Rheological properties of alkaline extruded and nixtamalized maize-sorghum doughs and *tortillas*[7]

Propiedades reológicas de masas y tortillas nixtamalizadas y extrudidas alcalinamente de maíz-sorgo[8]

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Abstract

Maize (*Zea mays*)-sorghum (*Sorghum bicolor* L. Moench) raw meal mixtures 40:15 mass were alkaline extruded with a low-cost extruder using 0.02% $Ca(OH)_2$. The precooked meals were rehydrated to form doughs, and used to make tortillas. For comparison, traditionally cooked masa doughs were prepared. Maize and sorghum were ground to a 20 mesh size and extruded in the presence of 0.2% mass calcium hydroxide and 160°C and 20% initial moisture content. There were no significant differences in Brabender viscoamylograph texture measured between alkaline extruded and traditionally cooked doughs neither for texture data collected for tortillas in an Instron Universal Tester.

Keywords: Maize (*Zea mays*), sorghum (*Sorghum bicolor* L. Moench), doughs, tortillas, rheological properties

Resumen

Se extrudieron alcalinamente mezclas de harina cruda de maíz (*Zea mays*) y sorgo (*Sorghum bicolor* L. Moench) en masa 40:15 con un extrusor de bajo costo. Las sémolas precocidas fueron rehidratadas para formar masas y utilizadas para hacer tortillas. Como comparación, se prepararon masas y tortillas cocidas tradicionalmente. El maíz y el sorgo se molieron hasta un tamaño de malla de 20 y se extrudieron alcalinamente en presencia de hidróxido de calcio al 0.2% masa y a 160°C y un contenido de humedad inicial del 20%. No hubo diferencias significativas en la textura del viscoamilógrafo Brabender medida entre las masas extrudidas alcalinamente y las cocidas tradicionalmente ni para los datos de textura de las tortillas usando un Probador Universal Instron.

[7] Authors' note: This paper, presented at the Third Chemical Congress of North America on Toronto, Canada, was submitted to Cereal Chemistry, an international journal, and was approved by the associate editor (Dr. Eckhoff), code 4352, along with another contribution "Chemical and Biological Comparison of Extruded and Nixtamalized Corn-Sorghum Meals" by María Victoria Saldaña-Morales, Zoila Nieto-Villalobos, and Carmen Durán-de-Bazúa, with the support of Yoja Gallardo and René Manzur (Code 4386) but, apparently, they were not published. For this reason, both have been submitted to this journal for its possible publication. The references are older than 5 years but they are classical studies and, thus, are still valid

[8] *Nota de los autores: Este documento, presentado en el Tercer Congreso de Química de América del Norte, en Toronto, Canadá, fue enviado a Cereal Chemistry, una revista internacional, y fue aprobado por el editor asociado (Dr. Eckhoff), clave 4352, junto con otra contribución Chemical and Biological Comparison of Extruded and Nixtamalized Corn-Sorghum Meals de María Victoria Saldaña-Morales. Zoila Nieto-Villalobos y Carmen Durán-de-Bazúa, con el apoyo de Yoja Gallardo y René Manzur (Clave 4386) pero, aparentemente, no fueron publicados. Por ello, ambas han sido sometidos a esta revista para su posible publicación. Las referencias son anteriores a 5 años pero son clásicas y, por ello, todavía válidas*

Palabras clave: *Maíz (Zea mays), sorgo (Sorghum bicolor L. Moench), masas, tortillas, propiedades reológicas*

Introduction

In the last two decades of the Twentieth Century, extrusion became an important process in the food industry. In Mexico, a special emphasis was given to cereal and other grains extrusion, and particularly to alkaline extrusion of maize and later on of sorghum (Díaz-Núñez et al., 2004; Durán-Domínguez, 1978; Durán-Domínguez-de-Bazúa and Sánchez-Tovar, 2005; Estrada-Alvarado et al., 2004; García-Sánchez et al., 2004; Gutiérrez-Dorado et al., 2004; Hernández-Ayala, 1993; Hilario-Rodríguez et al., 2004; Milán-Carrillo et al., 2004; Pérez-Ramírez and Rodríguez-Méndez, 1987; PUAL Award, 1984; Sánchez-Tovar and Durán-de-Bazúa, C., 2004; Vara-Flores et al., 1997; Yánez-Ortega et al., 2004). Extruders may be as simple as the low-cost Brady models or as complicated as the twin screw or the highly instrumented U.S. and Europe versions.

Alkaline extrusion of maize (*Zea mays*), either normal or high-lysine varieties, and sorghum (*Sorgum bicolor* L. Moench) to produce traditional Mexican products has been successfully carried out (Bazúa et al., 1976, 1979; Durán-de-Bazúa, 1976; Durán-de-Bazúa and Guerra, 1977, 1980; Durán-Domínguez, 1978; Guerra et al., 1983). Also, mixtures of maize with sorghum have been alkaline extruded in order to produce precooked meals for tortillas (Saldaña-Morales, 1987). For high-tannin sorghum varieties, grains were 'pearled' or decorticated to eliminate the colored testa and pericarp before grinding (Saldaña-Morales et al., 1986). For the experiments with normal and opaque-2 maize varieties, a Wenger X-5 extruder and a low cost extruder were used (Bazúa et al., 1979; Bazúa et al., 1976; Guerra et al., 1983), and for the maize-sorghum experiments a Brabender fully instrumented laboratory extruder was employed. The complete procedure and conditions are duly explained elsewhere (Saldaña-Morales, 1987).

There are some data reported in the literature (Cuevas and Puche, 1986; de-Padua and Padua-Maroun, 1984) concerning rheological properties of pre-cooked maize flour for 'arepa' (Colombia and Venezuela) and 'tortilla' (Mexico and Central America). However, for both papers, a comercial precooked flour was used, and therefore, no knowledge of the actual processing conditions during the precooked meal preparation were available. It is known that cooking temperature is a very important factor in the correlation of rheological characteristics and apparent viscosity of doughs made from these meals (Anderson et al., 1969; Mercier et al., 1979).

Thus, in order to corroborate the results obtained in a Brabender extruder (Guerra-Vargas, 1978), as well as the results presented in the literature in previous paragraphs, experiments were conducted in a low-cost extruder using mixtures of meals of pearled and white sorghums with maize. To evaluate the quality of the precooked meals obtained, rheological tests were carried out with the doughs and the tortillas made out of these doughs. Thus, the objective was to compare these extrusion equipments in the quality of doughs and tortillas using as a control traditionally made doughs and tortillas by the pre-Columbian nixtamalization method considering texture as the response variable.

Materials and Methods

Raw materials. Three raw materials were used: Maize of the Huamantla variety with origin INIA-SARH (see Glossary), white sorghum of the Blanco 84 variety from ICRISAT fields in the state of Mexico, and red-brown commercial 'pearled' sorghum decorticated according to the procedure established by Nieto et al. (1986), emulating the one for rice by abrasion, and patented by Laso and Núñez (1977) in Mexico. With the three grains, the following samples were studied:

- Corn or maize 100% (M100), White sorghum 100% (SB100), pearled colored sorghum 100% (SP100)
- Mixtures of maize with the two types of sorghum: M85-SB15, M70-SB30, M60-SB40, M85-SP15, M70-SP30, M60-SP40

Nixtamalization. Nixtamalization is a Nahuatl derived word meaning lime cooked maize (*nextli*=lime ashes and *tamalli*=cooked maize, maize cooked with lime ashes). This native American cooking technique is almost as ancient as the maize domestication itself (Cabrera et al., 1985). The procedure for cooking the three grains and its mixtures using traditional nixtamalization is also described elsewhere (Alarcón et al., 1985). Once the grains were cooked and washed they were divided into two lots, one was ground to produce doughs ready to prepare fresh tortillas. The second lot grains were dried and ground simultaneously to obtain a meal with the granulometry specified for it (DOF, 1980). Using a drier-grinder designed and commercialized by a company in Guadalajara, Mexico, for the plants that produce pre-cooked nixtamalized meal, at laboratory level using warm clean air (Durán-Domínguez-de-Bazúa, 1976-1977).

Tortilla production. The preparation of tortillas for the six mixtures followed the technique standardized by Alarcón et al. (1985).

Bench scale alkaline extrusion. For the extrusion operation to produce 50 kg/h of alkaline extruded product a low cost extruder was used. This extruder was built in Mexico by a Conacyt center, CIATECH (see Glossary), an institution that based its design in the Brady extruder (Crowley, 1975) (Figure 1), as well as in the modifications proposed by the Colorado State University researchers (Harper, 1979). It has a 30HP motor and a constant flighted screw. Instead of a die, the extruder outlet had a movable truncated cone that allowed the output of a doughnut-like extruded product. The only instrumentation present in this model was the feeding system acquired with Brabender that allowed a controlled constant feed speed of the granular material and, therefore, residence time in the extruder could be controlled. Also, a thermopar located at the extrusion section indicated the maximum temperature reached by the product in this zone (Guerra et al., 1983). The limitations of this equipment are the following: Screw speed is constant and the temperature can only be measured at the "head" of the extruder. The thermopar has an accuracy of ±15% experimental error.

Figure 1. CIATECH Low-cost extruder and behind it there is a Celorio brand (Mexico) automatic tortilla maker

Bench scale alkaline extrusion preliminary tests. For operating the extruder, and to corroborate the características of the extruded meals, an experimental design was performed. Variables were granulometry (coarse grits, mesh 10, mesh 20), initial moisture contents of ground grain mixtures (20, 30, 40%), initial $Ca(OH)_2$ concentration (0.5, 0.3, 0.2%), and extrusion temperature (130, 140, 150, 160, 170°C). For pre-grinding the three grains before extrusion, the same equipment provided by the Guadalajara company was used but without the washing operation and using only cold air to remove any undesirable straw or fragments to grind the clean grains. After finding the suitable extruding conditions from the preliminary experiments, extrusion of the different maize-sorghum samples was carried out. After extrusion, the products were dried and ground and the meals were stored in hermetically closed containers before use.

Chemical analyses. Formerly called proximate or bromatological analyses, following the Mexican official standard analyses procedures were carried out for all samples, raw, nixtamalized, or alkaline extruded meals: Ash (NOM-F-66-S), nitrogen contents (NOM-F-68-S), moisture (NOM-F-83), fat (NOM-F-89-S), crude fiber (NOM-F-90-S).

Rheological tests. Three sets of tests were done to compare the precooked meals, doughs, and tortillas obtained from nixtamalization and extrusion processes. For meals a Brabender viscoamylograph was employed to determine the changes in the starches behavior after the lime-heat treatment using 45 g of each meal (d.b.) and 450 mL drinking water. Starting point was estabished using nixtamalized 100% white maize dough (*masa* in Spanish). Normal heating cycle was used in all experiments. For the second set of tests, for doughs, an Instron Universal Tester, Table Model 1130, using a 500 kg reversible cell, with the back extrusion accesory, was used. The third set of tests for tortillas was done in the same Instron Universal Tester using a 2 kg compression cell and a star-like puncturing probe. Curves indicating the deformation after a shear stress application were drawn from both types of tests. Crosshead and chart speeds were 10 and 20 cm/min, respectively, for both types of tests.

Sensory analyses. These evaluations were divided into two parts. The first part was made by the authors, based on their experience and previous training on taking part of sensory or organoleptic panels, to evaluate the products of the preliminary experiments. Once the more adequate conditions were determined, the second part was carried out. A trained panel of ten people using texture, flavor, visual color, and consistency of tortillas with a coded randomized sampling identification following the analysis of results presented elsewhere. The escale was from excellent 1, good 2, regular 3, bad 4, and worst 5 (Guerra et al., 1983).

Color analyses. To compare the precooked meals, whole tortillas, and ground tortillas powder color a Hunter Lab colormeter. Control blank were the white 100% maize nixtamalized products (precooked meals, whole tortillas, and ground tortillas powder). The equations of Glasser et al. (1958) to correlate the color parameters L, a, and b to obtain ΔE were used.

Statistical analyses. Experimental data by triplicate were evaluated following variance analysis and considering probability significance levels of 5% ($p<0.05$) (Huntsberger, 1959).

Results and discussion

Bench scale alkaline extrusion

From the preliminary experiments to determine the most adequate extrusion conditions to produce doughs and with them tortillas similar to the nixtamalized ones the parameters were: Raw meal moisture content 20% (w.b.), lime concentration of 0.2%, and extrusion temperature of 160°C (Pérez-Ramírez and Rodríguez-Méndez, 1987, 1988).

Chemical analyses

An example of the meals analyses is presented in Figure 2a. It was chosen the fat content because extruded meals had consistently lower values. It is believed that a lipid-carbohydrate complex is formed during extrusion and that such complex allows the extruded products to have longer shelf life, since rancidity reactions took place more slowly. Previous shelf life studies demonstrated this hypothesis doing tests at 4, 22, and 50°C (Pérez-Ramírez and Rodríguez-Méndez, 1988). Nitrogen (protein), crude fiber, and ashes ae available in the literature (Pérez-Ramírez and Rodríguez-Méndez, 1988). It is particularly important the very low values for this nutrient in decorticated sorghum indicating the loss of the embryo during the abrasion unit operation where most lipids are. Thus, it might be desirable to study the biological value of whole colored sorghum after extrusion to corroborate the effect of this unit operation on the polyphenols as it happens with blue maize anthocyanins (Frías-Hermosillo et al., 2013; García-Gómez et al., 2022; González-Cruz et al., 2013; Juárez-Zamora et al., 2013; Moreno-Morales et al., 2013).

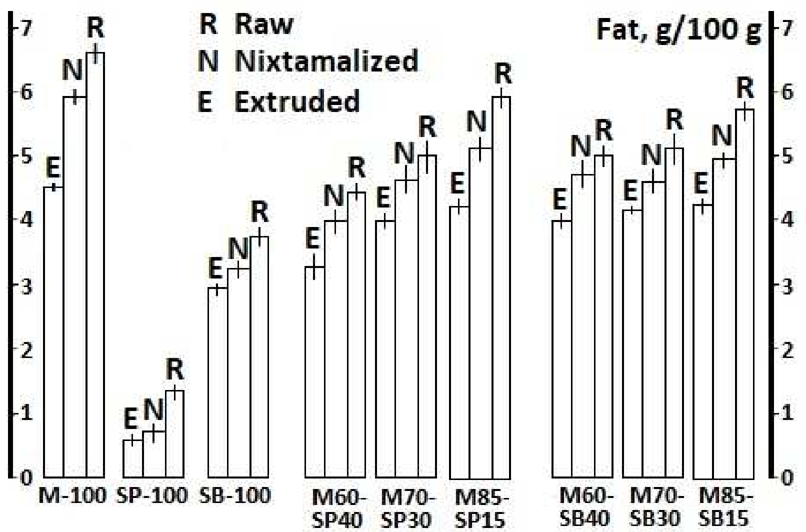

Figure 2a. Fat content average data (triplicate) for raw (R), nixtamalized (N), and extruded (E) meals, g fat/100 g meal

Calcium content data for meals are presented in Figure 2b. It was interesting to observe that nixtamalized meals had the highest contents of calcium probably due to the washing unit operation that traditionally is done until grains recover their original color (white for white maize or white sorghum, and calcium added is generally reduced remaining only the one that became bioavailable within the grains. For extruded meals its value remains relativly constant, around 0.15 g/100 g, that considering the addition of 0.2% during extrusion is reasonable. And the very low values for raw meals are, of course, expected since the grains studied have low calcium concentrations (Pérez-Ramírez and Rodríguez-Méndez, 1988).

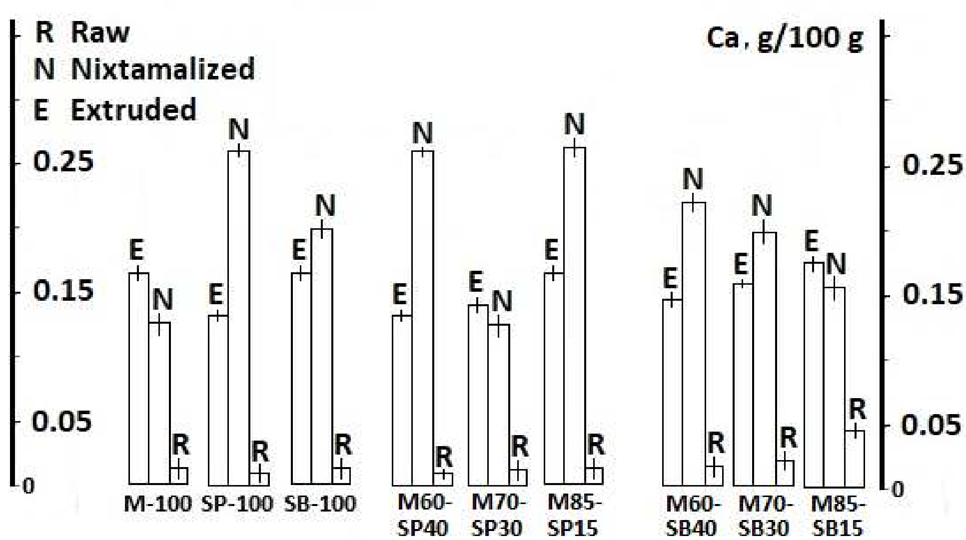

Figure 2b. Calcium content in raw (R), nixtamalized (N), and extruded (E) meals, g Ca/100 g meal

Rheological data
Viscoamylograph curves for the precooked meals are presented in Figures 3 to 5.

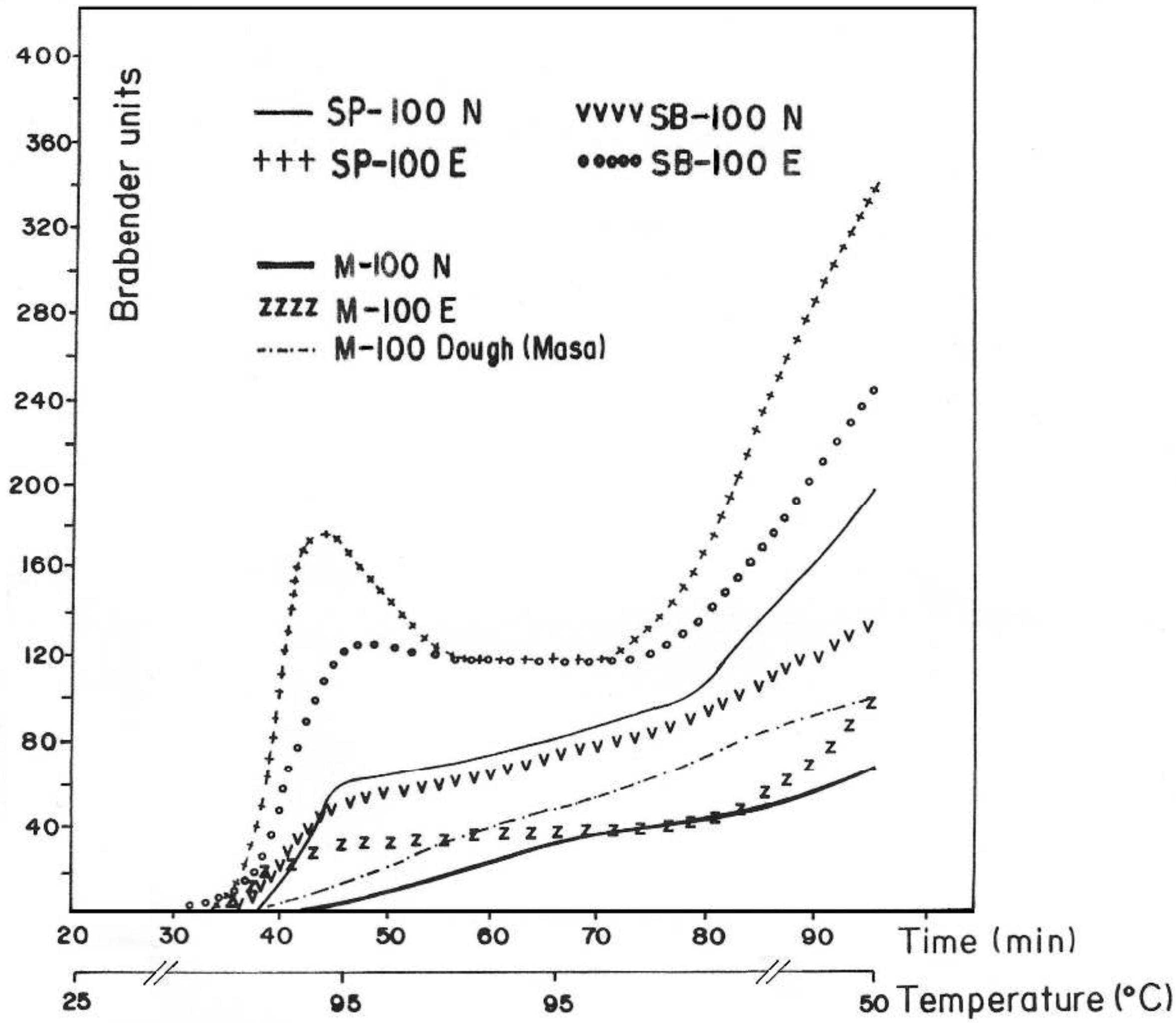

Figure 3. Viscoamylograph of nixtamalized (N) and extruded (E) maize (M-100), sorghum pearled (SP-100), sorghum white (SB-100) doughs made of meals, and a control of traditional nixtamalized dough (*masa*, in Spanish) (translated of Durán-de-Bazúa, Coordinator, 1988)

As it has been reported in literature the prototype viscoamylographs have a maximum in viscosity when the swollen starch granules, as temperature increases, occupy most of the available cell volume. As heating progresses, i.e. temperature is furthermore increased, the swollen starch granules burst, and the viscosity starts dropping. If temperature is decreased at this point of the process, viscosity augments, but this is due to the retrogradation phenomena with the reassociation of the amylose and amylopectin molecules (Jia et al., 2023; Pérez-Ramírez and Rodríguez-Méndez, 1988).

It may be observed in Figure 3 that extruded pearled sorghum starch granules follow more closely this pattern. This behavior is logical, since these particles were first subjected to an abrasion process during decortication. These particles are also the ones that present more surface area to the transport phenomena associated with the lime-heating process. The opposite phenomenon occurs with the nixtamalized particles, since they were obtained from the cooking of whole maize grains that, proportionally, have a lower surface area.

In Figures 4 and 5 these results can be corroborated since, according to the particle size ratio, the maximum consistency data are found for the originally smaller particles. This fact is confirmed by the results obtained with the Venezuelan precooked maize meals for *arepas* (de-Padua et al., 1984).

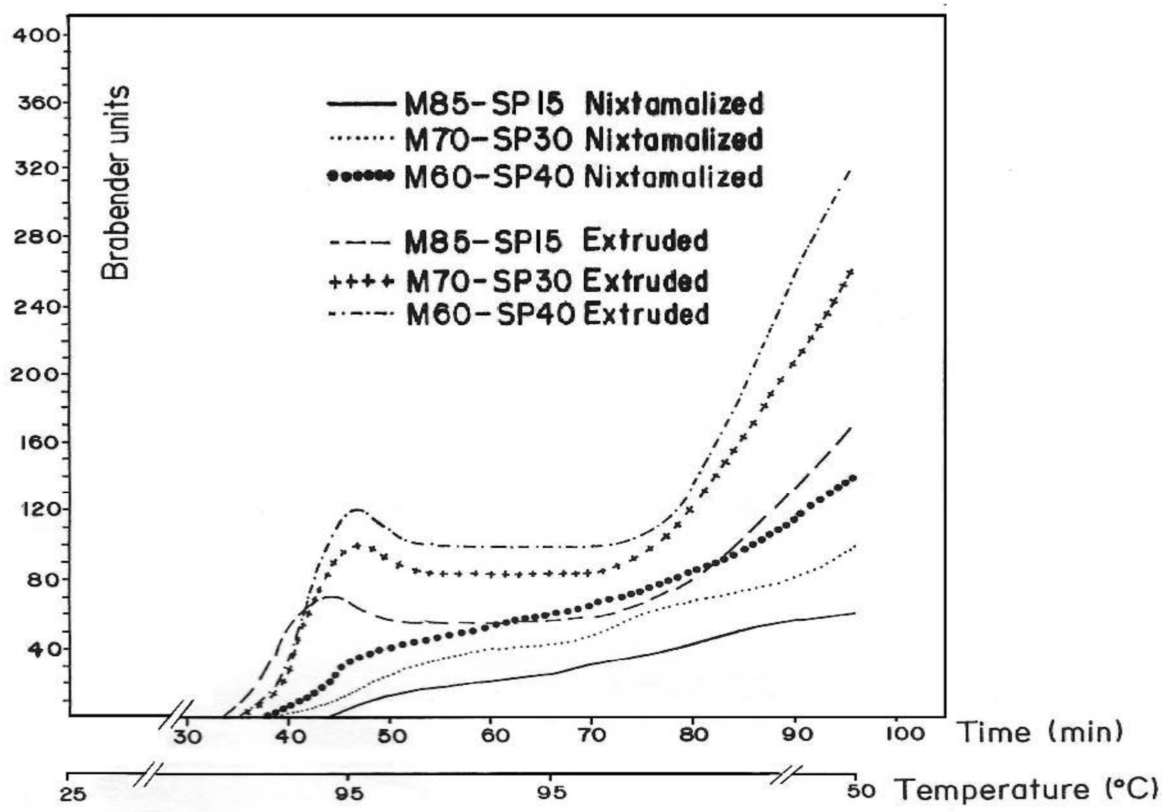

Figure 4. Viscoamylograph of nixtamalized (N) and extruded (E) maize-pearled sorghum (M85-SP15, M70-SP30, M60-SP40) meals (translated of Durán-de-Bazúa, Coordinator, 1988)

For the Instron Universal tester: F = Force necessary to compress 97.22% of the mass, W = Work necessary to compress the mass, and A= Area under the curve. The results are shown in the Table 1.

Table 1. Compression values for doughs made of nixtamalized and extruded meals

Dough	**F (kg_f)**		**W ($kg_f m$)**		**A (cm^2)**	
	Nixtamalized	**Extruded**	**Nixtamalized**	**Extruded**	**Nixtamalized**	**Extruded**
M-100	205.0	250.0	8.97	10.9	4.06	5.04
SP-100	192.5	171.0	8.42	7.48	3.73	4.38
SB-100	212.5	195.0	9.30	8.53	4.51	4.20
M60-SP40	158.0	146.0	6.92	6.39	3.70	3.72
M70-SP30	255.0	162.5	11.2	7.11	4.71	3.52
M85-SP15	124.0	132.0	5.43	5.58	3.07	3.68
M60-SBP40	260.0	212.5	11.4	9.30	4.50	4.36
M70-SB30	183.0	127.0	8.03	5.56	4.48	3.67
M85-SB15	185.0	250.0	8.09	10.9	4.79	5.09

For the doughs, it was observed that, in general, greater forces were applied to the nixtamalized doughs than to the extruded ones. There was an exception for doughs M-100, M85-SP15, and M85-SB15 indicating that the extruded doughs are softer (forces applied are lower). The height of the masses remained constant and the piston traveled the same distance in all of them, the work being proportional to the applied force, following what was pointed out by Rizley and Suter (1977) who related the area under the curve with the work applied (Figure 6). It is important to mention that the water added to the meals for the tests was different since to obtain doughs with the same consistency some require more water than others. The evaluation parameter to define the consistency was the control mass of 100% nixtamalized corn.

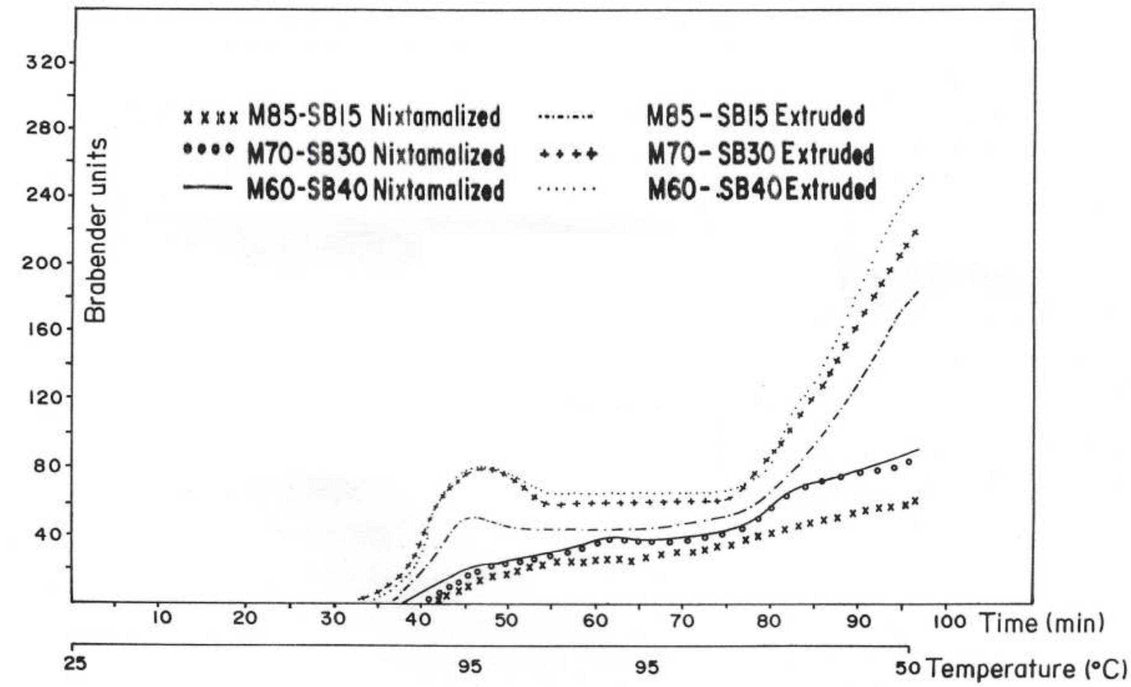

Figure 5. Viscoamylograph of nixtamalized (N) and extruded (E) maize-white sorghum (M85-SB15, M70-SB30, M60-SB40) meals (translated of Durán-de-Bazúa, Coordinator, 1988)

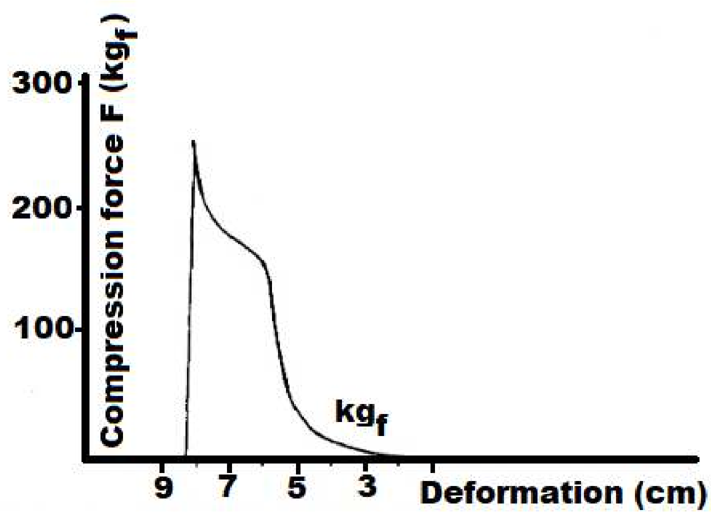

Figure 6. Instron Universal Tester example of response to the doughs evaluated

In the case of *tortillas*, the results obtained showed that the force needed to puncture through the *tortilla* was greater for the nixtamalized samples with respect to the extruded ones, having a different hardness or elasticity index of the respective tortilla (Smith et al., 1979). However, these results can not be considered representative since the thickness of the *tortillas* and their cooking time were not identical, which affected the data obtained (Pérez-Ramírez and Rodríguez-Méndez, 1988). Unfortunately, the Celorio brand automatic *tortilla* maker seen in the back of Figure 1 and which provides a similar force to form the *tortilla* giving a similar thickness and an equal cooking time for all *tortillas* was not available to do these experiments. They were performed in a manual *tortilla* maker. These results are left for the next stage of this research.

Sensory analyses
The results from the sensory evaluations demonstrated that no significant differences were found between 100% maize alkaline extruded and nixtamalized *tortillas*, both for color and consistency. For flavor, a significant difference ($p<0.05$) favoring the extruded *tortillas* was found.

For 100% white sorghum *tortillas*, no significant differences were found for color and consistency ($p<0.05$), but for flavor a better qualification with a significant difference was associated to the alkaline extruded white sorghum *tortillas* ($p<0.05$).

For pearled sorghum *tortillas*, the same results as for white sorghum products were found.

Statistically, the extruded white sorghum tortillas obtained better scores than the ones made with 100% nixtamalized maize. Judges made comments on the better consistency, flavor, and color of the alkaline extruded sorghum tortillas (judges did not know they were made with sorghum).

Color analyses using Hunter Lab colormeter data
Table 2 presents the calculation of ΔE using the average of three determinations per sample obtained for color (L, a, and b) of precooked meals, tortillas, and meals for ground tortillas.

Table 2. Data for ΔE* of precooked meals, tortillas, and meals for ground tortillas (L, a, b) (translated of Durán-de-Bazúa, Coordinator, 1988)

	ΔE*		
	Precooked meals	**Tortillas**	**Ground tortillas**
Nixtamalized samples			
Maize 100%, M	Control	Control	Control
White sorghum 100%, SB	8.00	6.84	9.44
Pearled sorghum 100%, SP	8.09	11.02	9.06
M85-SP15	1.68	2.49	0.64
M85-SB15	2.51	3.19	0.87
M70-SP30	3.54	2.53	2.00
M70-SB30	4.38	3.28	2.72
M60-SP40	5.24	2.63	5.94
M60-SB40	6.93	4.13	3.64
Alkaline extruded samples			
Maize 100%, M	5.00	2.63	2.09
White sorghum 100%, SB	5.66	12.41	14.96
Pearled sorghum 100%, SP	5.04	13.60	11.79
M85-SP15	6.21	4.63	1.77
M85-SB15	5.32	3.65	1.64
M70-SP30	5.92	5.33	2.96
M70-SB30	5.03	5.52	2.26
M60-SP40	4.90	5.82	6.90
M60-SB40	3.69	5.98	5.71

* $\Delta E=\sqrt{\Delta L^2+\Delta a^2+\Delta b^2}$

It is interesting to correlate the results obtained from the trained panel concerning color with the objective results from the Hunter Lab colormeter. The alkaline extruded products have the most luminous colors (L), and the higher yellow to blue values (b). In fact, extruded maize precooked meals, *tortillas*, and meals from *tortillas* are whiter than its nixtamalized counterparts. The pearled products are the darkest, and the white sorghum ones are intermediate. However, no significant differences ($p<0.05$) were found between the mixtures of maize with sorghum up to 40% with the 100% maize products.

Conclusions

From the results obtained, the following conclusions may be drawn:

1. It is possible to alkaline extrude both, corn and sorghum, and its mixtures, to obtain precooked meals that can be successfully used instead of traditional nixtamalized meals for the production of tortillas.

2. Optimal alkaline extrusion conditions were, for the raw meals fed, 20% moisture content, mesh number 20, 0.2% calcium hydroxide, and 160°C for temperature.

3. Organoleptic *tortilla* characteristics are as good as the traditional ones, and if texture and color are considered, these are even better than the 100% nixtamalized maize tortillas, especially the ones made of white sorghum alkaline extruded.

4. Viscoamylographs show that, for broken particles, such as the ones found in pearled sorghum, lower extrusion temperatures should be employed to get similar results to the ones found with nixtamalized precooked meals.

Some recommendations are to continue the research to improve the quality of the doughs in order to have better *tortillas* and other traditional Mexican products such as *tamales* and *atole*. There is a very recent review on lipid and protein oxidation and their impact on functional properties that might help choosing the best alkaline extrusion conditions for maize and sorghum either alone or in its mixtures (Hülsebusch et al., 2024).

Also, it would be advisable to study the effects of alkaline extrusion on the colored sorghum not only from the physical and chemical points of view but to learn with biological tests the efects on body mass gain, and other parameters usually used for these types of evaluations. These experiments have been previously done but not at the extrusion conditions applied in these experiments.

Glossary

Acronyms or terms	**Meaning**
Anthocyanins	The word means blue flower and comes from the Greek language. The chemical structures of anthocyanins contain polyhydroxy or polymethoxy derivatives of 2-phenylbenzophyryllium. A phenolic compound consists of two aromatic rings (A and B rings) linked by 3-carbon chain that forms an oxygenated heterocyclic ring (C ring) (taken form Anthocyanins. H.U. Seitz, W. Hinderer, a chapter in Phytochemicals in Plant Cell Cultures (1988)
Arepa	Maize made flat unleavened bread cooked on a hot surface. The dough is made by cooking grains and once ready the embryo is removed and the grains grinded
Atole	A drink made of nixtamalized maize (Pérez-Ruiz et al., 2024). The word "atole" comes from the Nahuatl "atolli", which means "drink made of maize", due to its root of "atl" water and "tlaoli", Nahuatl name of *Zea mais* (Cabrera, 2002)

Acronyms or terms	Meaning
b. C.	Before Christ
CIDESI	*Centro de Ingeniería y Desarrollo Industrial del Instituto Politécnico Nacional* (Center for Engineering and Industrial Development of the National Polytechnical Institute, in Spanish)
CIATECH	*Centro de Investigaciones y Asistencia Tecnológica del Estado de Chihuahua, A.C., Conacyt*, in Spanish. Research and Technological Assistance Center of the State of Chihuahua, A.C., Conacyt
Conacyt	*Consejo Nacional de Ciencia y Tecnología*, in Spanish. Mexico's National Council for Science and Technology
d.b.	Dry basis
ICRISAT	International Crop Research Institute for Semi-Arid Tropics, Hyderabad, India. A Mexico's fraternal center is located at El Batán, State of Mexico, Mexico
INIA-SARH	*Instituto Nacional de Investigaciones Agrícolas de la Secretaría de Agricultura y Recursos Hidráulicos*, in Spanish. Mexico's National Institute of Agricultural Research of the Secretary of Agriculture and Water Resources
INIFAP	*Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias*, in Spanish. The fusion of three institutes into one, *INIA*, *INIF*, and *INIP*, during the government of Salinas-de-Gortari, reducing their capabilities and personnel
L, a, b, ΔE	Color parameters using the Hunter Lab colormeter (Glasser et al., 1958)
Maize	Maize is a word introduced by the Spanish conquerors to Mexico because they arrived first to the Caribbean islands and the language there was Taino's. This change took effect along the more than 400 years of conquering. *Zea mays*, a grain originally from Puebla, Mexico (domesticated around 4000 years b. C.), and then its cultivation expanded to the American continent and later on, after the Spanish conquest in 1521, to the rest of the world. The maize grain is covered by a coat called testa. The testa is fused with the pericarp (fruit wall) and both form a single outermost layer. Internally, the grain is unequally divided into two parts by epithelium. The upper big part is the endosperm and the lower small part is the embryo
M100	Maize, 100%
M85-SB15, M70-SB30, M70-SP30, M60-SB40, M60-SP40	Mixtures of maize with the two types of sorghum, white (SB) and 'pearled' or decorticated (SP) at different proportions
Sorghum	*Sorghum bicolor* L. Moench, a grain originally from Africa where it was domesticated around 8000 b. C. in Ethiopia and Sudan. It later spread to East and South Africa and India. Wall paintings and archaeological excavations have provided evidence of the cultivation of sorghum in Egypt in the 7th century b. C. (https://www.alimentarium.org/en/fact-sheet/sorghum#:~:text=Sorghum%20originated%20in%20the%20heart,the%207th%20century%20BCE). It has the same parts as maize grains: Testa, pericarp, endosperm, and embryo (Ravi-Shankar and Dayanandan, 2020). It was introduced to Mexico in the second half of the Twentieth Century and because at that time maize was the staple food of people and it was not allowed to use it for feeding cattle people in Mexico associates sorghum as an animal feedstuff and not to be edible by persons. In Africa is just the opposite:

Acronyms or terms	Meaning
	Sorghum is for people and not for animals. It is consumed as a gruel (a kind of *atole*) or in *chapaties* (in India a kind of *arepas* or *tortillas*)
SB100	White sorghum, 100%
SP100	'Pearled' or decorticated sorghum, 100%
Tamal	The word tamal comes from the Nahuatl "tamalli" (maize dough cooked with lime). Mexico is the country with the greatest variety of tamales in the world. There are more than 500 types in the Mexico
Tortilla	Maize made flat unleavened bread cooked on a hot surface. The full grains are cooked with lime or $Ca(OH)_2$
w.b.	Wet basis

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[10] Polyglucids is the right term instead of polysaccharides since the monomer is glucose not sucrose (note of last author)

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