Effect of Flour Extraction Rate on White and Red Winter Wheat Flour Compositions and Tortilla Texture

Benjamín Ramírez-Wong,[1,2] C. E. Walker,[3] Ana I. Ledesma-Osuna,[1] Patricia I. Torres,[1] Concepción L. Medina-Rodríguez,[1] Guadalupe A. López-Ahumada,[1] María G. Salazar-García,[1] Refugio Ortega-Ramírez,[1] A. M. Johnson,[3] and Rolando A. Flores[4]

ABSTRACT

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Wheat flours commercially produced at 74, 80, and 100% extraction rates made from hard white winter wheat (WWF) and hard red winter wheat (WRF) were used to produce tortillas at a commercial-scale level. Flour characteristics for moisture, dry gluten, protein, ash, sedimentation volume, falling number, starch damage, and particle-size distribution were obtained. Farinograms and alveograms were also obtained for flour-water dough. A typical northern Mexican formula was used in the laboratory to test the tortilla-making properties of the flours. Then commercial-scale tortilla-baking trials were run on each flour. The baked tortillas were stored at room and refrigeration temperatures for 0, 1, 2, and 3 days. Maximum stress and rollability were measured every day. Tortilla moisture, color, diameter, weight, and thickness were measured for each treatment. Finally, tortilla acceptability was tested by an untrained sensory panel. Analyses of variance (ANOVA) were performed on the data. WWF had higher protein content, dry gluten, sedimentation volume, and water absorption than the WRF. The WWF was the strongest flour based on farinograph development time and alveograph deformation work. It also produced the most extensible dough measured with the alveograph (*P/L*). Flour protein and ash contents, water absorption, and tenacity increased directly with the flour extraction rate. Both WWF and WRF performed well in commercial-scale baking trials of tortillas. Tortillas made with both types of flours at 74 and 80% extraction rates had the best firmness and rollability. However, tortillas made with WWF 80% had the best color (highest *L* value). Tortillas prepared with 100% extraction rate flour were also well accepted by the sensory panel, had good textural characteristics, and became only slightly firm and slightly less rollable after three days of storage at room temperature.

Wheat flour tortillas are flat breads traditionally consumed in the northern part of México, and in the last 10–15 years they have become a very popular food item in the United States and several European countries. Tortillas are consumed as bread to complement a food dish and are also used as a wrap or a carrier for different fillings. As such, tortillas must resist folding and tearing without cracking or breaking. It has been recognized that flexibility (Qarooni 1993; Torres et al 1993; Waniska 1999) is one of the most important textural characteristics of the tortilla. Flexibility will allow the tortilla to be folded and rolled without cracking. Bello et al (1991) described a good quality tortilla as one that resists tearing, with a soft exterior (crust) and a layered and puffy interior (crumb). A good tortilla also has a uniform satiny white appearance with few browned spots. The same characteristics also describe good quality tortilla of those consumed in the northern part of Mexico. Although these tortillas have a layered interior they are not puffy. The difference can be explained by the presence of baking powder in the formulation of the tortilla (Bello et al 1991).

It has been consistently reported that the preservation of tortilla textural characteristics during storage correlates with the protein content of the flour (Bello et al 1991; Suhendro et al 1993; Qarooni et al 1994; Friend et al 1995; Wang and Flores 1999a) and it has been reported that flours with moderate protein content (11.5%) are the most appropriate for hot-press tortillas (Serna-Saldivar et al 1988; Qarooni 1993). Several studies have addressed the importance of the wheat flour type (Wang and Flores 1999b) and the effect of particle size of the flour on the finished tortillas (Wang and Flores 2000; Mao and Flores 2001).

[1] Departamento de Investigación y Posgrado en Alimentos, Universidad de Sonora, Hermosillo, Sonora, México.
[2] Corresponding author. Phone: 662-259-2207. Fax: 662-259-2207. E-mail: bramirez@guaymas.uson.mx
[3] Department of Grain Science and Industry, Kansas State University, Manhattan, KS 66506-2201 U.S.A. E-mail: chuckw@ksu.edu
[4] Food Science and Technology Department-Food Processing Center, 143 Filly Hall, University of Nebraska, Lincoln, NE 68588-0919 U.S.A. E-mail: rflores2@unl.edu

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White wheat flour has been used to prepare bakery products including tortillas (Symns and Cogswell 1991; Friend et al 1992; Qarooni et al 1994) and advantages of improved flavor and color were claimed when whole wheat products were used. Due to the favorable bran color, white wheat presents the miller with a potential increment in flour extraction that could create an additional economic benefit. However, this potential could be offset by the flour properties (Friend et al 1992). The objectives of this research were to evaluate the physical, chemical, and rheological properties of commercial flours made from white and red pericarp hard wheats milled to different extraction rates for the production of wheat flour tortillas with good texture, based on acceptability and storage stability.

MATERIALS AND METHODS

Flour Samples

Wheat flour samples (75 lb each) from Kansas-grown hard white and hard red winter wheats were milled by Cereal Food Processors (McPherson, KS) to three different extraction rates: 100, 80, and 74%. Flours with 80 and 100% were made by reconstitution, adding finely ground high ash mill feed streams back to the flours. Milled white wheat was cultivar Trego, crop year 2001. The red wheat flour was a commercial mix. The flours were kept in air-conditioned storage for three months before use. The flours from white wheat were designated WWF. The flours from hard red wheat were designated WRF.

Proximate Composition of Flours

Flour protein content was determined by the micro-Kjeldahl method (Approved Method 46-13, AACC International 2000). Moisture and ash by Approved Methods 44-40 and 08-03, respectively. Protein and ash were reported on a dry basis (moisture-free; protein factor was N × 5.7).

Flour Quality Analysis

Dry gluten content was determined using a Glutomatic apparatus (Falling Number 2100, Falling Number, Huddinge, Sweden) according to Approved Method 38-11 (AACC International 2000). Sedimentation volume was determined with Approved Method

56-62. Falling Number was evaluated using Approved Method 56-81B and Falling Number 1400 apparatus. Flour starch damage was determined according to AACC Approved Method 76-30 with the Megazyme kit. Flour particle-size distribution was evaluated using a rotatory tapping sieve shaker (Chopin Instruments, Rotachoc Type, Villeneuve-La-Garenne, France) with 50-g samples and a set of sieves with 149-µm openings (U.S. mesh No. 100), and 125-µm openings (U.S. mesh No. 120) and the pan by sieving for 5 min.

Flour Dough Tests

Farinograph (Brabender Instruments, South Hackensack, NJ) tests were conducted on all flours according to Approved Method 54-21 (AACC International 2000). Alveograph (Chopin Instruments, Villeneuve-La-Garenne, France) tests characterized flour-water dough for extensibility and resistance to extension using Approved Method 54-30A. The 100% extraction flours could not be tested because the high-fiber dough did not make disks capable of being expanded into a bubble.

Tortilla Formulation

Before going to the commercial tortilla plant, the tortilla formula tested was flour (100% basis), shortening 15%, and salt 2%. (Note that no leavening or yeast was used.) This is a typical tortilla formula used in Sonora, México. In the laboratory, 300 g of flour, 45 g of shortening, and 6 g of salt were placed in the 300-g farinograph and mixed for 5 min. Then sufficient water was added to reach the 450 BU line (Ramirez-Wong et al 1996). All tortillas prepared in the laboratory from all six flours had acceptable appearance and texture. Once the preliminary test results were acceptable, the tortilla formulas were tested on a commercial scale.

Tortilla Manufacturing Commercial Procedure

Lots of 11 kg each of the different flours were mixed for 10 min with the other ingredients in a horizontal mixer (Villamex) with capacity of 44 kg. The farinograph water absorption and mixing times were used. The dough was rested (first resting) at room temperature (25°C) before dividing. This first resting time was subjectively determined by the operator of the commercial tortilleria, who touched the dough. If it was not sticky, no resting time was given, but if the dough was sticky, the operator gave it sufficient resting time until the dough was machineable. The dough was then extruded with 207 kPa air pressure, divided into 45-g pieces, and rounded in a ball rounder (Villamex model V-180). The dough balls were rested (second resting) for 70 min. The dough balls were flattened in a hot press at 77°C to form disks (pressing time 1.67 sec). The disks were baked in a two-zone oven (Villamex model 1300) for 95 sec. The first zone was 312.5°C and the second zone was 193°C. The baked tortillas were cooled for 3 min with ambient air and heat-sealed in plastic bags containing 12 pieces each. The finished tortillas were then transported back to the University of Sonora location for evaluation.

Tortilla Physical Evaluation

Moisture content of the baked tortillas was determined using Approved Method 44-15A (AACC International 2000). The diameter was the average of two perpendicular lines on each of 10 baked tortillas. The thickness of 10 baked tortillas was measured with a vernier caliper. The weight was taken as the average of 10 baked tortillas. Tortilla color for all the treatments was determined using a colorimeter (CR-300, Minolta Corporation, Tokyo, Japan) with standard calibration plate (CR-44). The color parameters evaluated were the *L*, *a*, and *b* values.

Tortilla Texture Evaluation

To evaluate firmness and rollability, the plastic bagged tortillas were stored at room temperature (ROT, 25°C) and refrigeration temperature (RET, 5°C). Firmness and rollability were measured at room temperature at 0, 1, 2, and 3 days after baking.

Firmness test. For each treatment, tortilla firmness was determined using the Kramer Cell attached to a texture analyzer (model 4465, Instron Co., Canton MA). A square was cut from the center of the tortilla with an area of 41.47 cm^2, and then a uniaxial compression force was applied at a crosshead speed of 100 mm/min. The maximum stress (Pa) to cut the tortilla was recorded. The firmness parameters were corrected for tortilla thickness. Five tortillas were tested for each treatment.

Rollability test. Three strips 2-cm wide were cut from each tortilla and individually tested (Waniska 1976). Each tortilla strip was wrapped around a 2-cm diameter dowel, and the degree of breakage was observed. A tortilla received a score of 5 if it did not break, 3 if partially broken, and 1 if completely broken. Five tortillas were tested for each treatment.

Tortilla Sensory Evaluation

Tortilla sensory characteristics were evaluated by an untrained panel of 50 people accustomed to eating tortillas. Evaluation was made on wheat flour tortillas stored under refrigeration for three days. The panel evaluated degree of acceptability using a nonstructured hedonic scale where the level of "likeness" was marked. An indicator in the center of the line served as a reference. Four samples were evaluated per day; tests were conducted from 10:00 to 12:00 in the morning. The hedonic scale was transformed to a numerical scale by measuring the line length in centimeters (Anzaldúa-Morales 1994). After transformation, the hedonic scale was 0, dislikes extremely; 7.5 neither likes nor dislikes; 15, likes extremely.

Experimental Design and Statistical Analyses

The independent variables were wheat flour source (WWF and WRF) and extraction rate (74, 80, and 100%). Analyses of variance (ANOVA) were performed on the data. The significance level was $P = 0.05$. For tortilla measurements, a 2 × 3 factorial design experiment was used. Each treatment was duplicated, for a total of 12 treatments. Tortilla texture evaluations made at different times (0, 1, 2, and 3 days) and temperatures (ROT and RET) used a 2 × 3 × 4 × 2 factorial complete block experimental design. Each test was conducted twice (replicates) for 48 total analyses results.

Analyses of variance (ANOVA) were performed using replicates as a block run at a significance level of $P = 0.05$. Differences among specific treatments were tested with Tukey's test ($\alpha = 0.05$). All statistical analyses were performed using the Statistical Analytical System software (SAS Institute, Cary, NC).

RESULTS AND DISCUSSION

Chemical and Physical Flour Evaluations

Moisture content. Before milling, the wheats were tempered to the same moisture levels (Table I). Values range was 10.7–11.1%. There were significant differences in the mean values for moisture content by flour type, but no significant differences were found by extraction rate.

Ash content. Differences in ash content between flour types were significant ($P < 0.01$) as were different extraction rates ($P < 0.01$). Values range was 0.57–0.73% for flours at 74% extraction (Table I). The ash content increased as the extraction rate increased. Mean values for the 100% extraction flours were 1.89 and 1.81% for WWF and WRF samples, respectively. This increase in ash content is also a consequence of a higher proportion of pericarp and aleuronic layers.

Protein content. The 74% extraction WWF protein content was 12.9%, but the 74% extraction WRF had a slightly lower protein content of 11.2% (Table I). The flour protein content increased as the extraction rate increased. This is a consequence of a higher proportion of aleuronic layer and peripheral endosperm in the flours.

Dry gluten. Differences in dry gluten content were also significant ($P < 0.01$) for flour type and extraction rate. Dry gluten content was higher for WWF (11.1%) than for WRF (10.8%) (Table I). As the extraction rate increased, the gluten content increased slightly for WRF but decreased slightly for WWF.

Sedimentation. The sedimentation value was 35.2% higher for WWF (46.8 mL) than for WRF (34.6 mL) (Table I). Sedimentation volume decreased with the extraction rate, probably due to the presence of coarse particles. Sedimentation is generally related to loaf volume and is considered a very important flour quality index for pan bread. It is also related to the "keeping" quality of tortilla textural properties during storage (Waniska et al 2004).

Falling number. Mean values of the falling number for the two flours were relatively high (508–550 sec) as shown in Table I. This indicates that these flours did not have sprout damage, or the α-amylase enzyme lost activity during handling or storage.

Damaged starch. There were significant differences among flour types and extraction rates. Slightly higher values for damaged starch were determined for WRF compared with WWF. It also varied with different extraction rates (Table I).

Particle size. Significant differences ($P < 0.01$) were observed for flour amounts retained on sieves with 149- and 125-μm openings and in the pan. These differences reflected not only flour type but also extraction rate. Figure 1 shows the percent retained for WWF and WRF; the percent retained on sieves with 149- and 125-μm openings increased as the rate of extraction increased, indicating a coarser average particle size. The percent retained followed the same pattern for both flour types.

Farinograph

Water absorption. Significant differences were observed in the farinograph water absorption for flour type and extraction rate ($P < 0.01$). Water absorption (%) was higher for the 74% extraction WWF (64.8%) as compared with the 74% extraction WRF (62.1%) (Table II). It was also observed that water absorption increased as extraction rate increased, presumably because of the higher protein and complex carbohydrate contents from the bran (Pomeranz et al 1977, 1988) which accounted for the higher extraction rate.

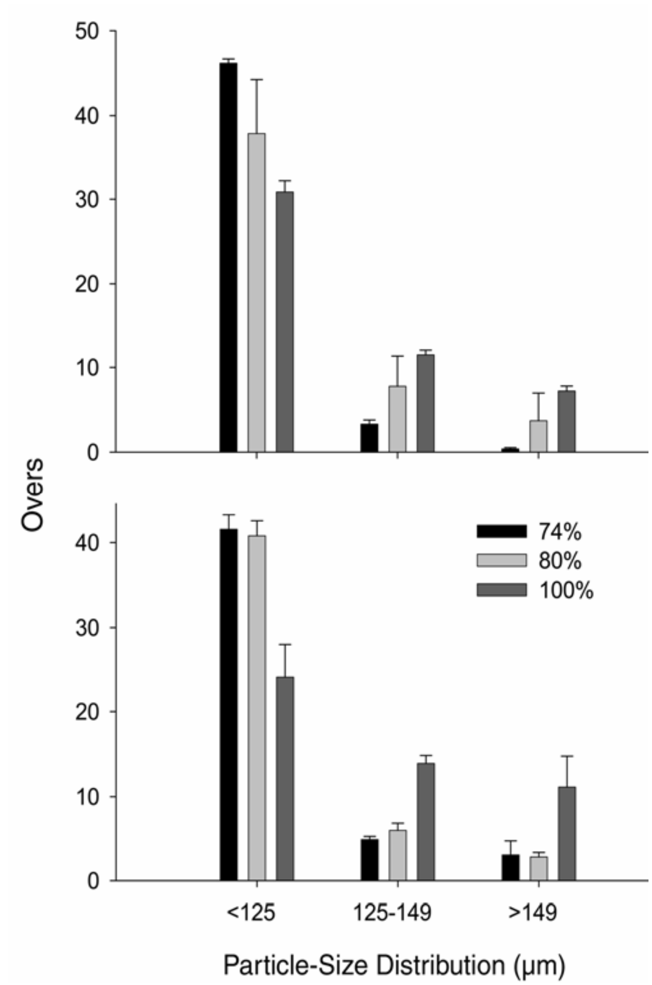

Fig. 1. Particle-size distribution from hard white winter wheat flour (WWF) and hard red winter wheat flour (WRF) at different extraction rates. Bars indicate standard deviation.

TABLE I
Chemical Characteristics of Flours at Different Extraction Rates[a]

	White Wheat Flour			Red Wheat Flour		
Flour Characteristics	**74%**	**80%**	**100%**	**74%**	**80%**	**100%**
Moisture content (%)	11.1 ± 0.5a	10.9 ± 0.6b	10.7 ± 0.4b	10.8 ± 0.2b	10.8 ± 0.0b	11.0 ± 0.3b
Protein content (N × 5.7, % db)	12.9 ± 0.3c	13.7 ± 0.1b	14.4 ± 0.3a	11.2 ± 0.3e	11.5 ± 0.3e	12.4 ± 0.2d
Ash content (% db)	0.7 ± 0.1c	0.9 ± 0.1b	1.9 ± 0.1a	0.6 ± 0.1d	0.8 ± 0.0c	1.8 ± 0.1a
Dry gluten (%)	12.2 ± 0.3b	12.8 ± 0.4a	11.3 ± 0.4c	10.4 ± 0.1c	10.9 ± 0.3c	5.8 ± 0.5e
Sedimentation (mL)	46.8 ± 0.7a	40.1 ± 0.1b	12.2 ± 0.4e	34.6 ± 1.0c	32.6 ± 0.5d	12.3 ± 0.5e
Falling number (sec)	550.0 ± 12.4ab	567.0 ± 56.7a	543.0 ± 28.8ab	508.0 ± 38.6bc	518.0 ± 43.3bc	484.0 ± 19.4c
Damaged starch (%)	4.8 ± 0.5cd	4.5 ± 0.3d	5.3 ± 0.2bc	5.9 ± 0.4a	5.7 ± 0.3ab	4.8 ± 0.5d

[a] Average of three replicates ± standard deviation. Values followed by the same letter in the same row are not significantly different ($P < 0.05$).

TABLE II
Rheological Characteristics of Flours at Different Extraction Rates[a]

	Extraction Rates					
	White Wheat Flour			Red Wheat Flour		
Flour Characteristics	**74%**	**80%**	**100%**	**74%**	**80%**	**100%**
Farinograph						
Water absorption (%)	64.8 ± 0.5d	69.8 ± 0.8d	76.3 ± 0.6a	62.1 ± 0.3e	64.6 ± 0.3d	71.6 ± 0.6b
Development time (min)	8.6 ± 0.8a	6.6 ± 0.3bc	6.9 ± 0.5b	6.4 ± 0.6bc	5.3 ± 0.2c	8.4 ± 2.3a
Stability (min)	12.5 ± 0.9ab	7.8 ± 2.0c	10.0 ± 2.3a–c	12.0 ± 1.4ab	9.5 ± 1.2bc	12.9 ± 1.4a
Alveograph						
Tenacity, *P* (mm)	94.1 ± 4.1bc	120.6 ± 9.9a	–	92.0 ± 5.4c	106.1 ± 10.3b	–
Tenacity/extensibility, *P/L*	0.6 ± 0.0c	1.1 ± 0.2b	–	1.1 ± 0.2b	1.6 ± 0.3a	–
Dough strength, *W* ($J \times 10^{-4}$)	399.0 ± 14.6a	363.0 ± 19.6b	–	267.0 ± 21.2c	248.6 ± 19.9c	–

[a] Average of three replicates ± standard deviation. Values followed by the same letter in the same row are not significantly different ($P < 0.05$).

Development time. Significant differences in the farinograph development time were also observed for flour type and extraction rate ($P < 0.01$). WWF (74%) development time was higher (8.60 min) than development time for WRF (6.4 min) (Table II). Variations in development time were observed for extraction rate but there was no obvious pattern.

Stability. Significant differences in stability were observed for both flour type and extraction rate ($P < 0.01$). WWF had the best stability (12.5 min), followed by WRF (12.0 min) (Table II). Stability was reduced in 80% extraction flours but when extraction increased to 100%, the dough stability increased again.

Alveograph

Tenacity (P). Alveograph parameters were tenacity or resistance (P), tenacity/extensibility ratio (P/L), and work of deformation (W). Significant differences in tenacity were observed for flour type and extraction rate (Table II). Tenacity for the WWF (94 mm) was higher than for WRF (92 mm). It increased with extraction up to 80% for both WWF and WRF. Alveograms could not be run on the 100% extraction flours because their tenacity (resistance to extension) was so high for those flours that a bubble could not be formed.

Tenacity/extensibility ratio (P/L). Significant differences ($P < 0.01$) were observed in the P/L ratio for flour type and extraction rate. The lowest value was for WWF (0.6) followed by the red wheat (1.1) (Table II). The WWF had the best balance between tenacity and extensibility parameters for tortilla dough. A low value is more desirable for tortillas because it means that the dough is more extensible and presumably more easily formed into flat bread.

Dough strength. Dough strength as measured by the alveograph is the area under the curve, the work of deformation (W). Significant differences in W were observed for flour type and extraction rate. WWF had the highest W (399), followed by WRF (267) (Table II). Increasing extraction rate decreased dough strength, as is commonly recognized, presumably because of protein dilution and impaired network formation.

The quality of the two flours was different from the viewpoint of chemical composition and particle-size distribution. Values of protein content as well as sedimentation volume and dry gluten were better for WWF than for WRF. However, protein content of WRF (11%) was the same as that proposed by Serna-Saldivar et al (1988) for tortilla flour. The protein content for WWF was higher than this value. Quality of both flours, estimated by the sedimentation volume, was good and values were higher than those of the normal Mexican baking flours (30–32%).

The slightly higher values of damaged starch, as well as the increased proportion of larger particles, are probably due to harder endosperm for WRF. The difference in particle-size distribution is more evident in the whole wheat flour (100%).

Doughs from the two types of flour were different in dough mixing requirements and mixing stability. Mixing time and stability were higher for WWF dough. This dough was also stronger and more extensible. Increasing the rate of extraction changes flour characteristics. Flours with higher extraction rates had higher protein and ash contents. However, a great part of the added proteins were albumins and globulins, as expected by the inclusion of the aleurone layer and germ (Pomeranz 1988). They were not gluten functional proteins, and a better performance due to increased protein content should not be expected. On the contrary, the presence of bran and larger particles may offset flour performance due to the disruption of the gluten network (Friend et al 1992). This can be observed in the reduction of the sedimentation volumes in flours with higher extraction rates and the reduction of dough strength (measured as W) and incremented tenacity (P).

Tortilla Physical Characteristics

Moisture content. Moisture content is an important parameter for tortilla shelf life because high values cause microbiological problems during storage and may increase starch retrogradation and, as a consequence, tortilla hardening. The average tortilla moisture content for all treatments was 30.07 ± 1.18%.

Moisture content differences were significant for flour type and extraction rate. WWF tortillas had higher moisture contents for all the extraction rates (30.2–31.7%) than WRF tortillas (Table III). Moisture contents for the tortillas were 28.77–29.85% for WRF. Moreover, moisture content slightly increased as extraction rate increased.

Physical characteristics. Tortilla weight range was 32.12–35.23 g (average 33.39 ± 0.95 g). Thickness range was 0.85–0.96 mm (average 0.90 ± 0.03 mm). Diameter range was 19.17–20.75 cm (average 19.93 ± 0.44 cm). As shown in Table III, tortilla physical

TABLE III
Average Values of Moisture, Weight, Thickness, and Diameter of Tortillas from Different Wheat Flour Types and Extractions[a]

Flour Type	Extraction Rate (%)	Moisture (%)	Weight (g)	Thickness (mm)	Diameter (cm)
White wheat flour	74	30.2 ± 1.9ab	35.2 ± 2.7a	0.96 ± 0.06a	20.1 ± 1.4a
	80	30.3 ± 2.0ab	33.0 ± 2.1bc	0.90 ± 0.08ab	19.4 ± 0.4a
	100	31.7 ± 0.4a	31.9 ± 1.6c	0.89 ± 0.11ab	19.2 ± 0.5a
Red winter wheat flour	74	28.7 ± 0.3b	33.8 ± 1.2b	0.85 ± 0.20b	19.9 ± 0.8a
	80	29.8 ± 0.6ab	32.6 ± 1.4bc	0.89 ± 0.70ab	19.9 ± 0.4a
	100	29.5 ± 1.8ab	32.1 ± 1.0c	0.89 ± 0.10ab	19.9 ± 0.5a

[a] Average of 20 replicates ± standard deviation. Values followed by the same letter in the same column are not significantly different ($P < 0.05$).

TABLE IV
Colorimetric Indices of Tortillas from Different Wheat Flour Types and Extraction Levels[a]

		Color Value[b]		
Flour Type	Extraction Rate (%)	*L*	*a*	*b*
White wheat flour	74	26.9 ± 4.4b	–1.7 ± 0.8d	9.2 ± 1.7c
	80	32.2 ± 3.6a	–1.5 ± 1.3d	11.9 ± 2.2b
	100	27.9 ± 3.1b	3.2 ± 1.7b	13.0 ± 1.5a
Red winter wheat flour	74	27.2 ± 6.2b	–1.8 ± 0.8d	9.3 ± 2.2c
	80	28.7 ± 4.2b	–0.1 ± 1.8c	11.1 ± 1.6b
	100	22.6 ± 3.0c	4.1 ± 1.0a	9.5 ± 1.5c

[a] Average of 9 replicates ± standard deviation. Values followed by the same letter in the same column are not significantly different ($P < 0.05$).
[b] Determined with a Minolta colorimeter. L = brightness (100 = white, 0 = black); $+a$ = red; $-a$ = green; b = yellow, $-b$ = blue.

characteristics were similar for flour types and extraction rates. The tortilla physical characteristics were probably similar because the commercial processing equipment conditions were held constant for all the treatments.

Color. Table IV shows mean values of color parameters obtained with the Minolta colorimeter. Significant differences were observed in the parameter *L* (an index of luminance, where 0 = black and 100 = white) for flour type.

On the other hand, differences among extraction rates were not statistically significant ($P > 0.05$). Tortillas prepared with both flour types and a 74% extraction rate were not different. However, higher values of *L* were observed for WWF tortillas when flour with 80% extraction rate was used in the preparation. For *a* value (where +*a* is a measurement of red and –*a* of green), differences were significant for flour type and extraction rate. It was observed that when the rate of extraction increased, the negative value of *a* for tortillas decreased.

This could be explained as a reduction of green tones or a shift toward the red. For the *b* value (a measure of yellowness), the differences were significant for flour type and extraction rate. For WWF, the *b* value in the tortillas increased as the extraction rate increased. For WRF, *b* values were similar for 74 and 100% extraction rates, but not for 80% (which had the highest value).

Tortilla Texture

Maximum stress. Table V shows the values of maximum stress by rate of extraction from tortillas made with WWF and WRF, respectively, stored at ROT and RET. The highest initial maximum stress values were for flours at 100% extraction, followed by those at 74% extraction. Regardless of flour type, highest maximum stress was for tortillas made from flours at 100% extraction, whereas tortillas made from flours at 74 and 80% extraction had the lowest values. Tortillas made with the two lower extractions showed no significant differences between them.

For both types of flours, the maximum stress for tortillas prepared with 74 and 80% extraction rates tended to decrease with one or two days of storage, but it increased slightly at the end of three days of storage. On the other hand, tortillas prepared with 100% extraction rate had a maximum stress relatively constant with storage time. It can be observed from the maximum stress values for both types of flours that WWF could have an advantage because, as the extraction rates increased from 74 to 80%, there was relatively little change in tortilla firmness and color.

Moisture content of WWF tortillas was higher than those of the WRF. This higher moisture content had no effect on developing a harder structure due to starch retrogradation. WRF tortillas had lower moisture content and at the end of the three days of storage they were harder. It seems that the increased moisture content of WWF tortilla due to higher protein content of the flour was somehow not available to increase the rate of starch retrogradation. Tortillas stored at room temperature were harder after three days of storage, especially the WRF tortillas. This is consistent and supports results reported for Kelecki et al (2003), who studied the effect of temperature on the staling of flour tortillas.

Rollability. Table VI shows the dowel rollability score by rate of extraction from tortillas made with WWF and WRF and stored at ROT and RET. Rollability decreased slightly with storage time. Slightly lower values were observed for tortillas stored for three

TABLE V
Maximum Stress Change with Storage Time for Tortillas Made with White Winter Flour and Hard Red Winter Wheat Flour at Different Extraction Rates and Stored at Room and Refrigeration Temperatures[a]

Flour Type	Extraction Rate and Storage Temperature[b]	Maximum Stress (kPa)			
		Day 0	Day 1	Day 2	Day 3
White wheat flour	74 (ROT)	34.3 ± 2.0bc	33.3 ± 6.9b–f	25.5 ± 1.0d	28.4 ± 2.0c
	80 (ROT)	39.2 ± 4.9ab	25.5 ± 2.94e	25.5 ± 1.0d	27.5 ± 2.0c
	100 (ROT)	44.1 ± 4.9a	37.3 ± 1.0a–d	36.3 ± 2.9e	37.3 ± 2.9b
	74 (RET)	34.3 ± 1.9bc	35.3 ± 5.9a–e	27.5 ± 1.0d	27.5 ± 2.9c
	80 (RET)	39.2 ± 4.9ab	28.4 ± 2.0d–f	28.4 ± 2.0d	30.4 ± 2.9c
	100 (RET)	44.1 ± 4.9a	41.2 ± 2.9ab	40.2 ± 2.9ab	37.3 ± 2.0b
Red winter wheat flour	74 (ROT)	35.3 ± 3.0c	29.4 ± 4.9c–f	25.5 ± 1.0d	29.4 ± 1.9c
	80 (ROT)	32.4 ± 2.9c	24.5 ± 2.0f	25.5 ± 1.0d	28.4 ± 1.0c
	100 (ROT)	42.2 ± 3.9a	43.1 ± 4.9a	44.1 ± 2.9a	47.0 ± 8.8a
	74 (RET)	35.3 ± 3.9bc	38.2 ± 14.7a–c	26.5 ± 1.0d	28.4 ± 2.0c
	80 (RET)	32.4 ± 2.9c	27.5 ± 2.9ef	25.5 ± 2.0d	0.3 ± 0.0c
	100 (RET)	42.2 ± 3.9a	43.1 ± 4.9ab	40.2 ± 2.9b	0.4 ± 0.0b

[a] Average of 10 replicates ± standard deviation. Values followed by the same letter in the same column are not significantly different ($P < 0.05$).
[b] ROT, room temperature; RET, refrigeration temperature.

TABLE VI
Dowel Rollability Score Change with Storage Time from Tortillas Made with White Winter Wheat Flour and Hard Red Winter Wheat Flour at Different Extraction Rates and Stored at Room and Refrigeration Temperatures[a]

Flour Type	Extraction Rate and Storage Temperature[b]	Dowel Test			
		Day 0	Day 1	Day 2	Day 3
White wheat flour	74 (ROT)	5.0 ± 0.00	4.9 ± 0.1	4.8 ± 0.2	4.5 ± 0.7
	80 (ROT)	4.9 ± 0.21	4.7 ± 0.3	4.7 ± 0.3	4.7 ± 0.5
	100 (ROT)	5.0 ± 0.00	5.0 ± 0.0	4.7 ± 0.3	4.2 ± 0.6
	74 (RET)	5.0 ± 0.00	5.0 ± 0.0	5.0 ± 0.0	4.9 ± 0.1
	80 (RET)	4.9 ± 0.21	5.0 ± 0.0	4.9 ± 0.1	4.9 ± 0.2
	100 (RET)	5.0 ± 0.00	4.9 ± 0.1	4.4 ± 0.9	4.8 ± 0.2
Red winter wheat flour	74 (ROT)	5.0 ± 0.00	4.8 ± 0.4	4.4 ± 0.4	4.4 ± 0.6
	80 (ROT)	4.9 ± 0.10	4.5 ± 0.3	4.2 ± 0.7	4.0 ± 0.9
	100 (ROT)	5.0 ± 0.00	4.7 ± 0.5	4.2 ± 0.8	4.4 ± 0.7
	74 (RET)	5.0 ± 0.00	5.0 ± 0.0	4.9 ± 0.1	4.9 ± 0.2
	80 (RET)	4.9 ± 0.10	4.8 ± 0.2	4.6 ± 0.3	4.7 ± 0.6
	100 (RET)	5.0 ± 0.00	4.7 ± 0.4	4.9 ± 0.2	4.8 ± 0.3

[a] Average of 10 replicates ± standard deviation.
[b] ROT, room temperature; RET, refrigeration temperature.

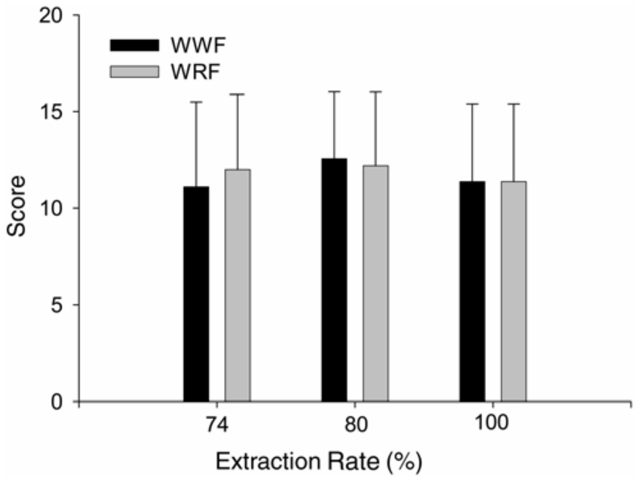

Fig. 2. Sensory evaluation scores from tortillas made with hard white winter wheat flour (WWF) and hard red winter wheat flour (WRF) at different extraction rates. Bars indicate standard deviation. Hedonic scale: 0, dislike extremely < neither like nor dislike < 15, like extremely.

days, prepared with WWF at 100% extraction rate and WRF at 80 and 100% extraction rate. There were only minor changes, but that could imply a bigger difference for a longer period of storage. These tortillas lost flexibility faster as reflected in the lower dowel scores. In this case, it was evident that tortillas stored at ROT had the lowest dowel scores. In pan bread, more retrogradation and greater firming rates for products stored at RET may be expected. It seems that the transfer of moisture from gluten to starch is more important than retrogradation in determining changes in texture as measured by rollability. On the other hand, Kelekci et al (2003) reported optimum staling temperatures of 4–35°C for tortilla.

Sensory Evaluation

Figure 2 shows the sensory analysis results. For 74 and 100% extraction rates, tortillas made with WRF had slightly higher score than tortillas made with WWF. However, for 80% extraction rates, the WWF tortillas scored slightly higher than those prepared from WRF, though these differences were not statistically significant. Results of sensory analysis showed that tortillas from both wheat flours and different extraction rates were well accepted. This was probably because they were not compared directly and were evaluated as different products.

CONCLUSIONS

The high protein content and high sedimentation values of WWF are indices of good quality for tortillas or breads. The WWF was the strongest flour, as shown by the farinograph mixing and development time and the alveograph *W* (work of deformation) values as well as by protein content. Moreover, the WWF showed the best balance by the alveograph *P/L*. The lower value means it produced a more extensible dough, which is highly desirable for tortilla dough. Comparing different extraction rates, WWF had higher protein content, water absorption, and tenacity than WRF, increasing with extraction.

The higher protein and fiber contents in WWF could be useful for producing wheat tortillas with greater nutritional value. Even though differences in tortilla color were not clearly shown by the instrumental numbers, tortillas prepared with WWF at 80 and 100% extraction rates had more attractive colors than those prepared with WRF. However, results showed that tortillas made with WWF at 80% extraction had the lighter color (*L* value), which could be an advantage.

The texture studies showed that tortillas prepared from WWF held their textural characteristics better, as they remained flexible and softer (the lowest maximum stress values). This includes the 80% extraction tortillas and to a lesser extent, the 100% extraction tortillas. This may be a consequence of the higher protein content and stronger gluten quality as reflected by the sedimentation value. The good gluten quality could be able to overcome the higher proportions of fiber and the presence of coarser particles.

Tortillas from both types of wheat flours and different extraction rates were not compared when they were evaluated for sensory characteristics. They were treated as different products, and they all were well accepted.

White wheat flours may be suitable for use in the commercial market to make tortillas because they have good baking performance and produce a product with good attributes such as color and texture. It must be realized, however, that many markets may not necessarily pay a premium for a very white, spot-free tortilla, and may prefer the darker, spotted ones, depending on local customs.

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