; and ash 0.34, 8.17, 1.32. Amylose content was 24.7% for potato starch and 23% for quality protein maize.

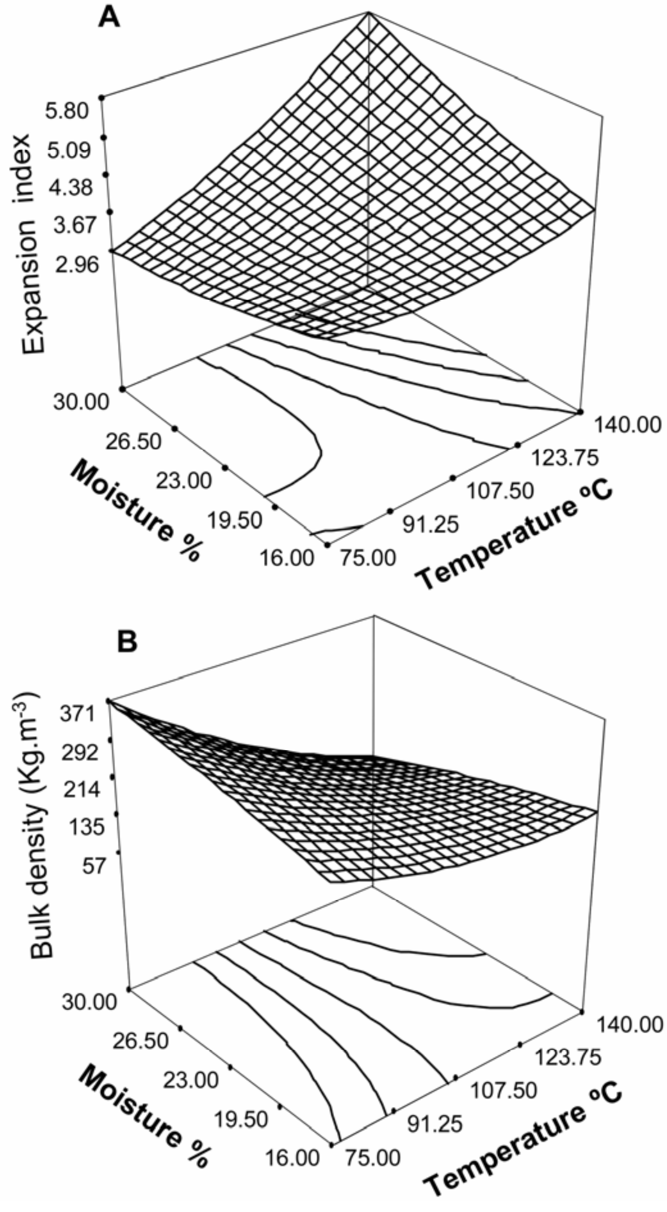

Fig. 1. Effects of barrel temperature and feed moisture on expansion index (**A**) and bulk density(**B**) of expanded pellets using a microwave oven.

Expansion Index (EI) and Bulk Density (BD)

Figure 1 shows the surface graphs of the expansion index (EI) and bulk density (BD) of the expanded pellets. All the parameters evaluated (Table II) showed a significant model of regression (RSM) with values of $R^2 \geq 0.77$, coefficient of variation CV $\leq$ 9.01, $P < 0.005$, and did not show lack-of-fit.

The statistical analysis (Table III) showed that, in general, feed moisture was the variable that had the lowest effect on the responses analyzed. The regression coefficients of the model show that only barrel temperature had a significant effect on the EI and BD. The EI was significantly affected ($P < 0.001$) by barrel temperature in its linear term (b_1) but not in its quadratic term (b_{11}, $P = 0.203$). Whereas BD was significantly affected in both its linear and quadratic terms ($P < 0.001$ for b_1 and $P < 0.005$ for b_{11}). On the other hand, the interaction between barrel temperature and feed moisture showed a significant effect on EI and BD (b_{12}, $P < 0.034$). The behavior of the effects of barrel temperature and feed moisture (Fig. 1A) shows that EI increased and BD decreased (Fig. 1B) over the entire interval studied. Similarly, Lee et al (2000) reported that the specific bulk volume of microwaved pellets with 11% moisture content before expansion was positively correlated with puffing efficiency ($P < 0.05$, $R^2 = 0.7196$). They also found the maximum puffing efficiency (91.3%), the highest specific volume (10.68 mL/g) and the lowest bulk density (0.12 g/mL) for expanded pellets made from normal corn starch occurred with a barrel temperature of 90°C, water injection rate 63 g/min, and 52% starch gelatinization. These researchers suggest that the reason for this is the degree of starch conversion for maize is relatively low compared with other cereals. In this work, the highest expansion occurred at near-highest barrel temperature (128°C) and feed moisture (28%) in the range studied. Extruded pellets show an increase in expansion with decreasing water content (Fig. 2). According to Carvalho and Michell (2000), expansion is particularly strongly dependent on the mechanical energy

The maximum EI and the minimum BD values were found at barrel temperatures >107.5°C. Also, the interaction effect between feed moisture and barrel temperature showed that EI decreased and BD increased at low barrel temperatures with increasing feed moisture, while EI increased and BD decreased at high temperatures with greater feed moisture.

In this work, the highest EI and lowest BD values were attributed to the increasing of barrel temperature, although the feed moisture effect was not significant, the interaction between barrel temperature and feed moisture showed a significant effect. Similarly, it was reported that the EI was affected by the interaction of barrel temperature with feed moisture, attributed to starch gelatinization during the extrusion process (Chinnaswamy and Bhattacharya 1983; Bhattacharya and Hanna 1987; Chinnaswamy and Hanna 1988; Moraru and Kokini 2003).

TABLE III
Regression Coefficients of the Model (codified variables) and Significant Levels for Response Variables of EI and BD of Expanded Pellets and V_{83} of Extruded Pellets Using Microwave Oven[a]

	Coefficients				
	Linear		Quadratic		Interaction
Responses	b_1	b_2	b_{11}	b_{22}	b_{12}
EI	0.53* (<0.001)	0.12 (0.203)	0.13 (0.203)	0.069 (0.491)	0.33 (0.034)
BD	–70.32 (<0.001)	–5.74 (0.228)	15.82 (<0.005)	–4.51 (0.373)	–27.47 (<0.001)
V_{83}	–4.02 (0.004)	+11.99 (<0.001)	–0.49 (0.718)	+10.10 (<0.001)	–2.84 (0.120)

[a] EI = expansion index, BD = bulk density, V_{83} = viscosity at 83°C. P value (*); b_0 values (intercept): EI = +3.79; BD = +197.56; V_{83} = +8.31. Coefficients (b) subindex: 1 = barrel temperature; 2 = feed moisture.

Case et al (992) reported that the volume of deep-fat-fried products from extruded pellets increased as the degree of gelatinization increased. Similar results were found by Lee et al (2000) and Sunderland (1996). Also, these researchers found that the best extruded pellet expansion was for pellets expanded by microwave heating with partial starch gelatinization of the pellets; they suggest that the expansion ratio was related to the mechanical properties of materials in a rubbery state and that increased amylose content resulted in less expansion. However, Lee et al (2000) found that expansion bulk volume of the microwave-heated products did not show any linear relationship with the degree of pellet gelatinization ($P < 0.05$). Probably these differences are attributable to the differences in the equipment and conditions used during expansion of the pellets, as suggested by Gropper et al (1997), who reported that the biggest challenge encountered in microwave heating is the uneven distribution of temperature within the product, which depends on the type of oven, location of the sample in the oven, sample size, and geometry. Also, the composition of the raw material can play an important role in expansion of pellets. Chen and Yeh (2000) found maximum expansion of rice pellets at 10% moisture content in a homemade laboratory-scale oven at 350°C. In this work, maximum pellet expansion had 9.5–10.5% moisture content of extruded pellets using a microwave oven. Chen and Yeh (2000), and Ernoult et al (2002), using different extrusion processes and microwave heating regimes, reported that maximum expansion took place at 10% moisture content of cereal pellets.

Viscosity at 83°C (V_{83})

The statistical analysis of the V_{83} data for the extruded pellets showed a significant regression model (RSM) ($R^2 = 0.87$, CV = 34.75, P of $F < 0.001$) and did not show lack-of-fit ($P > 0.99$) (Table II). Barrel temperature had a significant linear effect ($P = 0.004$), but statistical analysis showed that its quadratic term (b_{11}) did not have a significant effect on the values of V_{83}. On the other hand, feed moisture showed highly significant effects in both linear (b_2) and quadratic (b_{22}) form ($P < 0.001$). The interaction of feed moisture with barrel temperature did not have a significant effect in extruded pellets (Table III). The viscosity profiles of extruded pellets as a function of the studied factors are shown in Fig. 3. V_{83} shows behavior tending toward a minimum stationary point type sidle with feed moisture of ≈19%, barrel temperature of ≈78°C, and viscosity value of 6.76 RVU (Fig. 4). Feed moisture and barrel temperature had an evident effect on viscosity, with feed moisture having the greater impact. The viscosity tends to increase when the feed moisture content increases to >23% and to decrease when the barrel temperature increases at feed mois-

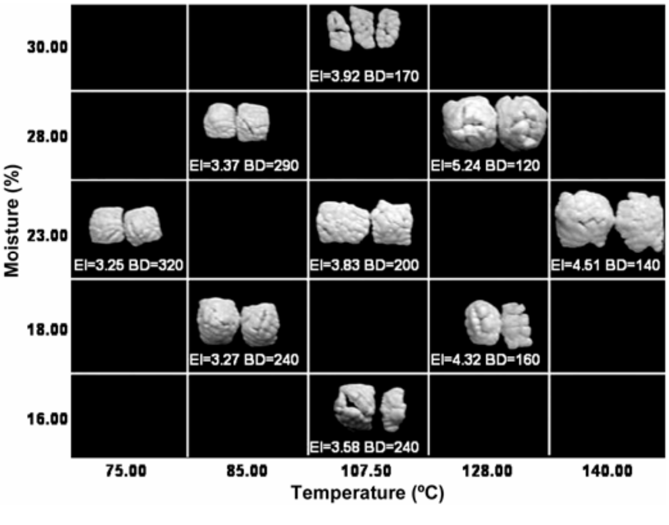

Fig. 2. Photograph showing effect of barrel temperature and feed moisture on expanded pellets using a microwave oven.

ture at <23%. Significant changes were found with barrel temperatures at 130°C and at 28% feed moisture, where better EI and low BD values were found and the viscosity of the extruded pellets showed intermediate values. According to Lai and Kokini (1991), moisture acts as a plasticizer during extrusion of starches and lowers the extent of shear degradation. This effect has been reported for hot paste and final viscosity in unmodified wheat starch (Mason and Hoseney 1986) and corn starch (Chinnaswamy and Hanna 1990). McPherson et al (2000) found that viscosity of extruded corn starches increased as starch moisture content increased from 30 to 40% and the samples extruded with 30% moisture content showed a slight increase in viscosity with increasing temperature of 60–80°C and remained unchanged at 80–100°C, which differed from those extruded with 35 and 40% moisture ($P < 0.0001$). According to these researchers, this difference may be attributed to the starch with lower moisture content having a higher glass transition temperature (T_g). Ascheri et al (1995) and Carvalho et al (2002) reported that at high barrel temperatures, the mass becomes plastic and less viscous, so molecules become more susceptible to compression during extrusion. Greater thermal and mechanical action is produced in this way, resulting in greater degradation of the starch granules and consequently lower viscosity values.

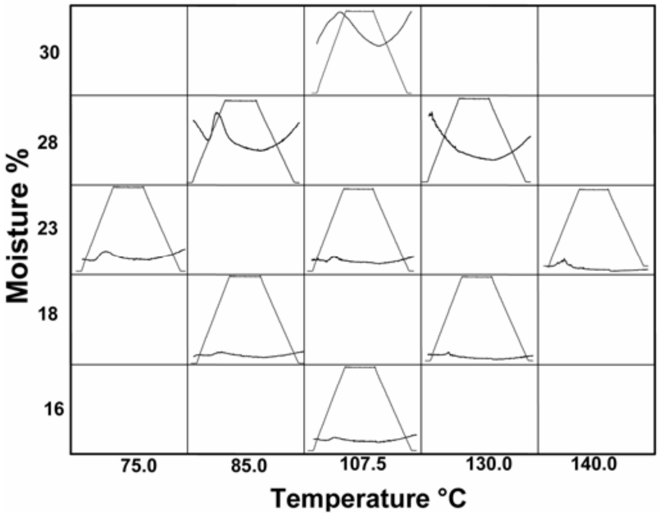

Fig. 3. Effect of barrel temperature and feed moisture on viscosity profiles (RVA) of extruded pellets.

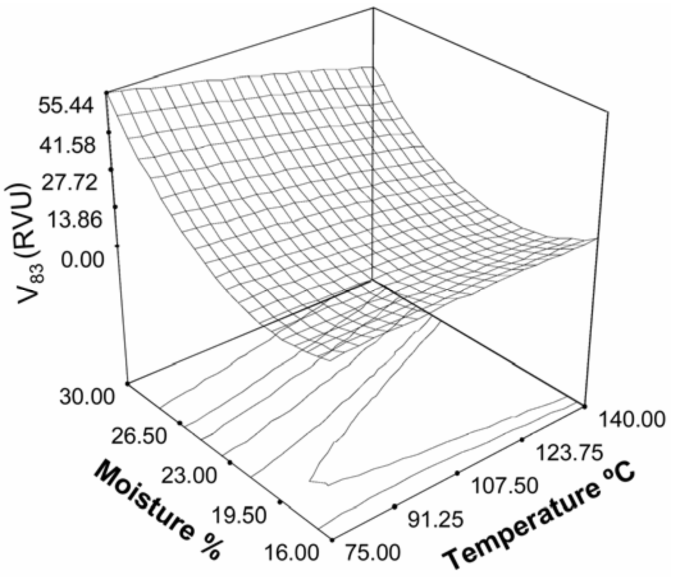

Fig. 4. Effects of barrel temperature and feed moisture on viscosity at 83°C (V_{83}) of extruded pellets.

X-ray Diffractograms and Crystallinity

The diffractograms of the expanded pellets as affected by barrel temperature (at 23% feed moisture) and feed moisture (at 107.5°C barrel temperature), as well as the raw sample are shown in Fig. 5. The raw sample (Rb) showed a type A X-ray pattern, typical of cereal starches (Miyoshi1 2002), with main peaks at 2θ values of ≈15.1, ≈19.2, and ≈22.4 Å. The last peak extended until 24 Å, probably due to the presence of a type B X-ray pattern typical of tubercles. This pattern was lost as the severity of the process increased; when the feed moisture content of the extruded sample decreased, the type A diffraction pattern was modified to a V_h pattern, the typical pattern for processed starches. These patterns are similar to those found by Singh et al (1998) and Cairns et al (1997). The same starch behavior was observed when the barrel temperature was increased, passing from an amorphous state to the formation of the V_h pattern (75°C barrel temperature and 23% feed moisture). Under these extrusion conditions, the native crystalline structure of the starch was probably modified, although there was no formation of new structures, as indicated by Mercier et al (1979).

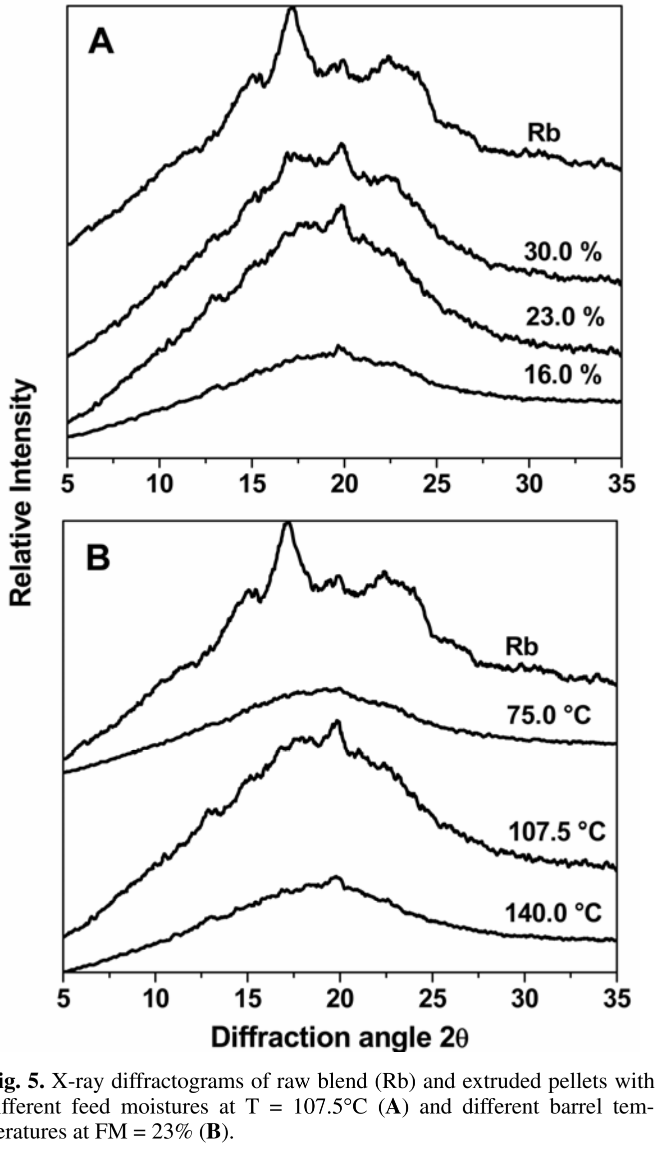

Fig. 5. X-ray diffractograms of raw blend (Rb) and extruded pellets with different feed moistures at T = 107.5°C (**A**) and different barrel temperatures at FM = 23% (**B**).

This same effect was found for the crystallinity values (Fig. 6). With increasing feed moisture, the crystallinity increased (Fig. 6A). Low feed moisture content probably increased the severity of the extrusion conditions, resulting in a greater degradation of the starch and therefore a loss of crystallinity (Chinnaswamy and Bhattacharya 1983; Bhattacharya and Hanna 1987). The effect of extrusion temperature on relative crystallinity is shown in Fig. 6B. Increasing barrel temperature from 75 to 107.5°C increased crystallinity, probably due to the formation of new structures. Nevertheless, a higher barrel temperature (140°C) led to lower crystallinity, probably due to destruction of the crystalline structures (Colonna et al 1989). McPherson et al (2000) indicated that native corn starch extruded at 30% moisture and high shear at 60°C displayed reduced crystallinity. At extrusion temperatures of 80 and 100°C, the starch was gelatinized as indicated by the absence of crystalline peaks. The extrusion process partially or totally destroys the crystalline structure of the starches, depending on the amylose-amylopectin proportion and extrusion conditions such as barrel temperature, feed moisture, and compression ratio, among others (McPherson et al 2000). At high barrel temperatures, the structure of starch is destroyed completely, leading to the formation of an amorphous state or the formation of a new structure. In extruded products, new structures have been attributed to the interaction between solubilized complexes of amylose and the native lipids in the sample (Colonna et al 1989; Singh et al 1998).

Thermal Properties

Transition enthalpies (ΔH) for raw materials were 0.485, 15.24, 4.5, and 9.11 J/g for SM, PS, QPM, and Rb, respectively. The thermal properties of native corn (McPherson et al 2000) and native potato (Lorenz and Kulp 1982) starches were reported. Potato starch had temperatures of 59.40°C for onset (T_o), 63.30°C for peak (T_p), 69.40°C for conclusion (T_c), and 15.90 J/g for ΔH. Native corn starch showed 61.50, 70.70, 75.20, and 13.20 J/g for T_o, T_p, T_c, and ΔH respectively. The raw blend (Rb) showed intermediate thermal values for raw materials of T_p at ≈66°C; T_o at ≈60 and T_c at 72°C; and a ΔH value of 9.11 J/g (Table IV). Figure 7 shows the thermograms of the extruded pellets and raw blend (50% PS, 35% QPM, and 15% SM) as an effect of the barrel temperature with a feed moisture of 23%, and as an effect of the feed moisture with barrel temperature of 107.5°C. Corn starch extruded at barrel temperatures of 60–80°C, and 100°C, moisture content at 30%; low, medium, and high shear showed T_o (63.2–73.3°C), T_c (73.6–80.3°C), T_p (69.3–76.9°C), and ΔH (0.4–4.3 J/g) values (McPherson et al 2000). With constant moisture content (23%), peak gelatinization temperature decreased with increased barrel temperature (Fig. 7A), which is similar to results reported by Chinnaswamy et al (1989) and Chinnaswamy and Hanna (1990). This is probably due to a greater degradation of the starch when increasing the severity of extrusion, with transition enthalpy values that varied from 0.0 to 1.11 J/g (Table IV) and were significantly different ($P = 0.05$). The feed moisture at a constant temperature (107.5°C) showed less evident effect on the thermograms of the extruded samples, with an increase in the gelatinization peaks

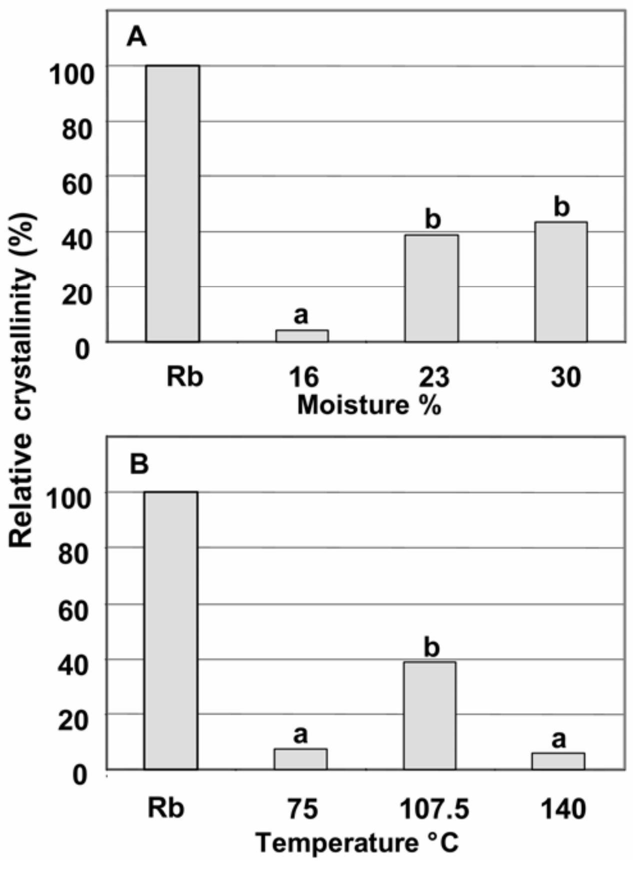

Fig. 6. Relative crystallinity of raw blend (Rb) and extruded pellets affected by barrel temperature at 23% feed moisture (**A**) and feed moisture at 107°C barrel temperature (**B**)

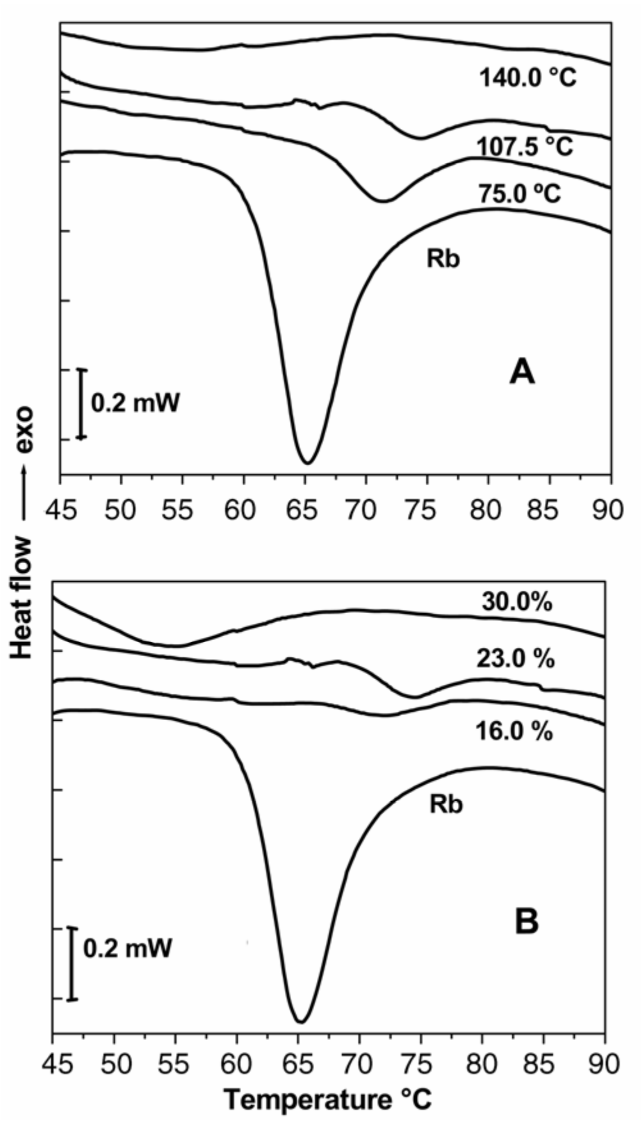

Fig. 7. Thermograms of raw blend (Rb) and extruded pellets affected by barrel temperature at 23% feed moisture (**A**) and feed moisture at 107°C barrel temperature (**B**).

when the moisture content increased from 16 to 23% (Fig. 7B). High moisture content probably decreased the friction effect of the extrusion process and decreased starch modification. The sample extruded at 30% feed moisture showed a displacement toward the left of the endotherm (Fig. 7), probably an increase in the feed moisture caused a decrease in T_g, which could modify the thermal behavior of the starch. Lai and Kokini (1990) reported that moisture acts as a plasticizer during extrusion of starches and lowers the extent of shear degradation and the thermal properties are displaced at low temperatures. McPherson et al (2000) reported similar behavior in native corn starch extruded at 30 and 40% moisture and low, medium, and high shear at 60, 80, and 100°C. Starches with lower moisture content have higher T_g values. Ernoult et al (2002) reported that the T_g for extruded pellets of amylopectin decreased linearly with increasing moisture content.

Duncan's multiple interval analysis ($P = 0.05$) showed that the ΔH values of the samples with 16 and 23% feed moisture content extruded at a constant temperature were statistically equal at 0.36–0.40 J/g (Table IV), which was different from the sample with 30% feed moisture, which showed a statistically significant increase at 0.69 J/g. This increase may possibly be attributed to the lubricant effect of the water, which decreased the mechanical degradation produced by the extruder, resulting in less gelatinized products and therefore greater transition enthalpy values, as indicated by Lee et al (1999). In all the assays (Table IV), the ΔH values of the extruded products in the different conditions evaluated were 12.2% lower than the value found for the raw blend (Rb), indicating a high degree of gelatinization of the starches. The products in the region of greater expansion did not show a gelatinization peak; nevertheless, the absence of a gelatinization peak does not indicate that the sample was completely degraded (Gomez and Aguilera 1984). According to McPerson et al (2000), DSC showed a small thermal transition peak for native corn starch extruded at 80°C, whereas X-ray analysis showed no diffraction pattern. These researchers suggested that it is possible that the remaining crystallites were too small to display an X-ray diffraction pattern. Also, the X-ray pattern of native corn starch extruded at 100°C displayed at ≈20° and small bumps at 13°, indicating a small amount of V-type amylose-lipid complexes.

CONCLUSIONS

The mathematical model used in analyzing the data from the extrusion study was satisfactory for the evaluated responses, with values of $R^2 \geq 0.77$, lack-of-fit ≥ 0.131, CV ≤ 9.01% (except V_{83}) and P of F (model) < 0.005. The barrel temperature was the variable that most affected the EI and DA, and the feed moisture had a significant effect on the V_{83}. Increasing barrel temperature and decreasing feed moisture, probably favored the degradation of starch in extruded products as shown by DSC, viscoamylograph properties, and X-ray diffraction analysis. Response surface methodology showed the best expansion of third-generation extruded products at 28% feed moisture and 130°C barrel temperature. In addition, the products obtained in this processing zone were probably not completely degraded. Thereforre, it is possible to produce third-generation snacks using extrusion technology that have a significant nutritional and nutraceutical value by using high-protein quality maize (QPM) and soybean meal (SM).

TABLE IV
Thermal Properties of Extruded Pellets as Affected by Barrel Temperature and Feed Moisture (°C/%)[a,b]

	Gelatinization Temperature (°C)			
Sample	**Onset**	**Peak**	**End**	**ΔH (J/g)**
Rb	60.17a	66.015a	72.02a	9.11a
75°C/23%	66.78b	71.25b	76.80b	1.11b
107.5°C/23%	69.68b	73.44b	77.35b	0.40c
140°C/23%	0c	0c	0c	0d
107.5°C/16%	68.00b	71.64b	76.82b	0.36c
107.5°C/30%	48.13d	54.18d	60.12d	0.69e

[a] ΔH, transition enthalpy; Rb, raw blend.

[b] Values followed by the same letter in the same column are not significantly different ($P < 0.05$).

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[Received November 17, 2005. Accepted March 14, 2006.]