Effect of Infrared Baking on Wheat Flour Tortilla Characteristics[1]

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ABSTRACT

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A new and improved method for baking wheat flour tortillas was evaluated. The method was faster and reduced tortilla dehydration. The aim of the study was to evaluate the efficiency of the infrared baking method on rollability, puffing, layering, color (lightness), and texture (cutting force and tensile strength) characteristics of wheat tortillas formulated and formed by the traditional (hand-rolled) and commercial (hot-press) methods. These tortillas were also compared with traditional tortillas cooked on a hot griddle and commercial tortillas cooked in a three-tier, gas-fired oven. In the infrared radiation (IR) method, tortillas were baked for 17 or 19 sec by IR using black-body radiation at a selected wavelength band and emission temperatures of 549 or 584°C. IR-baked tortillas showed good characteristics of rollability, puffing, layering, color, and texture. The loss of moisture during baking of the tortillas formed by hot-pressing and baked by IR was significantly lower than that of tortillas baked by traditional and commercial methods. X-ray diffraction of tortillas prepared by the traditional process and baked by the IR method showed a pattern similar to that of homemade tortillas baked on a hot griddle. The average energy used by the IR oven was less than that used in the commercial method which, in turn, is more efficient than the traditional hot griddle method.

Wheat flour tortillas have been produced in the northern region of Mexico for centuries, and their recent popularity in other states and in the United States has led to large-scale commercial production. Wheat tortillas can compete economically with corn tortillas as food carriers and are very popular in fast-food franchises and other restaurants. Some other wheat tortilla-related products are burritos, quesadillas, chimichangas, fajitas, buñuelos, and tacos. Commercial wheat flour tortilla products are prepared mainly by hot-pressing, although rolled and die-cut procedures are also used (Bello et al 1991). The tortilla products are then baked in three-tier commercial ovens generally heated by gas, electricity, or hot air (Orfeil 1981). The conveyor temperature ranges from 190 to 250°C and baking time varies from 60 to 120 sec. Although this method is satisfactory in producing capping layers in the tortillas, it has some drawbacks such as moisture loss, energy waste in heating up the conveyor, and poor thermal energy transfer, which result in a slow and inefficient process. In addition, with the traditional or commercial methods, the layers formed during tortilla baking assume the roughness of the surface of the hot conveyor or plate.

A new method based on infrared radiation (IR) (Martínez et al 1996) solves most of the basic disadvantages of the commercial and traditional methods. With the IR method, heat transfer is much more efficient, baking time is reduced to 17–19 sec, and moisture loss is lower. The textural qualities of products baked using the IR method, such as a thinner crust and a finer crumb structure, are more desirable to consumers (Lentz et al 1995). IR baking technology for biscuits has been developed to a degree that makes it industrially attractive. For example, while browning is achieved with another specific source (Wade 1987), IR-baked biscuits do not experience spontaneous breakage after cooling and packaging.

The present study shows that IR technology for wheat tortilla production is also attractive and that there is still room for optimization by testing different ingredients, formulations, and equipment. The aim of the study was to evaluate the efficiency and quality of the IR method and compare it with the commercial and traditional methods. The rollability, puffing, layering, color (lightness), and texture (cutting force and tensile strength) of tortillas cooked by the IR method were compared with the characteristics of tortillas cooked by commercial (three-tier, gas-fired oven) and traditional (hot griddle) methods.

MATERIALS AND METHODS

Tortilla Formulation and Preparation

Experimental raw tortillas (hand-rolled and hot-pressed) were obtained from local wheat tortilla factories and cooked by the infrared method. Also, as controls, hand-rolled tortillas were cooked by hot griddle (traditional method) and hot-pressed tortillas were cooked in a three-tier, gas-fired oven.

Hot-Pressed Wheat Flour Tortillas

Enriched, unbleached wheat flour (Gamesa, Monterrey, N.L., Mexico) was used in the tortilla formulations. The doughs for hot-pressed wheat flour tortillas were prepared from a commercial formula that included 1.0 kg of flour, 0.5 kg of water, 120 g of shortening (oil), 15 g of salt, 15 g of baking powder, 0.2 g of propionate, 0.20 g of sodium stearoyl-2-lactylate, and 25 ppm of bisulfite. The dough was divided into 25-g spherical pieces with a divider (model 1140, Dutchess Tool Co., Acon, NY), dusted with flour, and rested for 30 min in a warm, moist chamber (30–36°C and 65–75% rh) (chamber model 3106-INF, National Manufacturing Co., Acon, NY). The rested dough patties were manually placed into a hot press at 10-sec intervals, using a 1.8-mm gap at a temperature of 220°C at the top and 200°C at the bottom. The hot-press device used was fabricated by Torcal (model 1100 220), Saltillo, Coahuila, Mexico.

Hand-Rolled Wheat Flour Tortillas

The dough ingredients were wheat flour (Gamesa), 50% water, 12% shortening (animal lard, Anderson Clayton), and 2% salt, all on a flour weight basis. The dry ingredients (flour, salt, and baking powder) were mixed at slow speed with a paddle for 2 min in a 20-qt mixer (Hobart model A-200, Querétaro, Mexico). Shortening was added and mixed for an additional 8 min to ensure uniform distribution of all ingredients. Warm water (50°C) was added and mixed at low speed for 1 min and then at medium speed for ≈6 min to obtain a soft and pliable dough.

The dough was divided into 25-g spherical pieces with a divider (Dutchess), dusted with flour, and rested for 30 min in a warm, moist chamber (30–36°C and 65–75% rh) (National Manufacturing Co.). The rested doughs were hand-rolled using wooden

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cylinders with significant amounts of dusting with wheat flour. After shaping, the tortillas were rested at temperatures of 28–30°C for 30 min and then baked.

IR-Baked Tortillas

IR baking (Fig. 1) was used for both hand-rolled and hot-pressed tortillas. Tortillas were placed on a continuous band made of stainless steel mesh of no. 18 wire gauge, providing 18 squares per inch as a means of conveying the products to the IR baking apparatus. The preferable wavelength was 2.5–4.0 μm to allow for the best coupling of the IR frequency with the dough IR absorption. The four resistive heat emitters were arranged such that two faced two, each 24 in. in length, 3/8 in. in diameter, and spaced at 1-in. intervals. The emitters of each array were round and made from a Ni-Cr alloy covered by a stainless steel sleeve and isolated with a MgO ceramic material. They were supported by a frame of stainless steel material and covered by an IR reflector made of polished stainless steel. The electrical power delivered to the heaters was ≈900 W each and was controlled with switches. The whole baking system was enclosed in a thermally insulated box. IR radiation was applied to the product at the selected wavelength band with a black-body emission temperature of 549 or 584°C for the baking time selected (17 or 19 sec).

Commercial and Traditional Baked Tortillas

Hot-pressed tortillas were prepared and baked in a commercial manufacturing plant. Tortillas were baked for 40 sec in a three-tier, gas-fired oven (Torcal). Oven temperatures were 232°C (top and bottom tiers) and 273°C (middle tier). The rates of gas flow to each tier were kept constant. Tortillas were cooled to 25°C on a three-tier cooling conveyor using fans below the conveyor and then were placed individually on a table and allowed to equilibrate for ≈10 min.

Hand-rolled tortillas were baked on a hot griddle heated by gas at 220°C for ≈3 min and then placed individually on a table and allowed to equilibrate for ≈10 min. The baked tortillas from both methods were packaged in plastic bags.

Subjective Characterization of Wheat Flour Tortillas

Rollability of the tortillas was determined by the Bedolla method (1983) using tortillas maintained for 30 min at room temperature after being formed. The whole tortilla was hand-rolled around a glass rod of 2 cm diameter, and the degree of breakage was determined subjectively. The puffing of the tortillas was estimated by observing the portion of the total surface that puffed (high or medium), irregular puffing, and presence of toasted spots. The layering of the tortillas was visually estimated. These characteristics, along with areas of browned, toasted spots and translucent (doughy) areas, were used to evaluate tortilla quality.

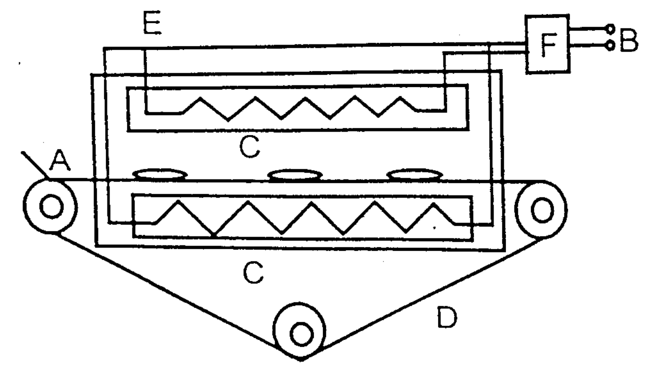

Fig. 1. Infrared baking apparatus: A = wheat flour tortillas, B = switches, C = resistive heating infrared radiation emitters, D = band, E = thermally insulated box, F = electrical power.

Analytical Methods

The moisture content was determined using AACC Approved Method 44-15A (AACC 1995). Loss of moisture during tortilla baking was calculated by weighing the raw and baked tortillas.

Color Measurements

Freshly baked tortillas were cooled to room temperature (25°C) for 10 min and the color scores (*L*, *a*, and *b* values) were measured directly on the same side of the tortilla using a spectrophotometer (CM-2002, Minolta Camera Co., Ltd., Osaka, Japan).

Relative Viscosity

The relative viscosities of the water suspensions of the dough and the tortillas were determined using a pasting viscometer (Rapid Visco-Analyser [RVA], Newport Scientific Narabeen, NSW, Australia). Dough samples were adjusted to 14% moisture, and distilled water was added to keep the total weight of water and sample constant at 28 g. The tortilla suspensions were made from tortillas dehydrated at room temperature for 9 hr and then milled in a coffee mill. Material (4 g, db), with a particle size <259 μm (U.S. no. 60 screen), was suspended in 24 mL of water. Samples were heated to 50°C in 1 min, then to 92°C at a rate of 5.6°C/min (7.5 min), held constant at 92°C for 5 min, cooled to 50°C (5.6°C/min), and finally held constant at 50°C for 1 min. Parameters read from viscometer curves were maximum viscosity during heating cycle and final viscosity during cooling cycle.

Texture Analysis

A texture analyzer (model TA-XT2, Texture Technologies Corp., Scarsdale, NY) was used to determine the tensile strength and cutting force of the tortillas. The tortilla sample, consisting of a 3.79- × 9-cm strip of the middle part of the tortilla, was placed on a TA-96 probe attached to the head of the texture analyzer and tested for tensile strength. Two tortillas from each treatment were evaluated after 30 min at room temperature (25°C). The same strips of tortilla were then placed on the platform and a TA-90 attachment used to determine the cutting force. The texturometer head moved the probe upward at a rate of 2.0 mm/sec until it broke or cut the tortillas. The tensile strength and cutting force were expressed as the peak force (N) required to break and cut the tortilla strip, and the area under the deformation curve was expressed as Nm.

X-ray Diffraction Analysis

X-ray diffraction was performed on the dried samples according to the method described by Rodriguez et al (1996). Wheat tortillas were ground to a fine powder to pass through a 150-μm mesh screen. The powder samples were densely packed in an aluminum frame. X-ray diffraction patterns of the samples were recorded on a diffractometer (D500, Siemens) operating at 35 kV and 15 mA and with a Cu Kα radiation wavelength of 1.5406 Å. Data were collected from 4 to 30° on a 2θ scale with a step size of 0.05°. Data were reported as interplanar *d*-spacing values expressed in Å. The crystallinity (%) was calculated by normalizing the integrated diffracted intensity over the measured 2θ range to the integrated noncoherent intensity. The noncoherent intensity was obtained using software to subtract the sharp diffraction peaks from the total diffraction pattern (Diffract/AT, Socobin V3.2, Siemens, Newton Square, PA).

Energy Efficiency

The energy employed for producing 1 kg of tortilla was measured for a commercial three-tier, gas-fired oven (Torcal) and compared with that employed using the IR method. This figure was obtained by measuring the amount of gas used to bake a predetermined amount of tortillas in a continuous operation. These measurements were performed in two local wheat tortilla factories. The amount of energy used in the gas-fired oven was calculated from the amount of gas employed, the heat power of the gas, and the tortilla production. For the IR oven, the amount of energy used was calculated from the electric energy expended during tortilla production.

Statistical Analysis

Data were analyzed with the SAS software system (release 6.04, SAS Institute, Cary, NC) using analysis of variance, Fisher's least significant difference, and the general linear model.

RESULTS AND DISCUSSION

Baking

Table I indicates that all the experimental tortillas baked by IR showed several toasted spots, which are characteristic of traditional and commercial tortillas, due to nonenzymatic browning or caramelization reactions. They also showed excellent puffing, layering, and rollability. The moisture contents of the IR-baked flour tortillas were similar to those of the commercial tortilla samples and experimental flour tortillas as reported by Serna-Saldivar et al (1988). The moisture contents of experimental flour tortillas reported by Gonzalez-Agramon and Serna-Saldivar (1988) ranged from 25 to 33% and from different factories from 26 to 29%. The moisture losses during baking of the wheat flour tortillas prepared by hot-pressing and baked by IR were significantly lower ($P < 0.05$) than those of tortillas baked by traditional and three-tier, gas-fired commercial methods (controls). Gonzalez-Agramon and Serna-Saldivar (1988) reported that the baking of wheat tortillas resulted in partial gelatinization of the starch, denaturation of the protein, and moisture loss. According to Serna-Saldivar et al (1988), the dough loses ≈2–3% moisture during the pressing operation and 7–11% during baking. During the pressing step, a film or skin is formed on the surfaces of the raw wheat tortilla, which helps to retain water and steam during baking.

Color

Table II shows that the wheat flour tortillas prepared by hot-pressing and baked by the IR method at 549°C for 17 sec did not show significant differences ($P < 0.05$) in lightness from the commercial tortillas baked using the three-tier, gas-fired oven method. Also, wheat flour tortillas prepared by hand-rolling and baked by the IR method at 584°C for 17 sec did not show significant differences ($P < 0.05$) in lightness compared to commercial tortillas baked on a hot griddle. The rest of the baking treatments significantly affected ($P < 0.05$) the color of the flour tortillas when compared to the traditional and commercial (control) tortillas. The lower values for lightness and yellowness of the IR-baked tortillas may indicate a lower degree of caramelization. However, tortillas baked by the IR method showed color characteristics similar to those of the traditional and commercial tortillas. Control tortillas baked in a three-tier gas-fired oven showed the highest values for lightness. Torres et al (1993) reported scores for commercial tortillas baked in a three-tier gas-fired oven that were similar to those found in this work using the same method of baking.

Viscosity

Tortillas prepared by hand-rolling and baked by IR showed the highest values for maximum viscosity during heating cycle and final viscosity durng cooling cycle, while hot-pressed tortillas baked by IR showed the lowest. The viscosity profile showed that hot-pressed tortillas were baked longer (with two steps of hot-pressing and the final baking) than hand-rolled tortillas (Fig. 2). The presence of

TABLE I
Characteristics of Wheat Flour Tortillas Baked by Infrared Radiation (IR) and Commercial Methods[a]

Baking Method	Method of Preparation	Tortilla Texture	Tortilla Appearance	Tortilla Moisture Content (%)	Moisture Loss (%)[b]
Hot griddle	Hand-rolled	Irregular puffing, layered	Toasted, baked	27.2b	9.8a
Three-tier, gas-fired oven	Hot-press	Medium puffing, layered	Toasted, doughy	28.0a	8.8a
IR 549°C, 19 sec	Hand-rolled	High puffing, layered	Toasted, baked	27.1b	9.2a
IR 549°C, 17 sec	Hand-rolled	High puffing, layered	Toasted, baked	27.0b	9.2a
IR 584°C, 19 sec	Hand-rolled	High puffing, layered	Toasted, baked	26.2cd	9.3a
IR 584°C, 17 sec	Hand-rolled	High puffing, layered	Toasted, baked	27.4b	7.7bc
IR 549°C, 19 sec	Hot-press	High puffing, layered	Toasted, baked	26.0cd	7.1c
IR 549°C, 17 sec	Hot-press	High puffing, layered	Toasted, baked	26.4c	7.0c
IR 584°C, 19 sec	Hot-press	High puffing, layered	Toasted, baked	25.8d	6.6c
IR 584°C, 17 sec	Hot-press	High puffing, layered	Toasted, baked	26.5c	7.7bc
LSD[c]				0.56	1.8

[a] Each value is the mean of 10 observations. Means with the same letter in the same column are not significantly different ($P < 0.05$).
[b] During processing.
[c] Least significant difference.

TABLE II
Effect of Baking Methods on Flour Tortilla Color Scores[a,b]

Baking Method	Method of Preparation	L	a	b
Hot griddle	Hand-rolled	63.78b	−1.62e	11.15c
Three-tier, gas-fired oven	Hot-press	64.82a	−2.17a	14.31a
IR[c] 549°C, 19 sec	Hand-rolled	63.31c	−1.59e	11.78b
IR 549°C, 17 sec	Hand-rolled	64.51a	−1.62e	8.72f
IR 584°C, 19 sec	Hand-rolled	61.63e	−1.21f	10.69d
IR 584°C, 17 sec	Hand-rolled	63.57bc	−1.92c	8.62f
IR 549°C, 19 sec	Hot-press	63.53bc	−1.73d	11.81b
IR 549°C, 17 sec	Hot-press	64.72a	−2.10b	14.28a
IR 584°C, 19 sec	Hot-press	62.62d	−1.91c	10.23e
IR 584°C, 17 sec	Hot-press	61.27f	−2.11ab	10.39de
LSD[d]		0.35	0.07	0.33

[a] Determined with a Minolta color meter. L = lightness: 100 = white, 0 = black; a = red (+ 100), $-a$ = green (−80), b = yellow (+ 70), $-b$ = blue (−80).
[b] Each value is the mean of 10 observations. Means with the same letter in the same column are not significantly different ($P < 0.05$).
[c] Infrared radiation.
[d] Least significant difference.

emulsifiers, gums, and preservatives in the dough prepared by hot-pressing affected the viscosity characteristics of the raw dough and baked tortillas. There is an aggregated effect between the dough formulations and tortilla preparations. Emulsifiers and gums have the ability to interact with many flour components during mixing and baking, improving the dough machinability and retarding staling of the tortillas (*unpublished data*).

Texture

Table III shows that the results for cutting force of the hand-rolled tortillas baked by IR (549°C, 17 sec, and 584°C, 19 sec) were statistically similar ($P < 0.05$) to those of control tortillas baked by the commercial (three-tier, gas-fired oven and hot griddle) methods. The area under the force-deformation curves of commercial wheat tortillas was greater than that for tortillas that were hand-rolled or hot-pressed and baked by IR.

Hand-rolled tortillas baked by IR at 549°C for 17 sec and hot-pressed tortillas baked by IR at 584°C for 19 sec had greater tensile strength (i.e., were more stretchable, elastic, and resistant to tearing and cracking) than were commercial tortillas baked in a three-tier, gas-fired oven or hot griddle (Table III). Work required to produce deformation in test strips of hot-pressed tortillas baked by IR was much greater than for hand-rolled tortillas baked by IR. This can be attributed to the different formulations and methods of baking used. Serna-Saldivar et al (1988) reported that commercial tortillas prepared by hot-pressing and baked in a three-tier, gas-fired oven were more elastic and resistant to tearing and cracking than hand-rolled tortillas.

X-ray Diffraction

Figure 3 shows that wheat flour tortillas prepared by hot-pressing and baked in a three-tier, gas-fired oven had the highest values ($P < 0.05$) for crystallinity (5.39%), while homemade tortillas baked on a hot griddle were most significantly affected ($P < 0.05$) with respect to their crystalline structure (4.34%). Hand-rolled and hot-pressed tortillas baked by IR methods showed higher values for crystallinity (4.52 and 4.75%, respectively) than hand-rolled tortillas baked on a hot griddle. Decreased temperatures and baking times of the IR method resulted in decreases in the crystallinity of the tortillas.

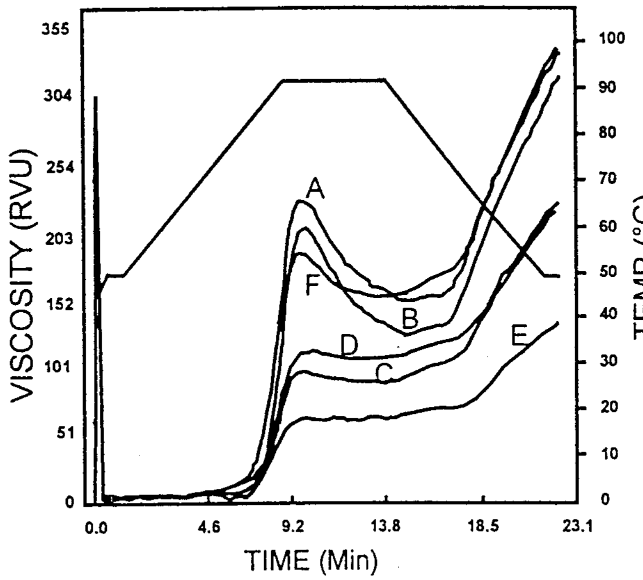

Fig. 2. Viscosity profiles of dough and tortillas baked by infrared energy: A = dough (hot-pressed); B = homemade dough; C = homemade tortilla baked on griddle; D = hot-pressed tortilla baked in three-tier, gas-fired oven; E = hot-pressed tortilla baked by infrared energy (584°C, 19 sec); F = rolled tortilla baked by infrared energy (549°C, 17 sec). RVU = Rapid Visco-Analyser units.

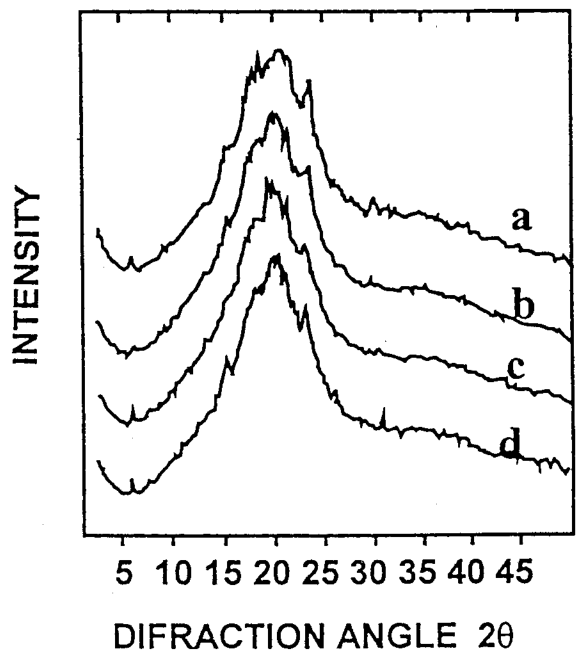

Fig. 3. X-ray diffraction patterns of wheat flour tortillas: a = hot-pressed tortilla baked in three-tier, gas-fired oven, 5.39% crystallinity; b = homemade tortilla baked on hot griddle, 4.34% crystallinity; c = homemade tortilla baked by infrared energy (584°C, 19 sec), 4.75% crystallinity; d = hot-pressed tortilla baked by infrared energy (549°C, 17 sec) 4.52% crystallinity.

TABLE III
Analysis of Cutting Force and Tensile Strength of Wheat Flour Tortillas Baked by the Infrared Radiation (IR) and Commercial Methods[a,b]

Baking Method	Method of Preparation	Cutting Force (N)	Area Under the Force-Deformation curve (Nm) × 10^{-2}	Tensile Strength Force (N)	Area Under the Force-Deformation Curve (Nm) × 10^{-2}
Hot griddle	Hand-rolled	33.8e	7.9a	4.3d	4.0a
Three-tier, gas-fired oven	Hot-press	34.1de	7.9a	4.1f	3.9a
IR 549°C, 19 sec	Hand-rolled	35.3c	5.5g	4.5c	3.0bc
IR 549°C, 17 sec	Hand-rolled	34.4d	6.5e	3.6j	3.9a
IR 584°C, 19 sec	Hand-rolled	33.8e	7.1c	3.9 h	2.7c
IR 584°C, 17 sec	Hand-rolled	32.5f	7.3bc	4.1f	3.2b
IR 549°C, 19 sec	Hot-press	35.8bc	6.8d	4.7b	3.9a
IR 549°C, 17 sec	Hot-press	36.7a	7.4b	4.8a	4.1a
IR 584°C, 19 sec	Hot-press	36.3ab	7.4b	4.0g	4.1a
IR 584°C, 17 sec	Hot-press	32.0g	6.2f	4.3e	3.9a
LSD[c]		0.52	0.28	0.03	0.33

[a] Determined with a TA-XT2 texture analyzer.
[b] Each value is the mean of 10 observations. Means with the same letter in the same column are not significantly different ($P < 0.05$).
[c] Least significant difference.

Energy Efficiency

The average energy used by a commercial three-tier, gas-fired oven per kilogram of wheat tortilla is ≈500 kcal ± 20%. In terms of energy, the commercial method is more efficient than the traditional method by at least half. At a black-body emission temperature of 800°C, the amount of energy used by our IR oven for 1 kg of tortilla is ≈100 kcal; this oven uses only half the IR radiation emitted, so by changing the design, the amount of energy can be reduced to 50 kcal. This value is considerably smaller than that of the commercial method. This large difference is due in part to the energy wasted in heating the griddle, which takes ≈25 min, but mainly to the poor heat transmission from the griddle to the tortilla. In contrast, IR heat is directly irradiated into the tortilla and takes 2 min to warm up. Also important is the fact that the IR radiation band was chosen in such a way that the coupling with the infrared absorption of the tortillas was optimized. The IR power radiated from all the elements was 11 W/cm^2. The IR power applied to the wheat tortillas was preferably 21 W/g of tortilla.

CONCLUSIONS

Wheat tortillas with good rollability, puffing, layering, color (lightness), and texture (cutting force and tensile strength) can be baked using the IR method in less time (549°C for 17 sec) and with lower dehydration. The highest values for the maximum viscosity during heating cycle and final viscosity during cooling cycle were for tortillas prepared by hand-rolling and baked by IR, while hot-pressed IR-baked tortillas had the lowest values. X-ray diffraction showed a similar pattern for tortillas prepared by the traditional process and baked by the IR method and for homemade tortillas baked on a hot griddle. The average energy used by the IR oven is less than that used in the commercial method. Selecting the appropriate wavelength band of the IR emitter increases the heat transfer and makes the method more efficient than the commercial and traditional methods.

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