Revista Mexicana de Ciencias Agrícolas
REMEXCA
DOI: https://doi.org/10.29312/remexca.v16i4.3702
Article

Rheological variations and industrial quality of bread wheat in Sonora

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Abstract

Wheat represents about 12% of the total value of agricultural imports in Mexico; it is mostly used to make bread, pasta, cookies, and flour tortillas. The research aimed to determine the rheological variation in dough and industrial quality of 12 advanced lines of bread wheat. The experiment was established in the Yaqui Valley under a randomized complete block design with three replications at an average temperature of 17.1 °C. The unit consisted of four rows 3 m long and 80 cm apart in double rows, on two sowing dates of the 2020-2021 agricultural cycle. The variables assessed were hectoliter weight and weight of one thousand grains, protein in flour, strength, tenacity/extensibility, grain hardness, and bread volume. The results show statistical differences between the main factors (dates, lines) and their interaction in all variables; the functional properties in flour and values in selection indices favored L-5, L-2, L-3, L-7, and Borlaug; a positive correlation was found between physical and chemical traits. In conclusion, sowing in November favored the concentration of protein in the grain and associated with strong and extensible dough, it showed higher volumes of bread.

Palabras clave:

Triticum aestivum, industrial quality, rheological properties.

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Introduction

Wheat is the third most valuable product in Mexico's agricultural imports, with about 12%, only behind soybeans and yellow corn; mostly from the United States. It is an important product in the baking industry since, due to its nutritional quality, it is used to make bread, pasta, cookies, and flour tortillas (Guerrini *et al*., 2020), as it contains up to 12.6% protein, 350 × 10^{-4} J of dough strength, 1.2 of tenacity-extensibility ratio, and 842 ml of bread volume (Canimolt, 2022). In addition, its importance also lies in its byproducts, both artisanal and industrial.

The development, production, and quality of wheat, as in other cereals, is influenced by environmental factors, mainly temperatures and sowing dates. Although the cooling needs are not similar for all varieties, those between 10 and 24 °C obtain better grain yield and industrial quality (CONAGUA, 2021).

During the 2022 agricultural cycle, 3.6 million tons of wheat were produced in Mexico (2.08 million crystalline wheat and 1.52 bread wheat), with average yields of 6.61 t ha^{-1} (SIAP, 2022). During this same cycle, 57% of the national production was produced in Sonora, which ranked first with 2.08 million tons (1.76 million tons of crystalline wheat and 258 000 t of bread wheat) (SIAP, 2022). Bread wheat is economically and socially relevant in Sonora since its consumption is mostly local, whereas crystalline wheat tends to be exported. In the end, this factor is of utmost importance to have new flour germplasm that can be established in a larger area and meet the specific milling needs (SIAP, 2022).

Wheat is classified according to its quality, which depends directly on the type of gluten, the byproducts derived from the flour, and the functional properties of the latter to make doughs with greater tenacity and less extensibility (Parenti *et al*., 2019). Studies such as Liu *et al*. (2019) contribute to the improvement in the quality of grains and the obtaining of products with traits for industrial purposes. In addition, based on these studies, it was determined that agronomic management significantly affects the chemical composition of the grain, therefore, the rheology of the dough and ultimately, the industrial quality are also affected (Cappelli *et al*., 2020). Due to the above, the objective of this research was to determine the rheological variation in dough and industrial quality of 12 advanced lines of bread wheat.

Materials and methods

Genetic material and development of the experiment

The trials were established in the experimental field of the National Technological Institute of Mexico-Yaqui Valley, in Ciudad Obregón, Sonora, Mexico (27° 24' 51" latitude, 100° 75' 2" longitude and altitude of 13 m). The predominant climate is BW (h), very hot extreme; the average annual temperature is 24°C and the average maximum is 31°C, between July and August, the maximum is 48 °C and in January, the minimum is 16 °C; average rainfall of 450 mm $year^{-1}$. The arable soils are loamy (21.96% clay, 46.04% sand, 32% silt and 0.86% organic matter) (García, 1973).

The work began in autumn-winter 2019-2020 by evaluating 276 advanced lines of bread wheats (trial 52 IBWSSN-131) provided by the International Maize and Wheat Improvement Center (CIMMYT). In this assessment, 12 lines with agronomic traits such as physiological maturity, grain yield, plant height, number of spike, weight of one thousand grains, and hectoliter weight stood out (Table 1). The sowing was on two dates (October 20 and November 20), taking the Borlaug F100 commercial variety as a control to evaluate its variation in dough and industrial quality (Table 2).

Table 1. Average of bread wheat lines that excelled in autumn-winter, 2019-2020, in the Yaqui Valley, Sonora.

Line	GY (t ha^{-1})	PM (days)	PH (cm)	NS (num.)	WTG (g)	HW (kg hl^{-1})
L-1	4.83	121.5	91	713	31	79.3

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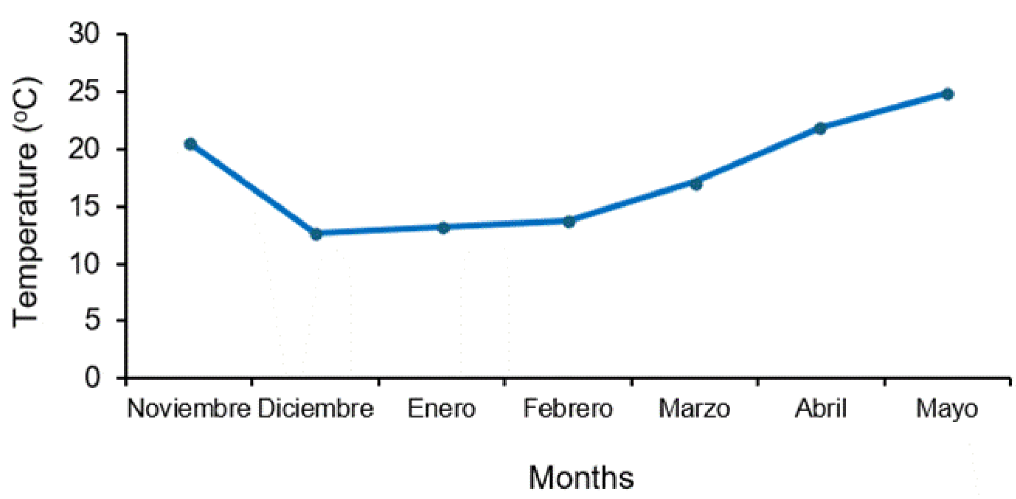
Line	GY (t ha^{-1})	PM (days)	PH (cm)	NS (num.)	WTG (g)	HW (kg hl^{-1})
L-2	5.54	131	101.5	813.5	31.5	79.05
L-3	4.9	125.5	98.5	745.5	30.5	78.15
L-4	6.12	129.5	102.5	894	32.5	79.3
L-5	7.33	130	100.5	1014.5	33.5	81.8
L-6	4.89	128.5	91.5	718	30.5	74.9
L-7	4.34	123.5	91.5	854.5	29.5	71.75
L-8	5.97	130.5	104	693.5	32.5	79.8
L-9	4.19	124.5	94	858.5	30.5	75.5
L-10	5.4	125	94.5	804.5	32	79.45
L-11	4.94	127.5	96.5	854	31	77.5
L-12	5.57	131	103	949.5	31.5	78.5
Borlaug F100	6.38	130.5	102	976.5	34	80.3
Mean	5.41	127.58	97.77	837.65	31.58	78.1

Table 2. Genealogy of bread wheats assessed at the TecNM-Yaqui Valley, Sonora, Mexico, for industrial quality.

Line	Genealogy	Line	Genealogy
L-1	CMSS07Y01083T-099TOPM	L-8	CMSS12Y00163S-152M-099NJ-3
L-2	CMSS10Y00374S-099M-1WGY-0B	L-9	CMSS12Y00235S-099Y-099N
L-3	CMSS10Y00023S-099Y-4WGY	L-10	CMSS12Y00276S-099Y-0WGY
L-4	CMSS12Y00031S-38Y-0WGY	L-11	CMSS12Y00276S-099Y-0WGY
L-5	CMSS12Y00064S-130M--0WGY	L-12	CMSS12Y00276S-099Y-16Y
L-6	CMSS12Y00069S-119Y-20Y	Control	Borlaug F100
L-7	CMSS12Y00070S-112M-21Y		

The experimental unit was established with four furrows three meters long and 80 cm apart, formed in a double row, to have a useful area of 9.6 m^2. The experiment was conducted under irrigation conditions in randomized blocks with three replications. Figure 1 shows the temperatures during the planting cycle.

Figure 1. Temperatures during the establishment of the experiment in the Yaqui Valley 2020-2021.



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Development in the laboratory

The varieties of analysis were hectoliter weight (kg hl^{-1}), in a sample of 500 ml of grain on a volumetric balance (Seedburo Equipment Co., Chicago, IL.), weight of one thousand grains, in triplicate by counting grains and weighing them (g) on a digital scale. These were defined in CIMMYT industrial quality laboratory. On the other hand, the strength (W) and the tenacity/extensibility ratio (PL) of the dough were calculated from the alveograph obtained from 60 g of refined flour using Chopin's alveograph (Tripette and Renaud, France) with the method 54-30A of AACC (2005).

Finally, the protein in flour was established by the Kjeldahl method through the determination of organic nitrogen, which consisted of directing the proteins in a mixture with sulfuric acid in the presence of catalysts; the digested mixture was neutralized with a base and subsequently distilled; in the distillate, it was collected in a boric acid solution; the anions of the borate thus formed are titrated with standardized HCl to determine the nitrogen contained in the sample.

Statistical analysis

An analysis of variance was performed using the PROC GLM procedure of the SAS statistical package version 9.4 (2012). When significant differences were found, the comparison of means was carried out through the least significant difference test, LSD, ($p\leq 0.05$). To discriminate the lines, the selection indices were estimated; for the selection of lines among the industrial quality properties, the indices were constructed based on the methodology proposed by Barreto *et al*. (1991). This is efficient for the simultaneous selection of several characteristics, the formula used to estimate the index was as follows:

$$SI=\left\{\left[(Y_j-M_j)^{2}*I_j\right]+\left[(Y_i-M_i)^{2}*I_i\right]+\ldots\ldots\left[(Y_n-M_n)^{2}*I_n\right]\right\}^{\frac{1}{2}}$$

Where: SI= selection index; Y= variable; M= selection goal; I= intensity of selection.

The selection goal was assigned to each variable, reporting the units of average standard deviation desired in the selection, that is, values from -3 to +3. With a negative value will be those that are below the average, with a positive value will be those that are higher than the average, and those close to the average will use values of zero.

The intensity of selection is the degree of importance assigned to each selected variable, which takes values from one to 10. During the development of the crop, there were temperatures of 14 °C below in the tillering and flowering stages (Figure 1). The smallest intensity value (1) was assigned to the variable of least interest and the highest value (10) represented the variable of greatest importance; for HW (10), WTG (9), protein (10), strength (5), PL (10), GH (5), and BV (8).

The variables included were found with different values in (%), ml g^{-1}, etc., so it was necessary to standardize all of them, so that the traits could be combined using this formula. Where: Z= standardized value; j= observed value for each hybrid j; y= average of all lines; s= standard deviation of the group of lines.

Regarding the standardized value of the variables, the closer to the desired goal, the smaller the value of the selection index and the closer to the desired criteria lines. Conversely, the larger the value of the index, the further away the lines were from the expected results. Lines with a smaller selection index were considered superior as they had most of the traits required in the selection. The construction of the indices considered higher protein, good extensibility, and tenacity of the flours and good volume of bread, that is, that they were strong flours for bakery production.

Results and discussion

The analysis of variance showed significant differences ($p\leq 0.01$) in the effects of the main lines (L), dates (D) and interaction (L*D) in all the variables assessed. According to Zhang *et al*. (2016); Ramírez et al. (2021), these contrasts are due to the genetic constitution of the lines and the established sowing date (Table 3).

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Table 3. Mean squares for physical and industrial quality traits of bread wheat in the Yaqui Valley, Sonora, Mexico.

	DF	HW (kg hl^{-1})	WTG (g)	Strength ($\times 10^{-4}$ J)	PL (0.1-6)	GH	BV (ml g^{-1})
Replication	2	7.51	2.51	44.47	0.22	30.27	1 845.94
Line	12	5.42**	32.12**	47 546.53**	1.11**	24.9**	1 2041.99**
Date	1	0.86*	26.66**	10 593.35**	1.23*	587.13**	2 832.05**
Line*date	12	4.87**	14.25**	2 938.82**	0.57*	65.83*	2 658.16**
Error	50	0.84	0.05	0.71	0.17	0.33	935.03
Total	77	2.36	7.67	8 007.04	0.4	22.1	2 982.8
CV (%)		11.14	9.44	10.31	10.27	14.32	15.13

*, **= significant and highly significant (α= 0.05); ns= not significant; CV= coefficient of variation; DF= degrees of freedom; HW= hectoliter weight; GH= grain hardness; PF= protein in flour; W= dough strength; P/L= tenacity/extensibility ratio; BV= bread volume.

According to Ramírez *et al*. (2021), the temperature requirements in bread wheat are between 15° and 23 °C. In our study, in the tillering, flowering, and grain-filling stages, there were temperatures of 14.6, 14.2 and 16.2 °C, respectively; these data were favorable for the development of the crop and to obtain good industrial quality. Similar results were achieved by Ramírez *et al*. (2021); Weiwei *et al*. (2015), who mentioned the genetic expression in the characteristics of the lines. In addition, Gauch and Zobel (1997) concluded that the environment is the most important component in the differentiation of all variables.

Line behavior

The accumulation of cold hours is important in wheat crops. During the agricultural cycle, temperatures of 14.6 °C were recorded, which allowed a good development of the crop. Thus, the sowing date of November 20 presented better behavior in all variables (Table 4), influencing climatic conditions during the development of the crop, accumulating an average of 796 cold hours (CONAGUA, 2021). On the other hand, accumulating less than 500 hours entails the risk of obtaining unacceptable yields and losing industrial quality.

Table 4. Average performance among lines in industrial quality of bread wheat in the Yaqui Valley, Sonora, Mexico.

Line	HW (kg hl^{-1})	WTG (g)	Protein (%)	W ($\times 10^{-4}$ J)	PL (0.1-6)	TG	BV (ml g^{-1})
L-1	80.35 cd	45.43 j	12.81 f	305.56 d	1.85 c	2 b	775.83 a
L-2	79.62 ef	46.98 i	12.97 e	232.27 g	2.28 b	1 c	750.83 a
L-3	80.45 c	50.93 c	11.51 j	231.66 g	2.41 a	1 c	651.15 cd
L-4	80.65 c	47.61 g	13.68 b	323.82 c	1.38 f	2 b	773.67 a
L-5	81.88 a	52.31 a	13.75 a	486.67 a	1.11 i	3 a	796.36 a
L-6	80.11 d	49.98 d	12.41 i	282.53 e	1.53 d	1 c	758.17 a
L-7	79.41 fg	47.23 h	12.58 h	161.58 j	0.83 k	2 b	603.67 d
L-8	80.61 c	44.88 k	12.68 g	223.67 h	0.81 k	2 b	725.83 abc
L-9	80.45 c	47.18 hi	12.74 g	203.36 i	1.31 g	2 b	738 ab
L-10	79.21 g	49.43 e	13.73 d	247.33 f	1.46 e	2 b	758.33 a
L-11	79.31 fg	48.33 f	13.41 c	322.66 c	1.18 h	2 b	773.36 a
L-12	79.76 e	48.38 f	12.86 ef	152.36 k	0.68 l	2 b	668.17 bcd
Borlaug F100	81.05 b	52.01 b	14.08 a	343.73 b	0.91 j	3 a	783.33 a

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Line	HW (kg hl^{-1})	WTG (g)	Protein (%)	W (× 10^{-4} J)	PL (0.1-6)	TG	BV (ml g^{-1})
LSD (0.05)	0.32	0.24	0.32	0.24	0.06	0.98	0.05
Sowing date							
November 20, 2020	80.41 a	51.36 a	13.04 a	281.9 a	1.51 a	1.92 a	745.23 a
December 202020	78.25 b	48.25 b	12.86 b	258.64 b	1.22 b	1.92 a	724.9 b
LSD (0.05)	1.86	2.81	0.11	19.38	0.14	2	18.87

W= strength; PL= tenacity/extensibility ratio; TG= type of gluten; BV= bread volume. LSD= least significant difference.

The weight (W) was a key parameter to evaluate the workability of the flours, and together with the volume acquired, it favored the obtaining of good bread. On this, Guerrini *et al*. (2020) point out that greater W and BV capacity will improve dough development and the quality of bread flours. In southern Sonora, less than 20% is planted with bread wheat, so, supported by the quality of the L-5, L-2, L-3, and L-1 lines, it is derived that, it can be an alternative to reconvert crops, with respect to crystalline wheat, which are established in 80% (Canimolt, 2022).

The highest protein content corresponded to line 5 and Borlaug F100 (13.75 and 14.08%), respectively, on both evaluation dates. Both genotypes are special for making bread, cakes, and flour tortillas; on this, Dang *et al*. (2020); Banfalvi *et al*. (2020) point out that wheats with more than 12% protein can be favorable in the baking industry because of their functional properties.

The strength variable (W) allowed the lines to be classified into different ranges: 1) L-5 (486.67 × 10^{-4} J), Borlaug (343.73 × 10^{-4} J), and L-4, L-11, L-1, and L-6, which had values higher than 330 × 10^{-4} J, desirable for making bread and cakes; and 2) lines L-10, L-2, L3, L-8, L-9, L-7, and L-13, below 270 × 10^{-4} J, for products with long fermentation and cold processes, for example, cookies and flour tortillas (Guerrini *et al*., 2020).

In P/L, most lines showed values above 0.9. In particular L-5 and Borlaug (1.11 and 0.9, respectively), special for cakes and breads; whereas L-7, L-8, and L-12 for cookies and puff pastries due to their values below 0.9 (Canimolt, 2022). The highest bread volumes were combined with W= 486.67, 343.73 × 10^{-4} J, and balanced to extensible due to their P/L= 1.11 and 0.9 as strong doughs due to the sowing date. L-7, L-8, and L-12 were less than 0.8, as tenacious doughs.

These results are consistent with Cappelli *et al*. (2020); Dang *et al*. (2020), who claim that higher values in gluten strength and bread volumes favor extensibility and give greater yield in the dough. Thus, L-5 and Borlaug presented strong gluten, for use in the mechanized baking industry (sliced bread); 30.7% of the lines (L-1, L-2, L-3 ,and L-6) show a soft texture with values of 1, for the artisanal sector or mixtures with strong gluten flours, 61.5% of medium or tenacious gluten (values of 2), due to their high tenacity, they are for semi-mechanized use (tortilla and cookies).

In PL, genotypes must have extensibility ranges between 0.2 and 1.3 for dough strength and viscosity (Canimolt, 2022). The L-1, L-2, L-3, L-6, L-8, and L-10 lines and Borlaug show high values, so they are considered special materials for making breads and long fermentation; whereas L-4, L-5, L-11, and L-12 are within the 0.8 range, feasible for very fast baking processes (Banfalvi *et al*., 2020).

To cushion the effects of the sowing dates (November and December), it is advisable to use one of the seven best-evaluated lines (L-1, L-2, L-3, L-6, L-8, L-10, and Borlaug), preferably L-8 since it obtained averages of 2.7 in PL, being excellent for bread (Boita *et al*., 2016; Konvalina *et al*., 2017; Guerrini *et al*., 2020).

The volumes found are higher than 760 and below 720, which decreases the industrial quality to achieve outstanding genotypes in bread volume (Cappelli *et al*., 2020; Dang *et al*., 2020). These traits are due to the accumulation of cold hours during the development of the crop: minimum 608.7, average 796, and maximum 823, temperatures below 14 °C during tillering and grain filling (INIFAP, 2022).

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Selection indices

Four lines with promising values were found: L-5, L-2, L-3, and L-7. They presented averages similar to Borlaug control. The lowest values (between 11.12 and 14.07) are competitive, compared with Borlaug, where the highest average HW was above 80.45 (kg hl^{-1}) (Table 5). Now, their advantage lies in the nutritional properties contained in the byproducts since all the physical and chemical variables are similar to the control (Estrada *et al*., 2015; Rodríguez *et al*., 2023).

Table 5. Simultaneous selection based on the selection indices between physical and chemical traits in bread wheat in the Yaqui Valley, Sonora, Mexico.

Line	HW (kg hl^{-1})	WTG (g)	Protein (%)	W (×10^{-4} J)	PL (0.1-6)	TG	BV (ml g^{-1})	Index
L-5	81.88	52.32	14.08	486.67	2.42	2	796	11.12
Borlaug F100	81.05	52.02	13.75	343	2.28	2	783.33	13.23
L-2	80.62	50.93	13.68	323	1.32	3	775.83	13.26
L-3	80.6	49.98	13.42	322.67	1.85	2	773	13.72
L-7	80.45	49	13	305.5	1.38	3	758.33	14.07
L-9	80.45	48.38	12.9	282.5	1.47	2	725.83	15.66
L-10	80.35	48.33	12.87	247.33	1.53	1	758.17	15.73
L-4	80.12	47.62	12.82	232	1.12	2	773.67	17.94
L-8	79.77	47.23	12.7	231.67	0.92	2	738	19.18
L-1	79.6	47.18	12.68	223	0.68	2	668.17	19.98
L-11	79.42	46.98	12.58	203	0.83	2	603.67	20.71
L-6	79.32	45.43	12.42	161.5	1.18	1	651	22.97
L-12	79.22	44.88	11.52	152	0.82	1	750.83	24.11
Mean	80.22	48.48	12.96	270.29	1.37	1.92	735.06	
SD	0.76	2.31	0.67	89.02	0.55	0.64	58.35	

W= strength; PL= tenacity/extensibility ratio; TG= type of gluten; BV= bread volume; SD= standard deviation; LSD= least significant difference.

Correlation between physical and chemical traits

Except for fiber, the correlation was significant in the rest of the agronomic and chemical variables (Table 6). HW was more associated with WTG, and the correlation between chemical traits was between 82 and 93%. As the protein increased, so did the proportions between chemical traits, especially strength and extensibility (PL). Making breads, flour tortillas, or biscuits with high protein content will have beneficial effects on human health (De Boni *et al*., 2019; Cappelli *et al*., 2020; Cappelli and Cini, 2021). In addition, temperatures below 14 °C in tillering and grain filling generate acceptable quality properties.

Table 6. Correlation between physical and chemical traits in bread wheats in the Yaqui Valley, Sonora, Mexico.

	WTG (g)	Protein (%)	W (× 10^{-4} J)	PL (0.1-6)	TG
HW (kg hl^{-1})	0.94*	0.85*	0.79*	0.74*	0.74*
WTG (g)		0.92*	0.82*	0.86*	0.92*
Protein (%)			0.82*	0.88*	0.82*
Strength (× 10^{-4} J)			0.93	0.92*	0.86*
PL (0.1-6)				0.89*	0.84*
TG					0.82*

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Conclusions

The rheological tests made it possible to know the functional properties of the bread wheat lines and classify them according to their use: flour for bread, pasta, and cookies, as well as their local demand due to the obtaining of unique cereals. November favored industrial quality and yield due to temperatures below 14 °C during the development of the crop. In addition, the protein concentration in the grain of the L-5, L-2, and L-3 lines was associated with strong and extensible doughs, presenting larger volumes of bread, similar to the averages of the Borlaug control. Nonetheless, the November percentages were higher in rheological properties.

Bibliography

1 AACC. 2005. American Association of Cereal Chemists. Approved methods of the AACC. 10th Ed. American Association of Cereal Chemists. St. Paul Minnesota, USA. 200 p.

2 Bánfalvi, A. B.; Németh, R. E.; Bagdi, A. A.; Gergely, S. M.; Rakszegi, M. L.; Bed#, Z. G.; Láng, L. J.; Vida, G. S. and Tomosközi, A. S. 2020. A novel approach to the characterization of old wheat (*Triticum aestivum* L.) varieties by complex rheological analysis. Journal of the Science of Food and Agriculture. 100(12):4409-4417. 10.1002/jsfa.10479.

3 Barreto, H. J.; Bolaños, J. A. and Córdoba, H. S. 1991. Programas índices de selección. guía para la operación del Software. Centro Internacional de Maíz y Trigo (CIMMYT). El Batán, Estado de México, DF. 27 p.

4 Boita, R. F. E.; Oro, T. A.; Bressiani, J. A.; Santetti, S. G.; Bertolini, E. T. and Hutkoski, C. L. 2016. Rheological properties of wheat flour dough and pan bread with wheat bran. Journal of Cereal Science. 71(1):177-182. 10.1016/j.jcs.2016.08.015.

5 CANIMOLT. 2002. Cámara Nacional de la Industria Molinera de Trigo. Reporte estadístico a 2022. 28 p.

6 Cappelli, A. N. and Cini, E. F. 2021. Opportunities in wheat flour, pasta, bread, and bakery product production chains: a systematic review of innovations and improvement strategies to increase sustainability, productivity and product quality. Sustainability. 13(5):1-16. 10.3390/su13052608.

7 Cappelli, A. N.; Oliva, N. B. and Cini, E. F. 2020. Stone milling versus roller milling: a systematic review of the effects on wheat flour quality, dough rheology, and bread characteristics. Trends in Food Science Technology. 97(1):147-155.

8 CONAGUA. 2021. Comisión Nacional del Agua. Estadísticas del agua en México. Edición primera . 360 p.

9 Dang, T. K.; Konvalina, L. P.; Capouchova, L. D.; Janovska, M. E.; Lacko, B. L. M. and Xuan, T. T. P. 2020. Comparative study on protein quality and rheological behavior of different wheat species. Agronomy. 10(11):1763. 10.3390/agronomy10111763.

10 De-Boni, A.; Pasqualone, A. E.; Roma, R. M. and Acciani, C. F. 2019. Traditions, health and environment as bread purchase drivers: a choice experiment on high-quality artisanal Italian bread. Journal of Cleaner Production. 221(1):249-260.

11 Estrada, P. W.; Lescay, B. E.; Álvarez, F. A. and Maceo, R. Y. C. 2015. Respuesta a la sequía de variedades de cebolla (*Allium cepa* L.) utilizando diferentes índices de selección. Revista Cultivos Tropicales. 36(3):75-81.

12 García, E. A. 1973. Modificaciones al sistema de clasificación climática de Köppen. Primera edición. 1-91 pp. http://cdigital.dgb.uanl.mx/la/1020081042/1020081042-011.pdf.

13 Gauch, H. G. and Zobel, R. W. 1997. Identifying mega-environments and targeting genotypes. Crop Science. 37(1):311-326. 10.2135/cropsci1997.0011183X003700020002x.

DOI: https://doi.org/10.29312/remexca.v16i4.3702

14 Guerrini, L. B.; Napoli, M. L.; Mancini, M. B.; Masella, P. E.; Cappelli, A. N. and Orlandini, S. B. 2020. Wheat grain composition, dough rheology and bread quality as affected by nitrogen and sulfur fertilization and seeding density. Agronomy. 10(2):1-15. 10.3390/agronomy10020233.

15 INIFAP. 2022. Instituto Nacional de Investigaciones Forestales Agrícolas y Pecuarias. Reporte anual. Ciencia y Tecnología para el Campo Mexicano. CIR-Noroeste, Sonora. 178 p.

16 Konvalina, P. M.; Grausgruber, H. E.; Dang, K. T. O.; Vlasek, I. L.; Capouchova, Z. S. and Kopecky, M. A. 2017. Rheological and technological quality of minor wheat species and common wheat. *In*: wheat improvement, management and utilization. Ed. IntechOpen. Norderstedt, Germany. 255-273 pp. 10.5772/67229.

17 Liu, N.; Sen, M.; Li, L. and Wang, X. 2019. Study on the effect of wheat bran dietary fiber on the rheological properties of dough. Grain & oil science and technology 2(1):1-5. 10.1016/j.gaost.2019.04.005.

18 Parenti, O. E.; Guerrini, L. A.; Canuti, V. B.; Angeloni, G. M.; Masella, P. L. and Zanoni, P. E. 2019. The effect of the addition of gelatinized flour on dough rheology and quality of bread made from brown wheat flour. Food Science and Technology. 106(2):240-246. 10.1016/j.lwt.2019.02.066.

19 Ramírez, P. L. O.; Zamora, V. M. M.; Colín, R. M. and De León, C. H. 2021. Interacción genotipo ambiente en fracciones de forraje de trigos en tres muestreos. Revista Mexicana de Ciencias Agrícolas. 12(3):485-498. 10.29312/remexca.v12i3.2621.

20 Rodríguez, P. G.; García, R. A.; Reynaga, F. J.; Mendívil, J. E. and Ochoa, A. R. 2023. Índices de selección entre caracteres agronómicos y químicos en híbridos de maíz morado (*Zea mays* L.) en el sur de Sonora, México. Anales Científicos. 84(1):35-53. 10.21704/ac.v84i1.1981.

21 SAS Institute. 2012. User's Guide of SAS. SAS Institute Inc. Cary, North Carolina, USA. 550 p.

22 SIAP. 2022. Servicio de información y Estadística Agroalimentaria y Pesquera. Anuario estadístico de la producción agrícola. Secretaría de Agricultura y desarrollo Rural. Ciudad de México. https://nube.siap.gob.mx/cierreagricola/.

23 Weiwei, M.; Yu, Z.; Zhang, Y.; Shi, Y. and Wang, D. 2015. Effects of supplemental irrigation on water consumption characteristics and grain yield in different wheat cultivars. Chilean Journal of Agricultural Research. 75(2):216-223. 10.4067/S0718-58392015000200011.

24 Zhang, Y.; Dai, X.; Jia, D.; Li, H.; Wang, Y.; Li, C. and He, M. 2016. Effects of plant density on grain yield, protein size distribution, and breadmaking quality of winter wheat grown under two nitrogen fertilization rates. European Journal of Agronomy. 73(2):1-10. 10.1016/j.eja.2015.11.015.

Rheological variations and industrial quality of bread wheat in Sonora

Journal Information
Journal ID (publisher-id): remexca
Title: Revista mexicana de ciencias agrícolas
Abbreviated Title: Rev. Mex. Cienc. Agríc
ISSN (print): 2007-0934
Publisher: Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias

Article/Issue Information
Date received: 01 April 2025
Date accepted: 01 June 2025
Publication date: 24 June 2025
Publication date: May-Jun 2025
Volume: 16
Issue: 4
Electronic Location Identifier: e3702
DOI: 10.29312/remexca.v16i4.3702

Categories

Subject: Articles

Keywords:

Keywords:

Triticum aestivum

industrial quality

rheological properties

Counts

Figures: 1

Tables: 6

Equations: 2

References: 24

Pages: 0