# Methods to Evaluate Hydration and Mixing Properties of Nixtamalized Corn Flours

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Cereal Chem. 75(4):417-420

**ABSTRACT**

Rapid ViscoAnalyser (RVA), consistometer, and mixograph methods were developed to evaluate the pasting, hydration, and mixing characteristics of commercial nixtamalized corn flours (NCF) used for masa production. The effect of moisture level (51–58%) on the mixing characteristics of NCF was evaluated with the mixograph. Masas were subjectively evaluated for machinability properties. Masa with a low moisture level (51%) had reduced mobility and firmer texture, resulting in higher and wider mixograms. The mixograph was able to differentiate between the various stages of masa preparation. The first stage involves hydration of NCF particles, which causes the force to increase. Then masa develops cohesiveness and reaches maximum consistency. Finally, masa develops stickiness due to overmixing, which makes the curve narrower and lower. At a high moisture level (58%), masa is lubricated and plasticized and yields a softer texture with reduced mixing consistency, evident on the mixograph and in lower subjective hardness readings. Flours with higher water absorption capacities produced thick slurries with increased RVA viscosities and shorter consistometer travel distances. Short consistometer travel distances were significantly correlated to increased initial and maximum viscosities in the RVA. The mixograph, RVA, and consistometer methods can be used in NCF quality control programs.

The consumption of Mexican foods (corn tortillas, tortilla chips, taco shells, etc.) has increased substantially in the United States. Retail sales for corn tortillas and tortilla chips during 1994 were more than $5 billion (Barret 1996). For this reason, the production of nixtamalized corn flour (NCF) has expanded in this country. NCF is produced by cooking corn in alkali to produce nixtamal, grinding the nixtamal, and then drying, sieving, and blending various fractions to yield a product with the desired functional characteristics.

Size, density, and hardness of kernels have a significant effect on the alkaline cooking characteristics of corn. Variations in moisture level, heating, cooling, and shear conditions during cooking, steeping, and grinding affect the water uptake and functionality of NCF (Almeida-Dominguez et al 1996).

More than 30 types of commercial NCF with different physical, rheological, and functional properties are available in the United States market. They vary widely in color, particle-size distribution, pH, and water absorption properties (Gomez et al 1987). Particle-size distribution is currently the most important criterion for NCF applications (Bedolla and Rooney 1984). Large particles are required for proper textural characteristics of fried products, while smaller particles are responsible for most of the water uptake, viscosity, cohesiveness, plasticity, and smoothness (Gomez et al 1991).

Development of methods to evaluate properties of NCF such as cohesiveness, stickiness, and consistency is necessary for both producers and processors of NCF to evaluate and monitor the quality of NCF and ingredients. The mixing and hydration properties of NCF affect the properties of tortillas and snacks. It is important to rehydrate and mix the NCF to its optimum level in order to obtain a product with the desired characteristics.

The objective of this research was to evaluate the use of the mixograph, Rapid ViscoAnalyser (RVA), and consistometer to study NCF mixing and hydration properties.

## MATERIALS AND METHODS

### Raw Materials

Tortilla 4 and taco 3 commercial nixtamalized corn flours with different particle size (Table I) were used in this study. Tortilla chip 1, tortilla 2, tortilla exp. 1, taco shell 1, and other commercial tortilla flours (tortilla A–H) with varying quality were also used in this study. These commercial flours are used to manufacture different kinds of products (tortillas, tortilla chips, taco shells). They vary in color and particle-size distribution. Flours were provided by different manufacturers.

### Subjective Machinability Properties

Tortilla 4 and taco 3 flours were hydrated and mixed on speed 1 for 5 min in a 19-L Hobart mixer (model A200, 20-qt capacity, Hobart Corp., Troy, OH) to make masa with 51.0, 54.5, and 58.0% moisture. Masas were rested for 15 min and subjectively evaluated during the sheeting and cutting process for cohesiveness, hardness, stickiness, and overall machinability using a 1–5 scale (1 = low and 5 = high). Optimum values of cohesiveness, hardness, stickiness, and overall machinability for corn masa were 5, 3, 1, and 5, respectively.

A portion of masa was handled manually, and hardness was measured subjectively by pressing the masa with the fingers and evaluating the resistance to manipulation. Stickiness was measured by the extent the masa stuck to the hands and fingers after handling. Cohesiveness was measured by how well the masa held together while it was pulled apart with the hands. In addition, the masa was sheeted in a commercial sheeter to evaluate how it performed.

### Mixograph Method

A 10-g mixograph (NSI-33R, National Mfg. Co., Lincoln, NE) was used to evaluate the effect of moisture content (51.0, 54.5, and 58.0%) on the mixing characteristics of tortilla 4 and taco 3 flours. Precalculated amounts of NCF and water were added to the testing bowl, placed on the mixograph, and mixed for 12 min. Mixograph spring was set at position 8. Commercial tortilla flours with varying characteristics were tested at a fixed moisture level (58%) to evaluate mixograph sensitivity and repeatability. Maximum con-

**TABLE I**
**Particle-Size Distribution of Commercial Nixtamalized Corn Flours[a]**

| | % Overs | |
|---|---|---|
| **Sieve (μm)** | **Taco 3** | **Tortilla 4** |
| 20 (840) | 0.0 ± 0.00 | 0.0 ± 0.00 |
| 40 (420) | 33.0 ± 0.06 | 0.1 ± 0.10 |
| 60 (250) | 28.1 ± 0.10 | 15.9 ± 0.90 |
| 80 (180) | 15.7 ± 0.10 | 29.3 ± 0.60 |
| 100 (150) | 3.7 ± 0.70 | 8.5 ± 0.60 |
| 120 (125) | 6.5 ± 0.70 | 18.4 ± 2.10 |
| <120 | 11.6 ± 0.70 | 23.9 ± 2.30 |

[a] Values are means of triplicate analysis. Mean ± standard deviation.

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Publication no. C-1998-0601-05R.

sistency (mixograph units), time to maximum consistency (min), time to develop stickiness (min), and cohesiveness (mixograph units) were recorded from the mixograms (Fig. 1).

## Consistometer Method

Consistometer (Bostwick CSC Scientific Co. Inc.) determinations of commercial NCF (tortilla 4, tortilla 2, tortilla exp. 1, tortilla chip 1, taco 3, taco shell 1, and tortillas A–H) were done on 22% solid slurries. Flour was weighed and manually mixed with water for 1 min using a spatula. Water temperature was 22–25°C. The slurry was poured into the testing compartment, the sample was immediately released and allowed to flow for 2 min. The distance (cm) traveled by the slurry was recorded as the consistometer reading. The room temperature during testing was 20–25°C.

## RVA Method

Pasting properties of commercial NCF were evaluated on 24% (tortillas A–F) and 27% (tortilla 4, tortilla 2, tortilla exp. 1, tortilla chip 1, taco 3, taco shell 1, tortilla G, and tortilla H) solid slurries using an RVA (Rapid ViscoAnalyser 3C, Newport Scientific Pty., Ltd., Narabeen, Australia) at 10°C/min heating rate. Flours with high water uptake capacities developed high viscosities, and RVA curves tended to go off the viscosity scale. Thus, this group of flours required evaluation at 24% solids level to keep the curve on scale. The rest of the flours were evaluated at 27% solids. Precalculated amounts of flour were weighed, and water was added to complete 28 g. The temperature (°C) and time (min) profiles used were 30:0, 30:1, 60:4, and 60:15. Initial and maximum viscosity (cP) were recorded.

## Statistical Analysis

Statistics were performed with SAS statistical software package (SAS Institute, Inc., Cary, NC).

# RESULTS AND DISCUSSION

## Subjective Masa Machinability Properties

Increasing the moisture level from 51–58% caused increased cohesiveness, stickiness, and overall machinability, and decreased hardness (Table II). This was true for both tortilla 4 and taco 3 flours.

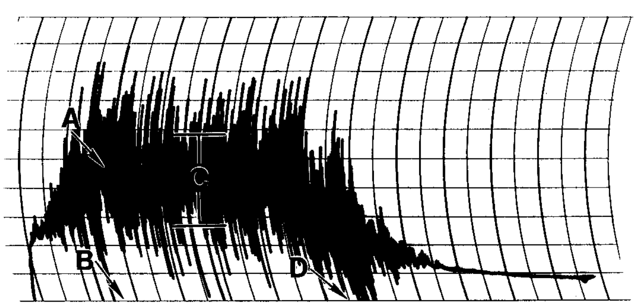


**Fig. 1.** Typical nixtamalized corn flour mixogram showing maximum consistency (A), time to maximum consistency (B), cohesiveness (C), and time to stickiness (D).

**TABLE II**
**Effect of Moisture Level on Subjective Masa Machinability Properties[a]**

| | % Moisture | Hardness | Cohesiveness | Stickiness | Machinability |
|---|---|---|---|---|---|
| Tortilla 4 | 51.0 | 4.5 | 2.4 | 1.2 | 2.6 |
| | 54.5 | 3.8 | 3.7 | 1.6 | 4.2 |
| | 58.0 | 2.1 | 4.9 | 2.8 | 4.4 |
| Taco 3 | 51.0 | 4.6 | 2.4 | 1.6 | 2.7 |
| | 54.5 | 3.6 | 3.7 | 2.0 | 4.0 |
| | 58.0 | 3.0 | 4.4 | 2.8 | 4.0 |
| LSD[b] | | 0.43 | 0.51 | 0.97 | 0.71 |

[a] Masas subjectively evaluated using a 1–5 scale (1 = low and 5 = high). Values are means of triplicate analysis.
[b] Least significant difference ($P < 0.05$).

Subjective hardness readings were related to maximum mixing consistency. Increased moisture levels decreased mixogram height (maximum mixing consistency) (Figs. 2 and 3) and subjective hardness values (Table II). Flours that produced sticky masas required shorter mixing times to develop stickiness in the mixograph. Increased moisture level increased stickiness of masa (Table II) and shortened the time to develop stickiness in the mixograph (Figs. 2 and 3).

## Effect of Moisture Level on Mixograph Characteristics

Three stages were observed during mixing using the mixograph: 1) hydration of NCF, causing the curve to go up; 2) masa develops cohesiveness, curve becomes wider and reaches maximum consistency; 3) masa becomes sticky and adheres to the bowl walls due to overmixing, causing the curve to become narrower and lower. During overmixing, excessive shear is applied to masa, causing physical damage to the starch, which promotes stickiness development in masa.

As moisture level increased, maximum consistency, time to maximum consistency, time to develop stickiness, and cohesiveness significantly decreased (Figs. 2 and 3) (Table III). Both tortilla 4 and taco 3 flours followed similar trends. However, taco 3 produced mixograms with significantly higher maximum mixing consistency, cohesiveness, time to maximum consistency and time to stickiness. Taco 3 had higher mixogram curves at each moisture level tested (Figs. 2 and 3) (Table III). This was possibly due to its higher water absorption capacity. Flour water absorption is related to flour particle size, but also to how the starch in the flour was cooked (gelatinized) during flour manufacture.

The excess water present in the system at increased moisture levels acted as a lubricant reducing the torque involved during mixing and producing soft masas with low maximum consistency and cohesiveness values that resulted in low and narrow mixograms. At increased moisture levels, flours hydrated and developed into a

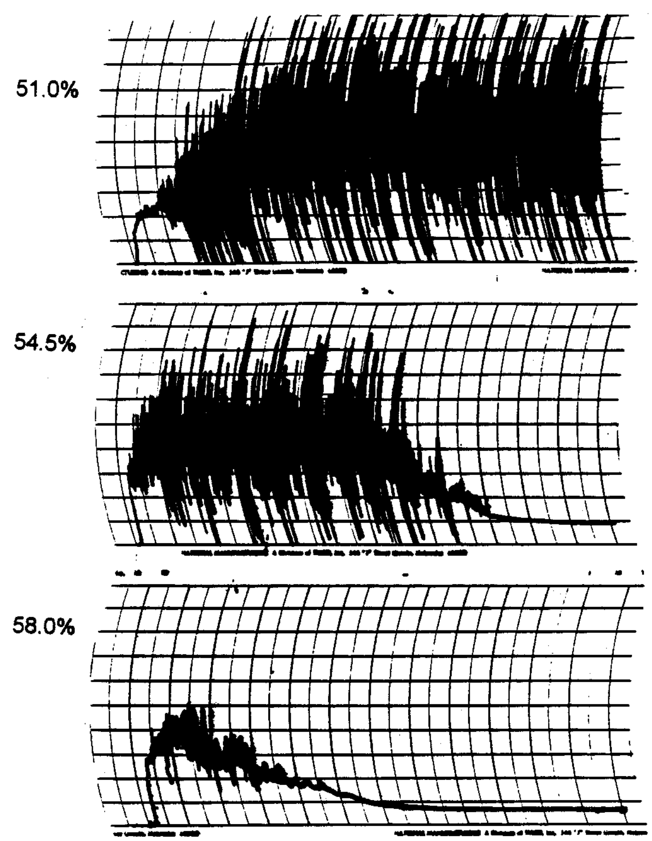


**Fig. 2.** Effect of moisture level on mixograph characteristics of tortilla 4 nixtamalized corn flour.

masa faster due to sufficient water availability, resulting in shorter times to maximum consistency. Excess water also caused masa to develop stickiness quicker.

The mixograph was able to detect a wide range of differences in mixing properties among commercial tortilla flours (tortillas A–H) with varying quality evaluated at a fixed moisture level (Fig. 4). Mixograms from these flours showed differences in all parameters recorded (maximum consistency, time to maximum consistency, time to stickiness, and cohesiveness) (Fig. 4).

Mixograph sensitivity was reduced when flours were evaluated at their optimum water absorption level. Thus, to detect differences among flours with different properties, it was necessary to evaluate them at moisture levels below their optimum water absorption capacity. Potential mixograph users must optimize the moisture level to maximize the instrument sensitivity for their particular application.

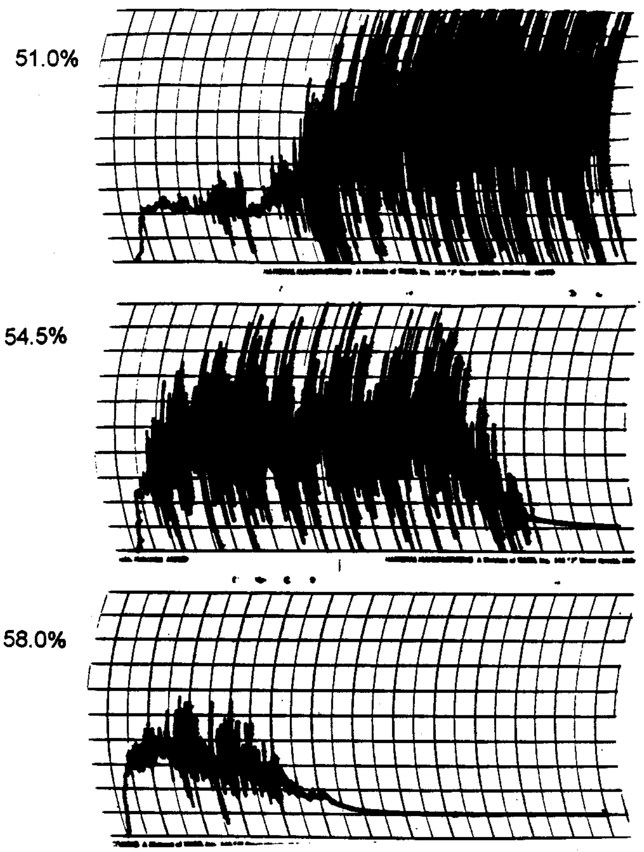


**Fig. 3.** Effect of moisture level on mixograph characteristics of taco 3 nixtamalized corn flour.

**TABLE III**
**Effect of Moisture Level on the Mixograph Characteristics of Commercial Nixtamalized Corn Flours[a]**

| | % Moisture | Maximum Consistency[b] | Time to Maximum Consistency[c] | Time to Stickiness[c] | Cohesiveness[b] |
|---|---|---|---|---|---|
| Tortilla 4 | 51.0 | 55.0 | 4.9 | >12.0 | 50.0 |
| | 54.5 | 45.0 | 1.9 | 7.6 | 31.7 |
| | 58.0 | 39.3 | 1.3 | 1.9 | 11.7 |
| Taco 3 | 51.0 | 65.0 | 7.6 | >12.0 | 65.0 |
| | 54.5 | 50.0 | 2.4 | 8.2 | 50.0 |
| | 58.0 | 38.0 | 1.6 | 2.3 | 17.7 |
| LSD[d] | | 0.7 | 0.2 | 0.7 | 2.8 |

[a] Values are means of triplicate analysis.
[b] Mixograph units (% of chart scale).
[c] Time recorded in minutes.
[d] Least significant difference ($P < 0.05$).

## Consistometer Characteristics

Consistometer sensitivity to differences among these group of commercial flours was optimum at 22% solids. Slurries from commercial NCF traveled different distances (Tables IV and V). The shortest distance was traveled by tortilla B flour while tortilla exp. 1 traveled the greatest distance. Tortilla B flour had a high water-binding capacity. Thus, there is less available water in the system, which reduced mobility of the slurry and shortened the distance traveled. Tortilla exp. 1 had very low water absorption capacity.

Water added to produce the slurry is both partially absorbed by and bound to large particles and used to dissolve soluble solids. The excess water remains as free water that imparts mobility to the slurry. Generally, NCF samples with higher water absorption capacity will travel shorter distances. Short distances traveled in the consistometer were related to higher mixogram curves. Potential users must optimize slurry solids content to maximize consistometer sensitivity to evaluate a particular group of flours.

## RVA Pasting Characteristics

Different RVA initial and maximum viscosities were developed by commercial flours (Tables IV and V). Typical RVA curves for commercial NCF are shown in Fig. 5.

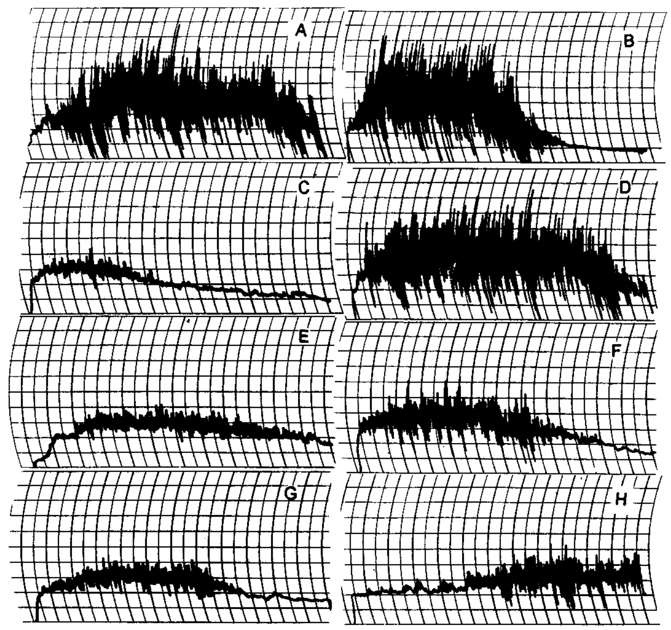


**Fig. 4.** Mixograms of commercial tortilla flours (A–H) with varying quality evaluated at 58.0% moisture level.

**TABLE IV**
**Rapid ViscoAnalyser (RVA) Pasting and Consistometer Characteristics of Commercial Nixtamalized Corn Flour Products Evaluated at 27 and 22% Solids[a]**

| | RVA Viscosity (cP)[b] | | Consistometer Distance Traveled (cm)[c] |
|---|---|---|---|
| | Initial | Maximum | |
| Tortilla 4 | 3,265 | 8,465 | 15.8 ± 0.10 |
| Tortilla 2 | 6,318 | 6,423 | 8.4 ± 0.05 |
| Tortilla exp 1 | 392 | 1,865 | 24.0 ± 0.00 |
| Taco 3 | 3,163 | 10,491 | 9.0 ± 0.30 |
| Tortilla chip 1 | 3,026 | 7,055 | 15.3 ± 0.30 |
| Taco shell 1 | 2,183 | 5,569 | 11.2 ± 0.40 |
| Tortilla G | 2,045 | 5,245 | 12.8 ± 0.25 |
| Tortilla H | 1,920 | 4,990 | 13.5 ± 0.40 |
| LSD[d] | 430 | 698 | |

[a] Values are means of triplicate analysis.
[b] Evaluated on 27% solid slurries.
[c] Evaluated on 22% solid slurries. Mean ± standard deviation.
[d] Least significant difference ($P < 0.05$).

TABLE V
**Rapid ViscoAnalyser (RVA) Pasting and Consistometer Characteristics of Commercial Nixtamalized Corn Flour Products Evaluated at 24 and 22% Solids[a]**

| | RVA Viscosity (cP)[b] | | Consistometer Distance Traveled (cm)[c] |
|---|---|---|---|
| | Initial | Maximum | |
| Tortilla A | 1,600 | 4,530 | 12.1 ± 0.15 |
| Tortilla B | 2,970 | 7,360 | 7.0 ± 0.10 |
| Tortilla C | 595 | 1,515 | 16.2 ± 1.04 |
| Tortilla D | 2,170 | 5,430 | 8.9 ± 0.06 |
| Tortilla E | 410 | 1,185 | 22.5 ± 0.15 |
| Tortilla F | 1,330 | 2,040 | 9.2 ± 0.29 |
| LSD[d] | 401 | 480 | |

[a] Values are means of triplicate analysis.
[b] Evaluated on 24% solid slurries.
[c] Evaluated on 22% solid slurries. Mean ± standard deviation.
[d] Least significant difference ($P < 0.05$).

NCF samples that were evaluated using the full viscoamylograph profile (50–95°C at 10°C/min heating rate and 14% solids) developed similar RVA curves (data not shown), this temperature profile was not sensitive to differences in starch pasting characteristics between NCF samples. Testing NCF samples at lower temperatures and higher solids concentrations reduced the artificially created viscosity during testing and was useful in the evaluation of the hydration and starch swelling ability of flour that developed during manufacture (Fig. 5).

The results obtained with the consistometer were confirmed by the RVA. Tortilla B flour had the highest maximum viscosity among flours evaluated at 24% solids, while tortilla exp. 1, even when evaluated at 27% solids, developed the lowest initial and maximum viscosity among all flours (Tables IV and V).

The contribution of starchy particles to the viscosity of flour depends on the properties conferred by the previous heat-moist treatment. If a high degree of gelatinization occurred during cooking and early stages of drying, combined with retrogradation that occurred during drying, the starch may have reduced solubility and low cold water absorption and viscosity. When starch is slightly gelatinized in excess water and rapidly dried with minimum retrogradation, it will exhibit high water absorption and viscosity upon hydration (Almeida-Dominguez et al 1996).

Potential users must optimize the slurry solids content to maximize RVA sensitivity for their particular application.

### Correlations Among Consistometer and RVA Readings

Consistometer readings were significantly correlated ($P < 0.05$) to RVA initial ($r = –0.84$ and $r = –0.72$) and maximum viscosity ($r = –0.74$ and $r = –0.67$) of flours evaluated at both 24 and 27% solids, respectively (Tables IV and V). Slurries from flours that traveled shorter distances in the consistometer, in general, developed higher initial and maximum viscosities in the RVA.

## CONCLUSIONS

Mixograph had good repeatability and sensitivity to hydration and mixing properties of commercial NCF with varying quality. The mixograph is a simple technique that is able to monitor the development of stickiness. The excess water present in masa at increased moisture levels significantly reduced resistance to mixing, producing shallow and narrow curves, which reduced the sensitivity of the mixograph to differences among the flours. Consistometer readings from commercial NCF were significantly correlated to RVA pasting data.

The consistometer is an inexpensive, simple and relatively fast method to evaluate NCF quality. The mixograph, RVA, and consistometer can be used in quality control programs of either manufacturers or consumers of NCF to evaluate and monitor the quality of NCF and ingredients. Quality of flours can be monitored by developing a standard curve for a specific flour and using this curve to compare to curves run from a different batch of the same flour. These techniques should be able to detect changes in flour manufacturing conditions (cooking time, cooking conditions, or drying conditions) that affect flour hydration properties.

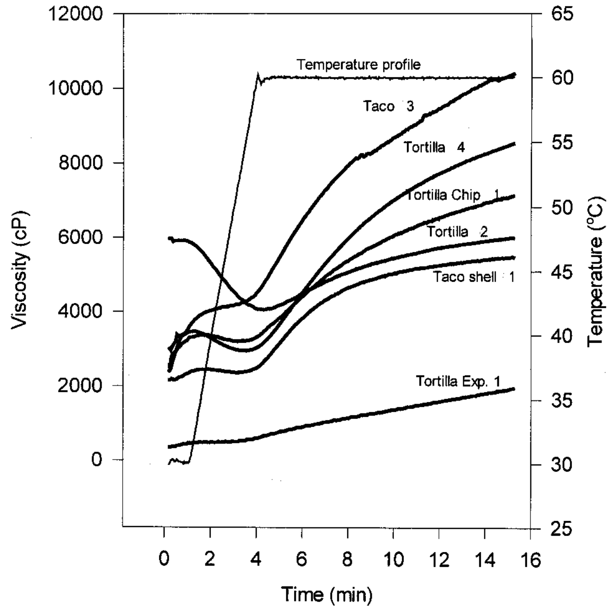


**Fig. 5.** Pasting characteristics of commercial nixtamalized corn flour evaluated on 27% solid slurries using the Rapid ViscoAnalyser.


## ACKNOWLEDGMENTS

We thank C. M. McDonough for her assistance in reviewing this manuscript and the Tortilla Industry Association for providing partial support for this study.


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[Received September 2, 1997. Accepted March 3, 1998.]