Journal of Cereal Science 52 (2010) 288–294

Contents lists available at ScienceDirect

Journal of Cereal Science

journal homepage: www.elsevier.com/locate/jcs

Predicting hot-press wheat tortilla quality using flour, dough and gluten properties☆

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ARTICLE INFO

Article history:
Received 31 January 2010
Received in revised form
26 May 2010
Accepted 14 June 2010

Keywords:
Wheat flour tortillas
Quality prediction
Texture analyzer

ABSTRACT

A cost-effective, faster and efficient way of screening wheat samples suitable for tortilla production is needed. This research aimed to develop prediction models for tortilla quality (diameter, specific volume, color and texture parameters) using grain, flour and dough properties of 16 wheat flours. Another set of 18 samples was used to validate the models. The prediction models were developed using stepwise multiple regression. Dough rheological tests had higher correlations with tortilla quality than grain and flour chemical tests. Mixograph mixing time and dough resistance to extension (from extensibility test using a texture analyzer) were correlated best with tortilla quality, particularly tortilla diameter ($r = -0.87$ and -0.86 respectively, $P < 0.01$). Insoluble polymeric proteins (IPP) and gluten index were significantly correlated with tortilla diameter ($r = -0.70$ and -0.67 respectively, $P < 0.01$) and specific volume ($r = -0.73$, $P < 0.01$). Tortilla diameter was the quality parameter best explained ($R^2 = 0.86$) by the prediction models using mixing time and dough resistance to extension. Rheological parameters such as rupture distance and maximum force were also successfully predicted. These prediction models, developed from linear equations, will be an easy and fast tool for breeders to advance or eliminate wheat lines specifically bred for tortilla production.

1. Introduction

Good quality flour tortillas are primarily shelf-stable (retain flexibility for at least two weeks) and usually have large diameters (17–18 cm) (Pascut et al., 2004). Opacity, puffiness and toast spots are other characteristics desired by consumers (Waniska, 1999). However, the specific characteristics of flour that give excellent tortilla quality are not completely understood. Waniska et al. (2004) stated that flour properties should at least include intermediate protein content (10–12%), intermediate protein quality (strength) and low levels of starch damage. These properties illustrate that tortillas have different flour requirements than bread, which requires a higher protein content (more than 11%) and stronger quality. Other flour characteristics that affect tortilla quality are ash content (Wang and Flores, 1999), amylose content (Guo et al., 2003; Waniska et al., 2002), and flour particle size (Mao and Flores, 2001; Wang and Flores, 2000).

Flour tortillas are manufactured by a hot-press, die-cut or hand-stretch procedure, and these methods differ in flour requirements. Flour for hot-press and hand-stretch tortillas have lower protein content (9.5–11.5%) than flour for die-cut tortillas (11.5–14%) (Serna-Saldivar et al., 1988). Moreover, flour for the former is usually treated to decrease gluten strength while flour for the die-cut method is oxidized to have stronger gluten. Hot-press tortillas are baked for a relatively longer time at lower temperatures and puff while baking. They resist tearing and have a smooth surface. Die-cut tortillas, on the other hand, are made from stronger doughs with greater water absorption, resulting in a product of lower moisture content and less resistance to breaking. The process is more efficient than hot-press but tortilla quality is inferior. Hand-stretch tortillas are larger and thinner than the other methods, and they have an irregular shape and intermediate quality (Anton, 2008; Serna-Saldivar et al., 1988).

Abbreviations: DRE, dough resistance to extension; FL, flour $L*$; GI, gluten index; HMW–LMW GS, high molecular weight and low molecular weight glutenin subunits; IPP, insoluble polymeric proteins; MT, mixograph mixing time; PC, protein content; PS, particle size; RD(12), rupture distance at day 12; RF(0), rupture force at day 0; RMSE, root mean square of error; SKH, single-kernel hardness; ST, stability time; SV, specific volume; TD, tortilla diameter; TL, tortilla $L*$; TPA, texture profile analysis; W(12), work at day 12; WQC, Wheat Quality Council.

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0733-5210/$ – see front matter
doi:10.1016/j.jcs.2010.06.009

Wheat breeders evaluate hundreds of experimental breeding lines for milling and predictive functional quality (Souza et al., 2002) as well as tortilla quality (Ibrahim, A.M.H. pers. comm.) every year. Currently, this is done by processing advanced lines into tortillas, which is time-consuming and costly. Finding predictors for outstanding tortilla quality from flour, dough and/or gluten properties would make it possible to eliminate poor quality wheat lines destined for the tortilla market earlier in the breeding program.

Various researchers (Andersson et al., 1994; Dowell et al., 2008; Lee et al., 2006; Millar, 2003; Razmi-Rad et al., 2007) have attempted to predict bread quality using models that take into account grain, flour and/or dough properties. Dowell et al. (2008) combined up to 50 parameters and found that flour protein content was the best predictor for bread loaf volume, whereas bake mix time was best predicted using mixograph mix time. The prediction model for loaf volume was improved by adding dough strength and viscoelastic properties (i.e., farinograph measurements).

For tortillas, Waniska et al. (2004) determined flour properties that affect tortilla quality in a relatively comprehensive scale (i.e., more samples; more parameters) using 61 commercial tortilla flours. The flours were evaluated for 13 parameters, which were correlated with tortilla properties (shelf-stability, diameter). The commercial tortilla flours varied in physico-chemical properties, treatments (e.g., bleaching) and additives (e.g., azodicarbonamide). This study, however, did not consider the combined effect of the flour properties that may provide a better picture or prediction model. More dough and/or gluten properties (e.g., rheological properties) could have been included to develop a stronger model. Likewise, including gluten properties will give a simpler system (Schober et al., 2002) and may further improve the prediction models.

The intent of this research was to develop prediction models for tortilla quality (diameter, specific volume, color and texture parameters) using grain, flour and dough properties by empirical measurements of 16 wheat flours. This is primarily geared for use in wheat breeding programs for a faster, cost-effective, and less labor-intensive way of selecting wheat lines that give good tortilla quality. Early identification of breeding lines that do not possess the characteristics required for good quality tortilla manufacturing may be eliminated earlier in the varietal selection process.

2. Experimental

2.1. Wheat flour samples

Flour from 16 diverse hard winter wheat varieties from the Wheat Quality Council (WQC) 2007 harvest were used in this study. Physico-chemical data of the grains and flours, and farinograph and mixograph profiles were provided by the WQC and used in developing prediction models. These parameters include single-kernel hardness, mean kernel diameter (mm), wet gluten (%), dry gluten (%), gluten index, flour L^*, a^*, b^* values, farinograph and mixograph data (Table 1), and they were determined using the methods described by Dowell et al. (2008). Single-kernel weight (mg) was determined using the Single Kernel Characterization System. Flour protein content (%, 14% mb) was determined according to AACC Method 46-30 (AACC International, 2000) with 5.7 as conversion factor. Particle size (microns) of flour was determined using the Fisher Sub-Sieve Sizer (Fisher Scientific, Nepean, Canada) as described by Xue and Ngadi (2006). Aside from the data provided by WQC, insoluble polymeric proteins (%) (Bean et al., 1998), glutenin to gliadin ratio (Gupta et al., 1993), and high molecular weight to low molecular weight glutenin subunit ratio (HMW–LMW GS) (Naeem and Sapirstein, 2007) were also measured.

Table 1
Means, standard deviations (SD), and minimum and maximum values of grain, flour and dough properties of the 16 wheat samples.

	Mean ($n = 16$)	SD	Min	Max
Grain and flour properties				
Single-kernel hardness	67	9	53	80
Single-kernel weight (mg)	32.5	2.4	29.2	38.5
Mean kernel diameter (mm)	2.34	0.15	2.11	2.63
Wet gluten (%)	33.2	3.5	25.9	39.2
Dry gluten (%)	11.9	1.1	9.5	14.3
Gluten index	93.5	6.0	80.6	99.2
Glutenin–Gliadin ratio	0.524	0.042	0.453	0.610
HMW–LMW GS ratio	0.38	0.06	0.30	0.49
Insoluble polymeric proteins (%)	47.23	4.99	38.07	56.21
Flour L^*	92.28	0.39	91.48	92.93
Flour a^*	−1.65	0.22	−2.07	−1.39
Flour b^*	9.77	0.81	8.53	11.70
Particle size (μm)	21.4	1.7	19.0	24.0
Protein content (%, 14% mb)	12.00	0.79	10.92	13.35
Dough rheological properties				
Farinograph				
Water absorption (%)	63.6	2.5	58.8	70.1
Development time (min)	9.5	5.8	5.2	26.3
Stability time (min)	19.0	6.7	10.7	31.6
Breakdown time (min)	19.5	8.7	9.4	34.2
Tolerance index	17	9	0	31
Mixograph				
Mixing time (min)	3.7	1.0	2.5	6.0
Mixing tolerance	3	1	1	6
Extensibility test				
Dough resistance to extension (N)	0.40	0.09	0.30	0.54
Dough extensibility (mm)	59.93	10.03	39.92	78.54
Gluten resistance to extension (N)	1.49	0.24	1.07	1.98
Gluten extensibility (mm)	50.79	7.87	33.99	62.00
Texture profile analysis (TPA)				
Hardness (N)	133.19	15.06	116.42	179.57
Cohesiveness	0.46	0.02	0.40	0.49
Adhesiveness (Nmm)	19.86	4.36	13.14	30.81
Springiness (mm)	3.60	0.36	3.04	4.19
Stress relaxation				
Relaxation time (s)	1.69	0.08	1.54	1.81

2.2. Tortilla formulation and processing

Dough and hot-press tortillas were prepared by the method described by Alviola et al. (2008). The following ingredients were used: 500 g wheat flour, 30 g shortening (Sysco Corp., Houston, TX), 7.5 g salt (Morton International, Inc., Chicago, IL), 3 g sodium bicarbonate (Arm and Hammer, Church and Dwight Company, Inc, Princeton, NJ), 2.9 g sodium aluminum sulfate (Budenheim USA, Inc, Plainview, NY), 2.5 g sodium steroyl lactylate (Caravan Ingredients, Lenexa, KS), 2 g sodium propionate (Niacet Corp., Niagara Falls, NY), 2 g potassium sorbate (B.C. Williams, Dallas, TX), 1.65 g encapsulated fumaric acid (Balchem Corp., New Hampton, NY), 0.015 g cysteine (Fleischmann's Yeast, Inc., Burr Ridge, IL) and distilled water (10% less the farinograph water absorption of the sample). Cysteine was used to improve dough machinability and tortilla quality (Pascut et al., 2004).

2.3. Evaluation of dough properties

Dough rheological properties were analyzed with a texture analyzer (Model TA-XT2i, Texture Technologies Corp., Scarsdale, NY/Stable Micro Systems, Godalming, Surrey, UK) using the texture profile analysis (TPA), stress relaxation and dough/gluten extensibility methods. For TPA, a dough ball (height = 2.1 cm, diameter = 5.2 cm, weight = 45 g) was compressed twice to 70% of its original height with a 10-cm cylindrical probe. The test speed was 10 mm/s with an interval time of 5 s between the two compression cycles. The parameters quantified were hardness, cohesiveness, adhesiveness and springiness (Barros, 2009).

For the stress relaxation test, a dough ball (same geometry as TPA) was compressed with a 10-cm cylindrical probe at 10 mm/s, and a force of 80 N that was held for 100 s. The parameter measured was relaxation time, which is the time it takes for the maximum force to decay by 36.8% (Barros, 2009; Steffe, 1996).

Dough and gluten extensibility were measured following the method of Smewing (1995), which uses the Kieffer dough and gluten extensibility rig, with modifications in sample preparation. After proofing the dough balls for 10 min at 32–35 °C and 70–75% RH, 20 g was taken from one dough ball and rolled into a cylindrical shape and placed into the Teflon molds to form the strips for analysis. Gluten was isolated by hand washing according to AACC Method 38-10 (AACC International, 2000). The parameters measured were extensibility and dough resistance to extension.

2.4. Evaluation of tortilla properties

Ten tortillas from each batch were randomly selected after one day of storage and measured for diameter. Likewise, two tortillas from each batch were randomly selected and measured for color using a chromameter (model CR-300, Minolta Camera Co., Ltd., Chuo-Ku, Osaka, Japan). Values for L^* (brightness or whiteness), a^* (redness and greenness), and b^* (yellowness and blueness) were measured from four different spots of each tortilla. Texture analyses were conducted after 0, 4, 8 and 12 days of storage using a TA.XT2i Texture Analyzer (Alviola et al., 2008). The deformation modulus, work, maximum force and distance needed to rupture the tortillas were obtained.

2.5. Statistical analysis

Single correlation coefficients (Pearson's correlation) were determined to investigate the relationships between wheat grain, flour and dough/gluten properties and tortilla quality indicators. Stepwise multiple regression was performed to develop prediction models using grain, flour and dough/gluten rheological properties as independent variables. A significance level entry of 0.05 and a significance level removal of 0.10 were used. The models were evaluated by the coefficient of determination (R^2) and root mean square of error (RMSE). All tests were done in three replications. SPSS v14.0 for Windows (SPSS Inc., Chicago, IL) was used for all statistical tests.

3. Results and discussions

3.1. Correlations between predictor variables and tortilla quality parameters

The means, standard deviations, minimum and maximum values of the independent (grain, flour, dough properties) and dependent (tortilla L^*, diameter, specific volume, and texture parameters) variables used in the analyses are presented in Tables 1 and 2, respectively.

Tortilla L^* value correlated positively with flour L^* value ($P < 0.01$, Table 3); whiter wheat flours yielded whiter tortillas. Tortilla diameter correlated negatively ($P < 0.01$) with gluten index, insoluble polymeric proteins (IPP), farinograph and mixograph parameters, dough resistance to extension and springiness, and correlated positively with dough extensibility. All these independent parameters are related to wheat protein quality, which is mainly determined by gluten content and quality. Gluten index (GI) is a measure of gluten strength where weak doughs have GI < 50 and very strong ones have GI > 80. IPP, like GI, is a protein quality indicator that correlates better than protein content to loaf volume, bake mix time and mixing tolerance (Bean et al., 1998). Park et al. (2006) and Ohm and Chung (1999) likewise reported correlations of IPP and GI with bread-making properties, respectively.

Table 2
Means, standard deviations (SD), and minimum and maximum values of flour tortilla properties from the 16 wheat samples.

	Mean ($n = 16$)	SD	Min	Max
Tortilla L^* value	83.71	1.04	81.97	85.43
Diameter (mm)	166	7	151	173
Specific volume (cm^3/g)	1.44	0.12	1.27	1.61
Deformation modulus (N/mm)				
Day 0	0.50	0.10	0.34	0.71
Day 12	0.99	0.14	0.78	1.28
Rupture force (N)				
Day 0	8.17	0.81	6.90	9.59
Day 12	7.45	1.37	5.19	9.60
Rupture distance (mm)				
Day 0	21.69	2.03	18.25	25.50
Day 12	11.14	1.05	9.75	13.75
Work (Nmm)				
Day 0	70.89	16.00	46.50	103.50
Day 12	31.80	9.33	19.00	53.50

Farinograph and mixograph tests provide information on dough development time and tolerance of dough to mixing or processing. The mixograph mixing time, which correlates with gluten strength, gave the highest correlation for tortilla diameter ($r = -0.87$, $P < 0.01$). This high correlation is advantageous because this test is fast and requires a small amount of sample. The mixograph and farinograph have been used by numerous researchers to develop prediction models for dough and bread-making properties, incorporating multiple parameters available in the mixing curves into statistical models (Stojceska and Butler, 2008). Qarooni et al. (1994) found mixograph water absorption to be correlated ($r = 0.76$) with tortilla quality score, and developed a prediction model for tortilla quality score with an $R^2 = 0.64$ incorporating mixograph and farinograph parameters.

Aside from protein quality, tortilla diameter correlated with protein content but to a lower extent ($P < 0.05$, Table 3). In general, the higher the protein content, the smaller the diameter. Waniska et al. (2004) also reported a negative correlation between protein content and tortilla diameter. In tortilla processing, high protein content and strong gluten wheats are undesirable because these generally give dough that shrinks back during hot-pressing, resulting in tortillas with small diameters, which are thicker and more dense (Pierucci et al., 2009; Waniska et al., 2004). Thus, intermediate protein content and protein quality were recommended to be included as flour requirements to yield good quality tortillas (Waniska et al., 2004). Commercial manufacturers resolve the problem of strong gluten by adding reducing agents and other dough conditioners such as enzymes.

Specific volume, which takes into consideration the thickness, diameter and weight of tortillas, approximates fluffiness. Consumers in general prefer puffed tortillas over dense, 'heavy' ones (Waniska, 1999). Specific volume also correlated with most of the protein quality-related parameters that were highly correlated with tortilla diameter (Table 3).

The 2-D extensibility test of tortillas documents the texture changes that occur during storage, specifically giving the following parameters: deformation modulus (ratio of rupture force and distance taken at the linear region of the curve), rupture force,

Table 3
Correlation values of flour physico-chemical characteristics and rheological properties with tortilla quality parameters.

Flour and dough properties	Flour tortilla quality parameters										
	L^* value	Diameter	Sp. volume	Modulus (0 d)	Modulus (12 d)	Force (0 d)	Force (12 d)	Distance (0 d)	Distance (12 d)	Work (0 d)	Work (12 d)
Dry gluten (%)											0.52*
Gluten index		−0.67**	−0.73**	0.50*							
Flour L^*	0.67**										
Flour a^*								−0.71**			
Flour b^*								0.57*			
Protein content (%)		−0.53*				0.53*	0.65**		0.85**	0.57*	0.75**
IPP (%)	−0.50*	−0.70**	−0.72*	0.50*		0.71**	0.62**		0.62*	0.74**	0.61*
Development time (min)		−0.79**	−0.57*			0.61*	0.58*		0.69**	0.74**	0.62*
Stability time (min)		−0.82**	−0.71**			0.69**	0.74**		0.84**	0.62*	0.84**
Breakdown time (min)		−0.82**	−0.65**			0.76**	0.68**		0.85**	0.72**	0.82**
Farinograph tolerance index		0.83**	0.68**			−0.78**	−0.59*		−0.66**	−0.74**	−0.67**
Mixing time (min)		−0.87**	−0.70**			0.57*	0.66**		0.59*	0.57*	0.64**
Mixograph tolerance index		−0.85**	−0.64**			0.54*	0.60*		0.59*	0.58*	0.61*
Dough resistance to extension (N)		−0.86**	−0.85**	0.72**		0.85**	0.77**		0.62*	0.69**	0.76**
Dough extensibility (mm)		0.74**	0.64**	−0.58*	−0.55*	−0.85**	−0.70**			−0.72**	−0.60*
Gluten resistance to extension (N)		−0.56*				0.52*				0.54*	
TPA cohesiveness		−0.53*									0.54*
TPA adhesiveness		0.57*	0.58*			−0.58*					
TPA springiness		−0.83**	−0.76**	0.63**		0.65**	0.77**		0.63**	0.52*	0.80**
Relaxation time (s)		−0.57*	−0.74**	0.53*		0.52*	0.57*				0.61*

*Correlation is significant at the 0.05 level; **Correlation is significant at the 0.01 level; modulus, force, distance, and work are tortilla texture properties taken after 0 and 12 days of storage; IPP = insoluble polymeric proteins.

distance and work. These parameters provide a profile of the increase in firmness and loss of extensibility or flexibility of tortillas with time. This method significantly correlates with the subjective rollability test that approximates the shelf-stability of tortillas (Bejosano et al., 2005).

Deformation modulus from fresh tortillas (day 0) positively correlated with gluten index, IPP, dough resistance to extension, springiness and relaxation time; and negatively correlated with dough extensibility (Table 3). After 12 days, deformation modulus correlated with dough extensibility. Days 0 and 12 of rupture force and work, and day 12 of rupture distance correlated with protein content, IPP, farinograph and mixograph parameters, dough resistance to extension and springiness.

Among the parameters considered, grain properties (hardness, weight, diameter), % wet and dry gluten, glutenin–gliadin ratio, HMW–LMW GS ratio and flour particle size did not significantly correlate with any of the tortilla quality parameters. Rheological parameters gave more significant correlations with tortilla quality.

The work of Waniska et al. (2004) is so far the only one that used a large number of commercial flour samples ($n = 61$) to determine the effect of flour properties on tortilla quality. Tortilla diameter negatively correlated with protein content, starch damage, sedimentation volume, IPP and mixograph water absorption. Tortilla shelf-stability (number of days before the subjective rollability score reached 3), on the other hand, positively correlated with protein content and starch damage. Our study took it a step further by determining grain, flour or dough properties that can predict tortilla quality parameters (i.e., determine properties that will significantly explain the variability observed in tortilla quality parameters).

3.2. Development of prediction models

Good quality tortillas are opaque, flexible, well puffed, with large consistent diameters (Waniska, 1999). Thus, the tortilla quality dependent variables used were L^* value (replacing the subjective opacity values), diameter, and specific volume, together with tortilla deformation modulus, maximum force, work and rupture distance taken on day 0 (fresh) and day 12 (stale).

The prediction equation models were developed by stepwise multiple regression analysis in three ways, namely: (a) using all grain, flour and dough parameters, (b) using only grain and flour properties, and (c) using only the rheological parameters. Prediction equations with an R^2 value greater than 0.7 were considered (Table 4). Moreover, equations with less parameters, and those with easy-to-measure parameters were given priorities.

3.2.1. Tortilla diameter

Mixograph mixing time and dough resistance to extension were the best predictors for tortilla diameter with an R^2 of 0.86 and RMSE was 2.6 (Table 4). When only grain and flour variables were used, insoluble polymeric proteins (IPP), gluten index and protein content were the variables that gave the best model ($R^2 = 0.84$, RMSE = 2.9).

Rheological properties explained tortilla diameter slightly better. Mixograph mixing time by itself provided a R^2 of 0.75. The model was optimized by adding dough resistance to extension. Both of them were negatively correlated with tortilla diameter ($r = -0.87$ and -0.86 respectively, $P < 0.01$). Gluten extensibility parameters were less desirable predictors of tortilla quality relative to dough extensibility properties. This implies that other wheat flour components like starch, non-starch polysaccharides and lipids contribute to overall tortilla quality aside from gluten (Alviola and Waniska, 2008; Alviola et al., 2008).

The best fit regression model for predicting tortilla diameter using rheological parameters was

$$\mathrm{TD} = 191.99 - 3.29(\mathrm{MT}) - 35.04(\mathrm{DRE}) \quad (1)$$

where TD is tortilla diameter, MT is mixograph mixing time and DRE is dough resistance to extension.

3.2.2. Tortilla L^* (to approximate opacity)

Flour L^*, gluten index and protein content were the independent variables in the prediction equation model for color using the grain and flour properties ($R^2 = 0.88$, RMSE = 0.40; Table 4). However, when all variables were used, flour L^* and dough resistance to extension gave a slightly better model, with $R^2 = 0.89$ and RMSE = 0.38.

Table 4
Regression analysis results.

Flour tortilla quality parameters	Groups								
	All grain, flour and dough parameters			Grain and flour properties only			Rheological parameters only		
	Variable entered	R^2	RMSE	Variable entered	R^2	RMSE	Variable entered	R^2	RMSE
Physical									
Diameter	Mix time and DRE	0.86	2.60	IPP, GI and protein	0.84	2.9	Mix time and DRE	0.86	2.6
L^* value	Flour L^* and DRE	0.89	0.38	Flour L^*, GI and protein	0.88	0.40	–		
Specific volume	DRE, particle size and GI	0.90	0.04	GI, IPP and dry gluten	0.89	0.04	DRE and RT	0.81	0.05
Rheological									
Rupture force (0 d)	DRE	0.73	0.44	IPP and SKH	0.73	0.45	DRE	0.73	0.44
Work (12 d)	ST, protein and SKH	0.87	3.8	Protein and GI	0.80	4.51	ST	0.71	5.19
Rupture distance (12 d)	Protein and ST	0.90	0.35	Protein	0.72	0.58	ST	0.70	0.60

RMSE = root mean square error.
DRE = dough resistance to extension; GI = gluten index; IPP = insoluble polymeric protein; RT = relaxation time; ST = stability time; SKH = single-kernel hardness.
– = No variable met the 0.05 significance level for entry into the model.

The best fit regression model for predicting tortilla L^* using all variables was

$$TL = -128.47 + 2.33(FL) - 7.75(DRE) \quad (2)$$

where TL is tortilla L^*, FL is flour L^* and DRE is dough resistance to extension.

3.2.3. *Specific volume*

Dough resistance to extension, particle size and gluten index were the best predictors for tortilla specific volume when all variables were used ($R^2 = 0.90$, RMSE = 0.04; Table 4). Gluten index, IPP and dry gluten were the predictors when only grain and flour properties were used ($R^2 = 0.89$, RMSE = 0.04). Dough resistance to extension and relaxation time were the predictors when only rheological parameters were used ($R^2 = 0.81$, RMSE = 0.05).

The best fit regression model for predicting specific volume, using all variables, was

$$SV = 2.90 - 0.90(DRE) - 0.02(PS) - 0.01(GI) \quad (3)$$

where SV is specific volume, DRE is dough resistance to extension, PS is particle size and GI is gluten index.

3.2.4. *Deformation modulus*

No prediction model for deformation modulus (both days 0 and 12) had R^2 values higher than 0.70, thus they were not considered.

3.2.5. *Rupture force*

Predictors were found for rupture force at day 0, but not for day 12. Dough resistance to extension was the best predictor when all variables and when only rheological parameters were used ($R^2 = 0.73$, RMSE = 0.44; Table 4). IPP and single-kernel hardness were the predictors when only grain and flour properties were used ($R^2 = 0.73$, RMSE = 0.45).

The best fit regression model for predicting rupture force at day 0 using all variables was

$$RF(0) = 5.130 + 7.529(DRE) \quad (4)$$

where RF(0) is rupture force at day 0 and DRE is dough resistance to extension.

3.2.6. *Work to rupture*

Predictors were found for work to rupture at day 12, but not for day 0. Stability time, protein content and single-kernel hardness were the predictors when all variables were used ($R^2 = 0.87$, RMSE = 3.8; Table 4). Protein content and gluten index were the predictors when only grain and flour properties were used ($R^2 = 0.80$, RMSE = 4.51), while stability time was the best predictor when only rheological parameters were used ($R^2 = 0.71$, RMSE = 5.19).

The best fit regression model for predicting work at day 12 using all variables was

$$W(12) = -20.29 + 0.80(ST) + 4.48(PC) - 0.25(SKH) \quad (5)$$

where W(12) is work at day 12, ST is stability time, PC is protein content and SKH is single-kernel hardness.

3.2.7. *Rupture distance*

Predictors were found for rupture distance at day 12, but not for day 0. Protein content and stability time were the predictors when all variables were used ($R^2 = 0.90$, RMSE = 0.35; Table 4). Protein content was the best predictor when only grain and flour properties were used ($R^2 = 0.72$, RMSE = 0.58), and stability time was the predictor when only rheological parameters were used ($R^2 = 0.70$, RMSE = 0.60).

The best fit regression model for predicting rupture distance at day 12 using all variables was

$$RD(12) = 0.85 + 0.73(PC) + 0.08(ST) \quad (6)$$

where RD(12) is rupture distance at day 12, PC is protein content and ST is stability time.

3.3. *Validation of prediction models*

Data from 18 wheat flours from the 2008 Wheat Quality Council (WQC) evaluations were used to validate the prediction models developed using the 2007 WQC samples (first sample set). Only the best model (highest R^2) for each tortilla quality parameter was validated. The range of values used to validate the prediction models was: dough resistance to extension = 0.37–1.33 N, mixograph mix time = 2.4–9.4 min, stability time = 8.1–39.7 min, protein content = 9.3–12.8%, particle size = 17.5–23.3 μm, flour L^* = 91.99–93.22, gluten index = 66.1–99.3 and single-kernel hardness = 52.3–85.3.

The correlation between the predicted and observed values was highly significant ($P < 0.01$) for all tortilla quality parameters. Tortilla diameter had the best correlation of 0.96, followed by rupture distance at day 12 ($r = 0.86$), work at day 12 ($r = 0.81$), maximum force at day 0 ($r = 0.80$), tortilla L^* ($r = 0.79$) and specific volume ($r = 0.75$). These high correlation values validate that the models can predict the tortilla quality parameters well. Among the three texture parameters, rupture distance may be the most relevant in terms of measuring the loss of flexibility of tortillas with time. It is the distance up to which the tortilla extends before breaking. Fresh tortillas, which do not tear easily, have higher rupture distance values than stale tortillas.

3.4. Applications and limitations

Currently, the suitability of wheat lines for tortilla production is done by milling the wheat, evaluating the flour, and processing it into tortillas. The process from wheat milling to tortilla evaluation takes about 90 h, which is distributed over 4 weeks. Moreover, it requires at least 1 kg of flour to do all the tests. This makes the wheat line screening process time-consuming, labor-intensive and costly (Ibrahim, A.M.H. pers. comm.).

Developing prediction equations is one approach to make this screening process more efficient. For example, from our results, one can predict tortilla diameter from any given flour by having the mixograph mixing time and dough resistance to extension values. Both parameters are determined using tests that are easy and require a small amount of flour sample. Moreover, the mixograph test can be completed in a short time and is already widely used in academia and the industry.

Aside from tortilla diameter, the dough resistance to extension can also predict (alone or with another parameter) tortilla L^* value, specific volume and rupture force at day 0. The extensibility test that is used to determine this parameter is done with a texture analyzer, and has the advantage of good repeatability. The only drawback is the 40 min resting time of the dough, but this is remedied by preparing dough samples one after another (instead of waiting to complete one sample).

Among the flour parameters, protein content, IPP and GI provided high correlation with some tortilla qualities and good prediction models. These parameters are determined using simple methods and a small amount of sample, which are criteria needed in screening wheat lines for tortilla quality. Thus, these parameters can be used as predictors of tortilla quality in wheat breeding programs.

Having predictors for texture parameters is advantageous. Another important tortilla parameter is shelf-stability, which is measured by a subjective rollability test. This test gives information on the number of days the tortilla can be used without breaking or cracking upon rolling. Having a predictor for this parameter is thus important.

4. Conclusions

Prediction models, with high R^2 and low root mean square error (RMSE), were obtained using simple regression equations. These models make it possible to predict physical and rheological tortilla quality parameters by just determining specific flour and dough properties. This will help breeders and tortilla companies save time in selecting wheat to make high quality tortilla.

The dough resistance to extension can predict the most number of tortilla parameters, namely: diameter, L^* value, specific volume and rupture force. This makes the extensibility test an important and reliable method in selecting promising wheat samples. Fitting mixograph mixing time values into the model will give approximate diameter measurements. Farinograph stability time and protein content are excellent predictors for texture properties, specifically rupture distance and work. When considering only flour properties to develop the models, insoluble polymeric proteins, gluten index and protein content are the parameters that are the best predictors of tortilla quality.

Acknowledgements

We sincerely thank the Wheat Quality Council for the wheat samples used in this study, and for allowing us to use their 2007 and 2008 data. We gratefully acknowledge the various suppliers for the ingredients, and the Texas Wheat Producers Board and Texas A&M AgriLife Research for the financial support.

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