Generation of a Mixolab Profile After the Evaluation of the Functionality of Different Commercial Wheat Flours for Hot-Press Tortilla Production

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ABSTRACT

Refined wheat flours commercially produced by five different U.S. and Mexican wheat blends intended for tortilla production were tested for quality and then processed into tortillas through the hot-press forming procedure. Tortilla-making qualities of the flour samples were evaluated during dough handling, hot pressing, baking, and the first five days on the shelf at room temperature. The predominant variables that affected the flour tortilla performance were wet gluten content, alveograph *W* (220–303) and *P/L* (0.70–0.94) parameters, farinograph water absorption (57%) and stability (10.8–18.7 min), starch damage (5.43–6.71%), and size distribution curves (uniform particle distribution). Flours produced from a blend of Dark Northern Spring (80%) and Mexican Rayon (20%) wheat had the highest water absorption, and tortillas obtained from this blend showed the highest diameter and lowest thickness. The whitest and best textured tortillas were obtained from the flour milled from three hard types of Mexican wheat blend. A Mixolab profile was generated from the best tortilla flours, those produced by mills 3 and 4. The Mixolab profile showed that a good flour for hot-press tortillas had a relatively lower absorption and short dough mix time compared with a bread flour and should have a significantly higher gluten compared with an all-purpose flour. Compared with bread flour, the tortilla flour had higher retrogradation and viscosity values. The Mixolab profile proved to be a good preliminary test to evaluate flours for hot-press tortillas.

Numerous publications have previously documented the process of wheat flour tortilla production and evaluation (Serna-Saldivar et al 1988; Bello et al 1991). Tailor-made flours, which are the main and more relevant ingredients in wheat flour tortillas, are commonly obtained from commercial milling systems by using different wheat qualities and blends. Serna-Saldivar et al (1988) described the types of flours suited for different tortilla production systems. None related to the commercial milling parameters that are known to affect the quality of flours and tortillas. The main objective in conventional flour milling is to optimize and reach maximal efficiency in separating the wheat anatomic parts. The variation in wheat characteristics shown between varieties (Wang and Flores 1999) or from one load to the next is significant. The conventional dry-milling process starts with the gradual scraping of the endosperm in the mill break stages, followed by various mechanical means of separating the bran from the endosperm and the final steps of reducing the endosperm particles with different cleanliness. Mills vary in their equipment and flowsheet diagrams that affect differently the major components of the flour: starch and gluten. To a large extent the milling process depends upon the miller's talent to understand the system and to manipulate it in such a way that given the variations in the wheat, the quality of the final flour will be uniform and sufficient in quantity (Posner and Hibbs 2005). Damage of starch during the milling process has a significant effect on flour qualities such as water absorption, amylase activity, and susceptibility to gelatinization. In general, adjustment of the grinding rolls by the miller is controlled by the break release (Posner and Hibbs 2005) and by the pressure between smooth or reduction rolls. Cauvain (2009a) provided a sample table of typical starch damage levels in the different mill stages. The flour particle size distribution depends on several features such as wheat conditioning prior to milling, roll adjustment, sieve aperture, and the ambient conditions within the mill. The particle size affects water absorption and rate of hydration of gluten and starch. Subsequently, the different chemical and physical properties of flour from the milling process affect its performance or functionality for tortillas (Wang and Flores 2000). On the other hand, the Mixolab profiler is relatively new, introduced in 2004, and has already appeared in many scientific assessments of dough rheological behavior (Chen et al 2013; Hrušková et al 2013; Rosell et al 2013). Its valuable working principle combines the farinograph and amylograph methods. However, there was not a Mixolab work related to wheat tortilla flour profile.

Texture and organoleptic characteristics of tortillas are major criteria that consumers use to judge the overall quality. Good quality tortillas should stay flexible and rollable without cracking and breaking when folded (Wang and Flores 1999) and reheated. One of the major problems in tortilla quality is the deterioration of texture with time because of staling (Friend et al 1993; Kelekci et al 2003). Retention of fresh tortilla properties is an increasing problem, especially when they are placed inside sealed plastic bags and expected to last several weeks at room temperature. The protein of the flour and the rate of starch retrogradation are primary factors affecting textural shelf life. Commercial wheat flours for tortilla production usually contain an intermediate protein level. It is recognized that tortillas obtained from low-protein flour crack and split apart when folded after one day of storage, whereas counterparts that contain more protein yield tortillas with improved textural stability (Kelekci et al 2003).

The aims of this research were to test five commercially manufactured refined flours for wheat flour tortillas and relate chemical, physical, and dough rheological parameters to fresh and stored hot-press tortillas. Furthermore, the goal was to generate the optimum Mixolab profile according to the properties of the best performing flours.

MATERIALS AND METHODS

Flour Samples. The untreated flour samples milled for tortilla production were taken from the different commercial mills with-

*The ***e*-X**tra logo stands for "electronic extra" and indicates that Figure 2 appears in color online.

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out any interference or change in existing procedures. The 350 ton capacity mill 1 processed a wheat mix of 10.4% protein made up from 60% Grupo Uno Mexican medium wheat with 10–11% protein and 40% soft red winter wheat (SRW) with 9.8% protein. The daily roll, sifter surfaces, and purifier capacity of mill 1 were 15.03 mm/100 kg, 0.066 m^2/100 kg, and 1.90 mm/100 kg, respectively. The 240 ton capacity mill 2 processed a wheat mix consisting of 15% hard red winter wheat (HRW) and 85% SRW. The daily roll, sifter surfaces, and purifier capacity of mill 2 were 10 mm/100 kg, 0.04 m^2/100 kg, and 0.76 mm/100 kg, respectively. The 220 ton capacity mill 3 milled a wheat blend of 80% Dark Northern Spring with a protein level of 12.6% and 20% Mexican Rayon containing 11.2% protein. The daily roll, sifter surfaces, and purifier capacity of this mill were 10.2 mm/100 kg, 0.05 m^2/100 kg, and 0.91 mm/100 kg, respectively. The 450 ton capacity mill 4 mixed three hard types of Mexican wheat: 45% Rayon with 12.5% protein, 15% Kronstad with 13% protein, and 40% Tacupeto with 12% protein. The daily roll, sifter surfaces, and purifier capacity of mill 4 were 11 mm/100 kg, 0.065 m^2/100 kg, and 1.07 mm/100 kg, respectively. In mill 5, the tortilla flour was obtained by blending refined flours milled by three different units.

Flour Characterization and Dough Tests. Moisture, protein, damaged starch, and ash contents of the flour samples were determined following AACC International Approved Methods 44-40.01, 46-30.01, 76-30.02, and 08-03.01, respectively. Flour particle size distribution was analyzed with laser diffraction technology (Tornado Dry Module LS 13 320, Beckman Coulter, Brea, CA, U.S.A.). Falling number was evaluated following AACCI Approved Method 56-81.03. The color of flours and tortillas was measured with a chromameter (model CR-300, Minolta Camera, Chuo-Ku, Osaka, Japan). Values for *L* (brightness or whiteness), *a* (redness and greenness), and *b* (yellowness and blueness) were measured. The wet gluten content was determined with a Glutomatic apparatus according to AACCI Approved Method 38-12.02. Sedimentation and farinograph tests (Brabender Instruments, South Hackensack, NJ, U.S.A.) were conducted on all flours according to AACCI Approved Methods 56-60.01 and 54-21.01, respectively. Alveograph tests (Chopin Instruments, Villeneuve-La-Garenne, France) characterized dough for extensibility and resistance to extension following AACCI Approved Method 54-30.02. The Mixolab profiler (Chopin) was used to analyze the flour samples according to AACCI Approved Method 54-60.01 and ICC method 173. The starch gelatinization was followed during the increase of temperature from 35 to 90°C at a rate of 2°C/min. Protein properties related to water absorption, stability, elasticity, and weakening were determined. The enzymatic activities and retrogradation as affected by mixing and the temperature increase were also monitored. A Mixolab wheat tortilla profile was generated based on these parameters (Dubat 2010).

Tortilla Formulation. Tortillas were processed following the hot-press procedure in which optimally developed doughs were hot pressed into discs and baked. The basic formulation included 100 g of flour (14% mb), 15 g of vegetable shortening (Productos Lirio, Monterrey, NL, Mexico), 1.5 g of refined iodized salt (La Fina, Sales del Istmo, Coatzacoalcos, Ver., Mexico), 2.0 g of double-acting baking powder (Rexal, Productos Mexicanos, Monterrey, NL, Mexico), 1 g of whole dry milk (Nido, Nestlé, Querétaro, Qro., Mexico), 0.2 g of calcium propionate (TECSA, Monterrey, NL, Mexico), 0.2 g of fumaric acid (PRIMAK, Monterrey, NL, Mexico), 0.2 g of carboxymethyl cellulose (PIASA, Monterrey, NL, Mexico), 0.2 g of sodium stearoyl-2-lactylate (SSL) (TECSA), and distilled water. The added water was adjusted to the water absorption capacity of each flour to create a good dough structure suitable for hot pressing.

Preliminary Tortilla Trials. Tortillas were prepared by methods delineated by Bello et al (1991) and Serna Saldivar (2012) with slight modifications. Batches of 200 g of flour (14% based on the tortilla formulation detailed earlier were mixed with a predetermined volume of warm water (40°C) in a 100–200 g dough mixer (National Manufacturing, Lincoln, NE, U.S.A.). Optimum water absorption and mix times were subjectively determined by observing dough handling properties. Dough texture was subjectively evaluated with a 1-to-7 rating. A subjective score of 1 meant that the dough was slack or soft and needed less force to extend, whereas a score of 7 was assigned to very tough or firm dough that needed high force to extend. Water absorption was

TABLE I
Chemical and Functional Characteristics of Tortilla Flours Produced by Five Different Types of Commercial Mills[y]

Characteristics	Mill 1	Mill 2	Mill 3	Mill 4	Mill 5
Wheat protein (%)	12.78b	13.3ab	13.6a	13.6a	NA
Flour extraction (%)	75.0	77.0	75.5	77.0	NA
Flour color					
L	92.60a	92.08b	91.86b	91.04c	92.15b
a	–1.43b	–1.71a	–1.41b	–1.45b	–1.31b
b	7.32c	8.96b	9.04b	10.07a	7.68c
Moisture (%)	14.2a	13.6b	13.6b	13.6b	12.8c
Ash (%)	0.42c	0.56ab	0.50b	0.56ab	0.63a
Flour protein (%)	10.87b	10.50b	12.22a	10.82b	10.42b
Sedimentation (mL)	19.04b	17.39c	19.90a	18.87b	18.56b
Falling number (s)	326c	376b	410a	405a	382b
Wet gluten (%)	30.0b	31.2b	37.2a	30.8b	28.4b
Rheological tests					
Alveograph					
W	201c	165e	303a	220b	184d
P/G	2.56d	2.19d	3.65b	3.94a	3.20b
P/L	0.53c	0.45c	0.77b	0.94a	0.70b
Farinograph					
Absorption (%)	55.2bc	54.6c	57.6b	57.3b	61.0a
Stability (min)	7.6c	8.6c	18.7a	10.8b	5.5d
Starch damage[z]					
Breaks (%)	8.12b	9.8a	5.12c	5.12c	ND
Sizings (%)	10.98b	19.3a	6.6c	6.6c	ND
Reductions (%)	8.05b	28.4a	5.22c	5.22c	ND
Straight-grade flour (%)	4.34c	4.11c	5.43b	6.71a	5.52b

[y] Data on 14% mb flour. Means with different letters in each row are statistically different ($P < 0.05$). NA = not available, and ND = not determined because this flour consisted of a blend of refined flours.

[z] Starch damage values of flour streams and straight-grade flour.

varied to obtain a dough with intermediate properties (4 in the subjective score of 1 to 7) suited for hot-press tortillas. Experimental doughs were divided into 30 ± 0.25 g pieces, mechanically rounded, and allowed to rest in a proof cabinet (National Manufacturing) adjusted to 29°C and 85% rh for 30 min. Each dough ball was flattened with a commercial inclined hot press for 3.13 s. The temperature of the plates was set at 187°C, and the gap between the hot plates was adjusted to 1.75 mm. The resulting flattened tortilla discs were baked on a four-pass circular moving griddle set at different temperatures (Manufacturas C&D Industriales, Monterrey, NL, Mexico). The raw tortilla was baked on one side for 10.79 s at 200°C, turned over, baked for another 11.01 s at 260°C, turned over again, baked for 11.04 s at 265°C, and finally turned over again and baked at 230°C for 13.60 s (Serna Saldivar 2012).

Pilot Plant Tortilla Trials. Tortilla trials consisted of mixing 5 kg of flour (14% mb) with the other ingredients in the proportions listed earlier and optimum water absorption as determined by the preliminary tortilla trials. The dough mixing protocol consisted of first blending dry ingredients with the shortening at slow speed with a hook attachment for 4 min. Distilled water tempered to 40°C was then added and the blend mixed at slow speed for 1 min and then at medium speed for an additional 5.07, 7.1, 8.45, 8.15, and 6.25 min for flours obtained from mills 1 to 5, respectively. Resulting doughs were placed in the hopper of an automatic dough cutter and rounder (Manufacturas C&D Industriales). The speed of the blade was adjusted to yield 30 g pieces; they were rounded mechanically and immediately placed in the proof cabinet set at 29°C and 85% rh for 30 min. The relaxed dough balls were then hot pressed into tortilla discs and baked as explained earlier. The baked tortillas were cooled on a wire rack to room temperature (25 ± 2°C) for about 30 min, placed inside sealed polyethylene bags, and kept at room temperature for further evaluations (Serna Saldivar 2012).

Evaluation of Tortilla Properties. Ten tortillas from each treatment were randomly selected and measured for weight, diameter, and thickness. The diameter of tortillas was the average of two diagonal perpendicular measurements. Likewise, two tortillas from each batch were randomly selected and measured for color with the Minolta chromameter. Surface color was measured from four different randomly selected spots of each tortilla. Tortilla moisture content was determined following AACCI Approved Method 44-15.02. Texture analyses were conducted after zero, one, two, and five days of storage with a TA.XT2i texture analyzer (Stable Micro Systems, Godalming, U.K.) and with a rollability or dowel technique (Friend et al 1992; Serna Saldivar 2012). A tortilla was rolled around a 1 cm wooden dowel and rated from 1 (breaks immediately, cannot be rolled) to 5 (no cracks, very flexible). Tortillas were considered unacceptable when the rollability score was lower than 3. To assess the reheating functionality of tortillas after a seven-day storage, a griddle was heated on a stove top to a surface temperature of 232°C. Five tortillas from each lot were reheated for 15 s on one side, turned over, heated for 15 s on the other side, and finally heated an additional 15 s on the initial side. Immediately after the reheating schedule, the rollability was evaluated with a scale of 1 to 5 in which 1 was very poor and 5 was excellent.

Statistical Analysis. Flour characteristics and tortilla data were analyzed following a randomized experimental design using analysis of variance procedures. Tortilla texture and rollability measurements were analyzed with nonparametric tests (Kruskal–Wallis). Minimum significant differences and Duncan's tests were applied to determine differences among means ($P < 0.05$). Pearson's correlation coefficients between tortilla quality factors and flour particle size were evaluated with PROC CORR in SAS version 9.2 (SAS Institute, Cary, NC, U.S.A.). The flour particle distributions from all five mills were pooled together and binned into six groups; 0–25, 25–50, 50–100, 100–150, 150–200, and >200 µm.

RESULTS AND DISCUSSION

Chemical and Functional Properties of Flours. Flour particle size distribution, gluten content, and starch damage were found to be significant variables that affected dough handling qualities. The flow sheets of the various commercial mills varied significantly. Results indicate that none of the mills processed wheat with the same method and procedures. None of the commercial mills followed methodical grinding rolls adjustment; instead, adjustment was based only on the head millers' experience. Table I summarizes results of flour chemical and functionality analyses of wheat and produced flours (75–77% extraction). The highest protein content was observed in the flour produced by mill 3. This

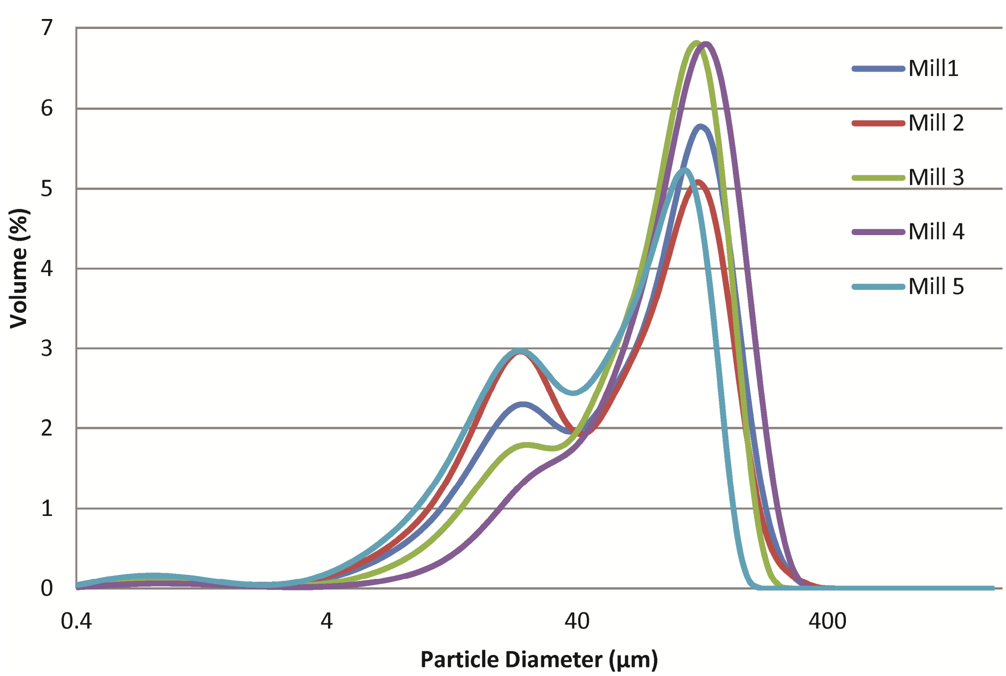

Fig. 1. Particle size distribution of five commercial flours evaluated to produce hot-press wheat tortillas.

protein content was higher than the one recommended for hot-press tortillas (Serna-Saldivar et al 1988; Waniska et al 2004; Ramírez-Wong et al 2007). The rest of the flours contained the protein content ideally suited for tortillas. The higher protein content of flour mill 3 was related to the relatively higher gluten content, sedimentation value, alveograph *W* and *P/G* values, and farinograph stability, indicating that this flour was capable of forming a stronger gluten network. The weakest flours were produced by mills 2 and 5.

The starch damage value is one of the best parameters to evaluate mill grinding adjustments. A good miller will evaluate continuously the starch damage in the flour streams and adjust milling rolls to the optimum required in the final product. The starch damage information of the flour streams and final refined straight-grade flours indicates inconsistencies in some of the mills (Table I). Typically, the starch damage after the break stages should be in the range of 4–5% and in the sizing and reduction stages in the range of 5–6 and 8–10%, respectively. In a well-designed and well-balanced commercial mill, the percentage of flour extracted in the breaks is relatively higher when grinding soft wheat and lower when grinding hard wheat. The incorrect adjustment of the rolls demonstrated especially in mills 1 and 2 yielded most of the final flour in the breaks. These two mills used a high percentage of SRW in the blend. This fact created a situation in which, although the starch damage was high in the breaks (an indication of inappropriate grinding severity), the total starch damage of the final flour was low. Waniska et al (2004) studied the effects of 61 wheat flour properties on tortilla quality and observed that the starch damage value for a good tortilla flour was between 4 and 12%, with an average of 7.6%.

TABLE II
Micromixing Tests of Refined Wheat Flours for Tortilla Production[x]

Mill	WA (%)	Optimum Mix Time (min)	Subjective Dough Consistency[y]	Optimum WA (%)[z]
1	48	3.65 ± 0.31	Slightly slack	47.5
	50	3.32 ± 0.02	Very slack	…
	52	3.13 ± 0.04	Extremely slack	…
2	48	3.87 ± 0.30	Firm	50.8
	50	3.34 ± 0.04	Slightly firm	…
	52	3.15 ± 0.05	Slightly slack	…
3	48	4.18 ± 0.02	Extremely firm	53.2
	50	3.71 ± 0.25	Very firm	…
	52	3.31 ± 0.36	Slightly firm	…
4	48	4.22 ± 0.03	Extremely firm	52.5
	50	3.43 ± 0.03	Very firm	…
	52	3.27 ± 0.03	Slightly firm	…
5	48	3.43 ± 0.03	Very firm	51.0
	50	3.18 ± 0.03	Slightly firm	…
	52	3.08 ± 0.03	Slightly slack	…

[x] Each value is the average of at least three observations. Data on 14% mb flour. WA = water absorption.
[y] Subjectively determined using a seven-point scale, where 7 = dough was extremely firm and 1 = extremely slack. The optimum consistency was rated as 4.
[z] Water was tempered to 40°C before dough mixing.

Tipples et al (1978) suggested that flour granulation could be a factor in achieving the desired qualities in terms of amylase activity. The superimposition of the particle size distribution curves of the five flours (Fig. 1) indicated that flours from mills 3 and 4 had similar smooth curves, indicating a relatively uniform particle size distribution. The rest of the flour curves had a distinctive peak belonging to larger particles. Granulation of flours from mills 1, 2, and 5 affected water distribution and subsequently tortilla quality and rollability. Wang and Flores (2000) observed that particle size of flours was the major factor affecting tortilla texture. Flours were fractionated by sieving into four different particle size fractions: <38, 38–53, 53–75, and >75 µm. Tortillas made from the medium fractions of hard red winter and hard white winter wheat, especially the 53–75 µm fraction, had longer rupture distance and better foldability. The finest fraction yielded tortillas with shorter rupture distance and worse foldability. Fractionation by flour particle size slightly affected protein composition of the flour. When all the mills were pooled and statistically evaluated against quality attributes and flour particle size distributions, the smallest populations (0–25 and 25–50 µm) resulted in –0.83 ($P = 0.1$) correlation to mix time. This relationship may be indicative of a higher degree of starch damage in the finer ground fraction (Wang and Flores 2000). Mix time was also positively correlated to the mid-range flour fraction, 100–150 µm (0.89, $P = 0.05$), possibly because of lower starch damage and better water distribution (Wang and Flores 2000).

Preliminary Tortilla Trials. Table II summarizes results of the preliminary tortilla trials. Flours (14% mb) were tested using three different water absorptions and optimum mix times, and dough consistency was evaluated. At the end of these trials, the optimum water absorptions for the pilot plant studies were determined. As expected and according to functional tests, the flour produced by mill 3 absorbed the highest water to produce optimum dough. This particular flour absorbed about 3.2% more water compared with the normal dough water absorption expected for hot-press tortillas. In contrast, flour produced by mill 1 absorbed 2.5% less water than recommended for hot-press tortillas, indicating that this particular flour despite its protein content yielded the slackest dough. This flour had among the lowest alveograph *W* and farinograph water absorption values. Results of the preliminary tortilla trials indicated that the dough rheological properties and gluten content values did not necessarily correlate to practical tortilla dough mixing properties. For instance, the weakest flours were the ones produced by mills 2 and 5, and these required relatively higher amounts of water to produce optimum doughs. In contrast, flour from mill 1 had relatively higher alveograph *W* and farinograph stability but required the lowest water absorption. Thus, preliminary functional dough and tortilla testing is necessary to optimize water absorption, dough mixing times, and hot-press tortilla quality values. Although only tortilla flours were used to produce tortillas, through this trial we confirmed very different processing properties for them. Tortilla quality is affected by both flour characteristics and process conditions. However, millers do not have a uniform set of specifications, and tor-

TABLE III
Weight, Diameter, Thickness, and Color of Commercial Hot-Press Tortillas Made with Five Different Flours[y]

Mill	Weight (g)	Diameter (cm)	Thickness (mm)	Tortilla Color Parameter			
				L	*a*	*b*	*E*[z]
1	26.42b	14.12b	1.41c	69.9c	–1.31d	16.2b	71.82
2	26.69ab	13.31e	1.77a	73.8b	–7.09a	19.1a	76.54
3	25.96a	14.63a	1.46c	72.8b	–1.12d	19.7a	75.38
4	27.03a	13.84c	1.64b	77.6a	–1.83c	17.2b	79.51
5	26.77a	13.57d	1.62b	62.2d	–4.66b	14.0c	63.93

[y] Each value is the average of at least three observations. Means with different letters in each column are statistically different ($P < 0.05$).
[z] Color index *E* for tortilla was determined by the equation $E = (L^2 + a^2 + b^2)^{1/2}$.

tilla manufacturers routinely compensate for variations in flour functionally by adjusting process parameters (Waniska et al 2004).

Pilot Plant Tortilla Trials. Table III summarizes results of the pilot plant hot-press tortilla trials performed at optimum water absorptions shown in Table II. All types of tortillas weighed approximately 26 g and had diameters and thicknesses after tortilla baking of 13 cm and 1.6 mm, respectively. The tortillas from mill 3 had a significantly larger diameter and smaller thickness. The whitest tortillas with the highest *E* values were obtained from the flour produced by mill 4. This particular flour was manufactured from a blend of three hard wheats of Mexican origin: 45% Rayon, 15% Kronstad, and 40% Tacupeto. Waniska et al (2004) reported similar physical tortilla values, and Ramírez-Wong et al (2007) reported a lower thickness (0.90 mm) and higher diameter (19.93 cm) at 32 g tortilla weight. In contrast, the lowest *L* and *E* color values were observed in tortillas produced from flours 1 and 5. These tortillas had approximately 7.5 units lower *E* color scores compared with counterparts obtained from mill 4. The tortillas from the flour obtained from mill 2 had the highest negative *a* value, probably because it contained a wheat mix consisting of only red wheats (15% HRW and 85% SRW). Parameter *a* and *b* values were similar to data reported by Barros et al (2010) and Ramírez-Wong et al (2007). However, *L* was lower than that reported by Barros et al (2010) and higher than that reported by Ramírez-Wong et al (2007).

Tortilla Texture. The textural shelf life of tortillas plays a critical role in terms of quality and acceptance. Most flour tortillas are expected to last on the shelf at room temperature for at least one week and up to three weeks. Staling of flour tortillas is mainly because of the gradual transformation of amorphous starch to a partially crystalline, retrograded state. The reassociation of starch molecules during storage corresponds to loss of freshness and increased structure or firmness of tortillas (Seetharaman et al 2002). Several additives such as carboxymethyl cellulose and SSL are purposely added to decrease the rate of starch retrogradation, enhance textural shelf life, and improve tortilla reheatability. The texture of tortillas is affected by the gluten, the amount and types of baking powder (Adams and Waniska 2002), shortening, and processing parameters such as time and temperature during the critical baking operation. SSL is an anionic surfactant used as a dough strengthener and crumb softener in the baking industry. This emulsifier interacts with gluten during mixing, resulting in improved dough strength, and then forms a complex with amylose and amylopectin during baking. This interaction results in crumb softening by retarding the staling process. The strong association between SSL and gluten at the dough stage has been suggested to delay denaturation and setting of gluten during baking. After baking, most of the SSL interacts hydrophobically with starch (Akdogan et al 2006). As expected, the fresh tortillas (day 0) had the lowest force and largest extension values (Table IV) and the best rollability properties (Table V). Most of the loss of texture in all the tortillas occurred throughout the first day of storage. According to Bejosano et al (2005), most of the changes in flour tortilla texture occurred during the first and the following four days of storage. Furthermore, these authors concluded that changes occurring in flour tortillas during staling were estimated better by subjective rollability and two-dimensional extensibility tests. Cracking and breaking of tortillas during rolling can be delayed by using flour with higher protein quality and by adding gluten and some hydrocolloids (Friend et al 1993). The force values related to tortilla firmness almost doubled after 24 h of storage. Likewise, the tortilla extension values after one day of storage were one-half to one-third of the values originally observed in fresh tortillas. The higher force and lower extension values are typically observed in bakery products and are mainly attributed to starch retrogradation. A comparison of the tortillas stored five days indicated that the samples belonging to mill 4 had the best textural properties. These tortillas had 20% less force compared with counterparts produced from mills 2, 3, and 5 and 50% less compared with tortillas from mill 1. In terms of extension, the best quality tortillas after five days of storage were produced from flours of mills 3, 4, and 5. It is well-known that the optimum protein for tortillas is intermediate, because soft wheats usually yield tortillas with limited textural shelf life that are more prone to lose texture and have less reheating capacity. On the other hand, the use of hard wheat flours yields doughs that require more proofing and result in doughy and firmer tortillas (Serna-Saldivar et al

TABLE IV
Effect of Type of Flour and Storage for Five Days at Room Temperature on the Textural Properties of Hot-Press Tortillas[z]

Storage	Mill 1	Mill 2	Mill 3	Mill 4	Mill 5
Force (N)					
Day 0	3.67a	3.28bc	3.28bc	2.99c	3.31b
Day 1	6.37a	5.59bc	4.75c	4.01d	4.91c
Day 2	7.31a	6.74a	5.04b	4.68b	4.73b
Day 5	10.79a	7.87b	6.44c	4.77a	6.62c
Extension (mm)					
Day 0	9.54a	9.74a	10.99a	7.60b	10.94a
Day 1	3.70a	2.36b	4.03a	3.25ab	3.86a
Day 2	2.29a	1.19b	2.54a	2.02ab	2.36a
Day 5	0.56b	0.50b	1.44a	0.97ab	1.35a

[z] Each value is the average of at least three observations. Means with different letters in each row are statistically different ($P < 0.05$).

TABLE V
Effect of Type of Flour and Storage for Five Days on Rollability of Wheat Flour Tortillas[z]

	At Room Temperature				Reheated
Tortilla	Day 0	Day 1	Day 2	Day 5	Day 7
Mill 1	4.9 ± 0.3a	4.4 ± 0.6a	3.2 ± 1.3b	1.3 ± 0.8b	2.4 ± 0.5c
Mill 2	5.0 ± 0.0a	4.2 ± 0.8ab	3.4 ± 0.7b	3.1 ± 0.8b	1.6 ± 0.5d
Mill 3	5.0 ± 0.0a	4.8 ± 0.6a	3.5 ± 0.6b	1.7 ± 0.9b	4.0 ± 0.0b
Mill 4	5.0 ± 0.0a	3.8 ± 0.7b	3.1 ± 0.8b	1.6 ± 0.5b	4.0 ± 0.0b
Mill 5	5.0 ± 0.0a	4.4 ± 0.7a	4.3 ± 0.5a	2.9 ± 1.0a	4.8 ± 0.4a

[z] Each value is the average of at least three observations, where 1 = breaks immediately, cannot be rolled and 5 = no cracks, very flexible. Means with different letters in each row or mill of "room temperature" and in the column of "reheated" are statistically different ($P < 0.05$).

1988; Waniska et al 2004). Thus, the best quality tortillas were obtained from mills 3 and 4. These tortillas were produced from flours with relatively higher protein content (10.8–12.2% protein), higher alveograph *W* values (220–303), high farinograph dough stability (10.8–18.7 min), and higher wet gluten contents (30.8–37.2%). These two flours also required the highest water absorption to compensate for their higher gluten content and yielded the best tortillas in terms of texture. The approximately 3% higher water absorption also affected tortilla yield. These flours yielded about 2% more tortillas compared with the rest of the flours. Tortilla rupture was also correlated to total flour starch damage. Accordingly, major variables to control during the milling process are the level of starch damage in flour and the stages in which damaged starch is generated. A high wet gluten content in relation to starch damage, along with optimal water distribution in the flour as affected by particle size, apparently had positive effects on final tortilla quality. Tortillas from the different mills were tested for rollability five days after baking. Data showed significant differences in the rollability of the different baked tortillas. The five-day-old tortillas from three of the mills showed rollability values near 1. Rollability tortilla values were negatively correlated to total flour starch damage as well as to that in the reduction stages, –0.828 and –0.946, respectively. Accordingly, an increased and controlled starch damage that affects water absorption will guarantee good rollability of the final tortilla. Again, when all mills were pooled and evaluated, the smaller particle size (25–50 μm) correlated negatively (–0.87, P = 0.1) to rollability on day 2. This observation may be because of lower protein content, a resultant higher starch content, and higher starch damage in the smaller fractions causing an increase in the rate of staling. Positive correlations to rollability were found in the larger populations of flour particles: rollability on day 1, >200 μm (0.83, P = 0.1); rollability on day 2, 100–200 μm (0.93, P = 0.05) and >200 μm (0.81, P = 0.5); and reheating and rollability on day 7 (0.87, P = 0.1). This observation is a good indication that tortillas made with larger particle size flour can improve shelf life of the end product.

Mixolab Profile. The Mixolab profiler allows the measurement of dough consistency over time and evaluates in the same assay both the mixing and pasting properties of flour during a gradual increase in temperature (Dubat 2010). Cauvain (2009b) determined optimum profiles for different products produced from wheat flours. However, the optimum profile for flour tortillas has not been established. A tentative Mixolab profile was generated with the best performing tortilla flours from mills 3 and 4. These flours performed well through dough handling and final tortilla characteristics. The generated profile was able to discriminate these two top-performing flours from the rest of the flours tested (Fig. 2). Compared with a bread flour Mixolab profile, the optimum flour for hot-press tortillas had lower water absorption, similar gluten strength, and higher viscosity and retrogradation. Interestingly, amylase and mixing values were similar between bread and tortilla flours. Koksel et al (2009) concluded that the Mixolab data could be related to farinograph and alveograph data, Zeleny sedimentation, and bread volume and could be used for screening for dough strength with the main advantage of measuring both the protein and starch properties in a single test. Hrušková et al (2013) observed a link between parameters of farinograph, amylograph, and Mixolab tests, and principal component analysis confirmed these relationships. Within 75% of explained variability (PC1 × PC2 plane) and considered farinograph characteristics, tight associations were revealed between dough development time or stability and C1 (behavior during mixing), as well as between mixing tolerance index and the difference C1 – C2 (protein quality). Amylograph viscosity maximum was connected with C3 (starch gelatinization), C4 (amylase activity), and C5 (starch ret-

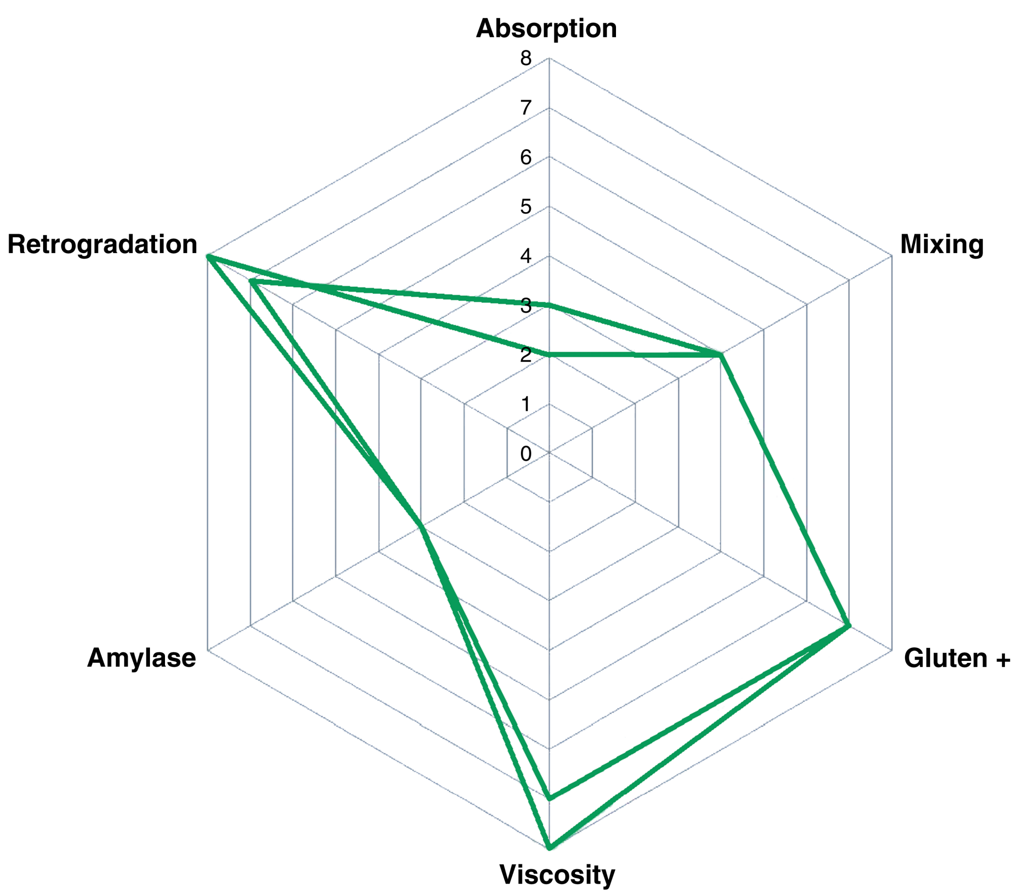

Fig. 2. Mixolab profiler values of flours from mills 3 and 4. These were the best tortilla-production flours.

rogradation) torque points (and also with C3 – C2, C3 – C4, and C5 – C4 differences, which corresponded to amylase activity and starch gel properties during heating and cooling phases of the Mixolab test). Levels of these torque points (C3, C4, and C5) corresponded to dough consistency changes (i.e., resistance against mixing) and to the farinograph dough development time and stability.

In short, the profile indicated that these flours had a relatively lower absorption, short dough mix time, and significantly higher gluten content that affected tortilla rupture, extension strength, and rollability. The best performing flours produced by mills 3 and 4 had comparatively higher falling number (low amylase activity), farinograph stability, and alveograph *W*, *P/G*, and *P/L* values that were related to the high viscosity, gluten, and retrogradation values obtained in the Mixolab profiler. The ability to achieve good viscosity in relatively short proofing and dough development times for hot-press tortillas is probably related to the low-to-medium amylase values of the Mixolab profiler. Freshness of the product on the shelf and ability to be used in traditional serving ways are of major importance for wheat flour tortillas and are indicated in the high retrogradation value.

CONCLUSIONS

Even though all commercial flours evaluated were intended for tortilla production, both the milling process and wheat quality affected flour performance. The best tortillas were obtained from flours of mills 3 and 4, which exhibited the highest protein content, water absorption, alveograph *W* values, farinograph dough stability, and gluten content. The Mixolab profiler was a good instrument to select a flour intended for hot-press tortillas. This instrument showed that the best performing flours had a relatively lower absorption and short dough mix time compared with bread flour and a high gluten profile within the category of all-purpose flours.

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LITERATURE CITED

AACC International. Approved Methods of Analysis, 11th Ed. Method 08-03.01. Ash—Rapid (2-hour, 600°) method. Approved April 13, 1961; reapproved November 3, 1999. Method 38-12.02. Wet gluten, dry gluten, water-binding capacity, and gluten index. Approved November 8, 2000. Method 44-15.02. Moisture—Air-oven methods. Approved October 30, 1975; reapproved November 3, 1999. Method 44-40.01. Moisture—Modified vacuum-oven method. Approved April 13, 1962; reapproved November 3, 1999. Method 46-13.01. Crude protein—Micro-Kjeldahl method. Approved October 8, 1976; reapproved November 3, 1999. Method 46-30.01. Crude protein—Combustion method. Approved November 8, 1995; reapproved November 3, 1999. Method 54-21.01. Farinograph method for flour. Approved November 8, 1995; reapproved November 3, 1999 (archived method). Method 54-30.02. Alveograph method for soft and hard wheat flour. Approved October 3, 1984; reapproved November 3, 1999. Method 54-60.01. Determination of rheological behavior as a function of mixing and temperature increase in wheat flour and whole wheat meal by Mixolab. Approved May 28, 2010. Method 56-60.01. Sedimentation test for flour. Approved April 13, 1961; reapproved November 3, 1999. Method 56-81.03. Determination of falling number. Approved November 2, 1972; reapproved November 3, 1999. Method 76-30.02. Determination of damaged starch. Approved May 1, 1969; reapproved November 3, 1999. Available online only. AACCI: St. Paul, MN.

Adams, J. L., and Waniska, R. D. 2002. Effects of amount and solubility of leavening compounds on flour tortilla characteristics. Cereal Foods World 47:60-64.

Akdogan, H., Tilley, M., and Chung, O. K. 2006. Effect of emulsifiers on textural properties of whole wheat tortillas during storage. Cereal Chem. 83:632-635.

Barros, F., Alviola, J. N., and Rooney, L. W. 2010. Comparison of quality of refined and whole wheat tortillas. J. Cereal Sci. 51:50-56.

Bejosano, F. P., Suman, J., Lopez, R. M., Kelekci, N. N., and Waniska, R. D. 2005. Rheological and sensory evaluation of wheat flour tortillas during storage. Cereal Chem. 82:256-263.

Bello, A. B., Serna-Saldivar, S. O., Waniska, R. D., and Rooney, L. W. 1991. Methods to prepare and evaluate wheat tortillas. Cereal Foods World 36:315-322.

Cauvain, S. P. 2009a. Application of testing methods in flour mills. Pages 91-124 in: The ICC Handbook of Cereals, Flour, Dough & Product Testing. S. P. Cauvain and L. S. Young, eds. DEStech: Lancaster, PA.

Cauvain, S. P. 2009b. The relevance of testing to the manufacture of bread and fermented products. Pages 125-156 in: The ICC Handbook of Cereals, Flour, Dough & Product Testing. S. P. Cauvain and L. S. Young, eds. DEStech: Lancaster, PA.

Chen, F., Li, H., Li, X., Dong, Z., Zuo, A., Shang, X., and Cui, D. 2013. Alveograph and Mixolab parameters associated with *Puroindoline-D1* genes in Chinese winter wheat. J. Sci. Food Agric. 93:2541-2548.

Dubat, A. 2010. A new AACC International Approved Method to measure rheological properties of a dough sample. Cereal Foods World 55:150-153.

Friend, C. P., Serna-Saldivar, S. O., Waniska, R. D., and Rooney, L. W. 1992. Increasing the fiber content of wheat tortillas. Cereal Foods World 37:325-328.

Friend, C. P., Waniska, R. D., and Rooney, L. W. 1993. Effects of hydrocolloids on processing and qualities of wheat tortillas. Cereal Chem. 70:252-256.

Hrušková, M., Švec, I., and Jurinová, I. 2013. Chemometrics of wheat composites with hemp, teff, and chia flour: Comparison of rheological features. Int. J. Food Sci. 2013:968020. http://dx.doi.org/10.1155/2013/968020

Kelekci, N. N., Pascut, S., and Waniska, D. R. 2003. The effects of storage temperature on the staling of wheat flour tortillas. J. Cereal Sci. 37:377-380.

Koksel, H., Kahraman, K., Sanal, T., Ozay, D. S., and Dubat, A. 2009. Potential utilization of Mixolab for quality evaluation of bread wheat genotypes. Cereal Chem. 86:522-526.

Posner, E. S., and Hibbs, A. N. 2005. Wheat Flour Milling, 2nd Ed. AACC International: St. Paul, MN.

Ramírez-Wong, B., Walker, C. E., Ledesma-Osuna, A. I., Torres, P. I. Medina-Rodríguez, C. L., López-Ahumada, G. A., Salazar-García, M. G., Ortega-Ramírez, R., Johnson A. M., and Flores, R. A. 2007. Effect of flour extraction rate on white and red winter wheat flour compositions and tortilla texture. Cereal Chem. 84:207-213.

Rosell, C. M., Altamirano-Fortoul, R., Don, C., and Dubat, A. 2013. Thermomechanically induced protein aggregation and starch structural changes in wheat flour dough. Cereal Chem. 90:89-100.

Seetheraman, K., Chinnapha, N., Waniska, D., and White, P. 2002. Changes in textural, pasting and thermal properties of wheat buns and tortillas during storage. J. Cereal Sci. 35:215-223.

Serna Saldivar, S. O. 2012. Production of chemical-leavened products: Crackers, cookies, cakes and related products, donuts and wheat flour tortillas. Pages 279-285 in: Cereal Grains: Laboratory Reference and Procedures Manual. CRC Press: Boca Raton, FL.

Serna-Saldivar, S. O., Rooney, L. W., and Waniska, R. D. 1988. Wheat flour tortilla production. Cereal Foods World 33:855-864.

Tipples, K. H., Meredith, J. O., and Holas, J. 1978. Factors affecting farinograph and baking absorption. II. Relative influence of flour components. Cereal Chem. 55:652-660.

Wang, L., and Flores, R. A. 1999. Effect of different wheat classes and their flour milling streams on textural properties of flour tortillas. Cereal Chem. 76:496-502.

Wang, L., and Flores, R. A. 2000. Effects of flour particle size on the textural properties of flour tortillas. J. Cereal Sci. 31:263-272.

Waniska, R. D., Cepeda, M., Sullins King, B., Adams, J. L., Rooney, L. W., Torres, P. I., Lookhart, G. L., Bean, S. R., Wilson, J. D., and Betchel, D. B. 2004. Effects of flour properties on tortilla qualities. Cereal Foods World 49:237-244.

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