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Agronomic performance and industrial quality of bread wheat (*Triticum aestivum* L.) genotypes cultivated in the northeast of Mexico

Comportamiento agronómico y calidad industrial de genotipos de trigo para panificación (*Triticum aestivum* L.) cultivados en el Noreste de México

Comportamento agronômico e qualidade industrial de genótipos de trigo panificável (*Triticum aestivum* L.) cultivados no Nordeste do México

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Rev. Fac. Agron. (LUZ). 2025, 42(2): e254228
ISSN 2477-9407
DOI: https://doi.org/10.47280/RevFacAgron(LUZ).v42.n2.XII

Received: 08-10-2024
Accepted: 17-04-2025
Published: 28-05-2025

Crop production
Associate editor: Dra. Evelyn Pérez Pérez
University of Zulia, Faculty of Agronomy
Bolivarian Republic of Venezuela

Keywords:
Triticum aestivum L.
Agronomic performance
Industrial quality
Flour
Bread

Abstract

Wheat is one of the main crops worldwide, it is distributed in different climatic, ecological and geographical regions around the world, being a basic food for human nutrition. The search for genotypes that have to different environments is a common practice in agriculture. The objective of this study was to evaluate the agronomic performance and industrial quality of four genotypes of bread wheat (BW), namely, BW1 (Control) (San Isidro NL M-2012), BW2 (Floreña NL M-2012), BW3 (Norteña F2007), and BW4 (Conatrigo F2015). Wheat genotypes were evaluated using a complete randomized block design with four replicates. Based on results, BW4 (Conatrigo F2015) had better agronomic performance with higher results in spike length (11.10 ± 0.38), number of spikelets per spike (18.78 ± 0.91), number grains per spike (55.65 ± 7.13), grain yield per hectare (6.42 ± 1.29), forage per hectare (12.25 ± 1.30), and $L*$ in the flour (88.74 ± 0.15). BW4 (Conatrigo F2015) also had the lower weight loss (10.15 ± 1.30) and the higher $L*$ in crust (68.55 ± 0.09). In conclusion, genotypes evaluated in the present work had similar or better results in most of the agronomic performance and industrial quality compared with BW1 (Control) (San Isidro NL M-2012), being BW4 (Conatrigo F2015) the outstanding genotype.

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Resumen

El trigo es uno de los principales cultivos a nivel mundial, se distribuye en diferentes regiones climáticas, ecológicas y geográficas alrededor del mundo, siendo un alimento básico para la nutrición humana. La búsqueda de genotipos que se adapten a diferentes ambientes es una práctica común en la agricultura. El objetivo de este estudio fue evaluar el desempeño agronómico y la calidad industrial de cuatro genotipos de trigo para panificación (BW), llamados, BW1 (Testigo) (San Isidro NL M-2012), BW2 (Floreña NL M-2012), BW3 (Norteña F2007) y BW4 (Conatrigo F2015). Los genotipos de trigo se evaluaron mediante un diseño de bloques completos al azar con cuatro repeticiones. Con base en los resultados, BW4 (Conatrigo F2015) tuvo mejor desempeño agronómico con mayores resultados en longitud de espiga (11.10 ± 0.38), número de espiguillas por espiga (18.78 ± 0.91), número de granos por espiga (55.65 ± 7.13), rendimiento de grano por hectárea (6.42 ± 1.29), forraje por hectárea (12.25 ± 1.30) y L^* en la harina (88.74 ± 0.15). BW4 (Conatrigo F2015) también tuvo la menor pérdida de peso (10.15 ± 1.30) y el mayor L^* en corteza (68.55 ± 0.09). En conclusión, los genotipos evaluados en el presente trabajo tuvieron resultados similares o mejores en la mayor parte del comportamiento agronómico y calidad industrial en comparación con BW1 (Testigo) (San Isidro NL M-2012), siendo BW4 (Conatrigo F2015) el genotipo sobresaliente.

Palabras clave: *Triticum aestivum* L., desempeño agronómico, calidad industrial, pan.

Resumo

O trigo é uma das principais culturas mundiais, está distribuído em diferentes regiões climáticas, ecológicas e geográficas ao redor do mundo, sendo um alimento básico para a nutrição humana. A busca por genótipos adaptados a diferentes ambientes é uma prática comum na agricultura. O objetivo deste estudo foi avaliar o desempenho agronômico e a qualidade industrial de quatro genótipos de trigo panificável (BW), denominados BW1 (Testigo) (San Isidro NL M-2012), BW2 (Floreña NL M-2012), BW3 (Norteña F2007) e BW4 (Conatrigo F2015). Os genótipos de trigo foram avaliados em delineamento experimental de blocos casualizados com quatro repetições. Com base nos resultados, o BW4 (Conatrigo F2015) apresentou melhor desempenho agronômico com maiores resultados em comprimento de espiga (11.10 ± 0.38), número de espigas por espiga (18.78 ± 0.91), número de grãos por espiga (55.65 ± 7.13), produtividade de grãos por hectare (6.42 ± 1.29), forragem por hectare (12.25 ± 1.30) e L^* em farinha (88.74 ± 0.15). BW4 (Conatrigo F2015) também apresentou menor perda de peso (10.15 ± 1.30) e maior L^* em casca (68.55 ± 0.09). Concluindo, os genótipos avaliados neste trabalho tiveram resultados semelhantes ou melhores na maior parte do comportamento agronômico e qualidade industrial em comparação com BW1 (Testigo) (San Isidro NL M-2012), sendo BW4 (Conatrigo F2015) o genótipo de destaque.

Palavras-chave: *Triticum aestivum* L., desempenho agronômico, farinha, qualidade industrial, pão.

Introduction

Wheat is a very important crop with a production of 808.44 million tons in the 2022 agricultural year according to data from the Food and Agriculture Organization of the United Nations. The main producers of this crop were China, India and Russia which contributed 17.03, 13.32, and 12.89 %, respectively (FAO, 2024). This crop is one of the main crops worldwide together with maize, rice, barley, sorghum, oat and rye, and it is distributed in different climatic, ecological, and geographical regions around the world; and is a basic food for humans, animal feed, and industrial raw materials (Le *et al*., 2019).

Within the genus *Triticum*, there are different species of great interest mainly for human consumption, this is the case of bread wheat (*Triticum aestivum* L.) genotypes, which is mainly used in baking because it is a very elastic and extensible gluten (Hernández *et al*., 2011). Bread wheat is hexaploid, which is the result of crossing a tetraploid wheat (2n = 4x = 28, AABB) and a wild one (2n = 2x = 14, DD) followed by spontaneous chromosome duplication. The evolution of wheat is distinguished by domestication and natural hybridization (Li *et al*., 2014).

Wheat can be evaluated in external and internal aspects. The first one is based on freedom from foreign material and weather damage, type, and purity of color. The second one based on weight test, moisture content, milling behavior and end-use of flour (Khalid *et al*., 2023).

The main products obtained from wheat are whole flour and white flour. Whole flour is obtained from the entire wheat grain and the principal anatomical components (starchy endosperm, germ and bran) are present in the same relative proportions as they exist in the intact caryopsis with extraction yield of 100 % (Pagani *et al*., 2014). On the other hand, white flour classified in: straight flour, which is obtained by removing most of the bran and germ, using mainly endosperm with extraction yield of 72 %; patent flour, which is obtained from the innermost part of the endosperm and is essentially free of bran and germ with extraction yield between 45 and 65 %; and clear flour, obtained from the outer part of the endosperm with high content of bran with extraction yield between 65 to 72 % (Finnie and Atwell, 2018; Figoni, 2010).

Quality can have different meanings depending on the link in the wheat value chain. For the farmer, a high-quality wheat crop could require the least inputs and has the highest grain yield, and a good price in the market. However, for the miller, quality is based on the flour yield, along with the energy needed to obtain it. For the industry, quality is based on the characteristics of different products (Guzmán *et al*., 2022).

Recommendation of wheat cultivars requires the knowledge of their response to environmental conditions in particular locations or zones. The best performing cultivars should be preferred for recommendation in locations of similar environmental conditions (Iwańska *et al*., 2020).

The environmental conditions, determined by the altitude and temperate-cold climate of the northeast region of Mexico, make wheat cultivation viable, making it a productive option for this region. Furthermore, the search for new wheat genotypes that adapt to new production areas with improved development, yield, and industrial quality characteristics is always a challenge. In this regard, the main objectives of this work were as follows: evaluate the agronomic performance of bread wheat (*Triticum aestivum* L) genotypes grown in northeastern Mexico and determine the flour and bread quality obtained from *Triticum aestivum* L. genotypes grown in northeastern Mexico.

Materials and methods

Characterization of the study site

Location of the study area was the experimental agricultural campus of La Ascensión Academic Unit, Agronomy College, within Universidad Autónoma de Nuevo León, in Ejido La Ascensión, Aramberri (24°19.5‘ N, 99°54.5’ W) Nuevo León, Mexico, at an altitude of 1963 m, with an average annual temperature and precipitation of 19.9 °C and 425 mm, respectively (INEGI, 2023). The soil characteristics were obtained by an external laboratory analysis with next results: loam soil (33 % clay, 33 % silt and 33 % sand), pH 8.1, 3.24 % of organic matter content, electrical conductivity of 1.97 $dS.m^{-1}$, rich in potassium (1026 ppm), optimum levels of nitrogen (169 ppm) and poor in potassium (25 ppm).

Genetic material

The genotypes of bread wheat (BW) were BW1 (San Isidro NL M-2012) (control), BW2 (Floreña NL M-2012), BW3 (Norteña F2007), and BW4 (Conatrigo F2015). BW1 and BW2 genotypes were developed by Dr. Ciro G. S. Valdés Lozano in the Agronomy College, within the Universidad Autónoma de Nuevo León, while BW3 y BW4 were developed by Villaseñor *et al*. (2012; 2020), respectively at National Institute for Forestry, Agriculture and Livestock Research (Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias, INIFAP).

Wheat genotypes are registered in National Catalogue of Plant Varieties (Catálogo Nacional de Variedades Vegetales [CNVV], 2024) as: TRI-136-190712, TRI-132-190712, TRI-102-260608, TRI-174-231117 for BW1, BW2, BW3 and BW4, respectively. General description of genotypes is presented in table 1.

Table 1. General description of bread wheat (*Triticum aestivum* L.) genotypes.

Genotype	Overview
BW1	Resistant to leaf rust, 65 cm plant height, 7.5 cm spike length, good grain yield and good industrial quality.
BW2	Resistant to leaf rust, 80 cm plant height, 9.5 cm spike length, good grain yield and good industrial quality.
BW3	Resistant to moderately susceptible to leaf rust, 86 cm plant height, 15 cm spike length, high yield and good industrial quality.
BW4	Resistant to rust, 89 cm plant height, high yield and good industrial quality.

Experimental design and field distribution

The genotypes were distributed in a randomized block design with four replicates. Each experimental unit consisted of four furrows, 5 m length and 1.8 m width each, with a separation of 0.45 m among them, resulting in an area of 9 m^2. There was a gap of 2 m between each block (figure 1).

Land preparation for planting

To ensure proper crop establishment, it is necessary to undertake a harrowing and crossing process, resulting in a more manageable planting bed. Sowing was conducted manually on May 25, 2021, with a sowing density of 100 $kg.ha^{-1}$ of seed three relief irrigations were conducted in a sprinkler irrigation system, and they consisted of 8160 L per irrigation (1020 $L.h^{-1}$, 4 h, 2 irrigation lines). In addition, a commercial bio-stimulant (auxins, gibberellins and cytokinins at

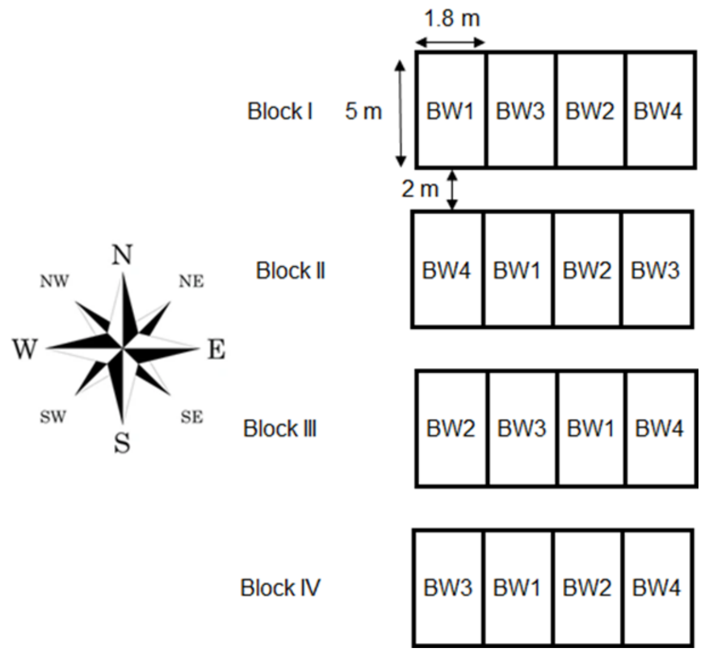

Figure 1. Experimental field layout of wheat crop.

0.09, 0.10 and 1.50 $g.L^{-1}$, respectively) of organic origin containing macronutrients (N, P_2O_5, K_2O, Ca and Cu at 6.6, 13.3, 13.3, 2.0 and 4.0 $g.L^{-1}$, respectively) and micronutrients (Cu, Fe, Mn and Zn at 13.3, 17.2, 13.3 and 26.5 $g.L^{-1}$, respectively) in chelated form at a dose of 2 $mL.L^{-1}$ (25 L of water). Weed control was conducted by giving an application with 2,4-D (480 $g.L^{-1}$) at a dose of 2 $L.ha^{-1}$ (35 L of water), when the plant was 10 to 20 cm high, and then weed control was conducted manually.

Harvesting

The harvest was carried out when crop reached 18 weeks of development on September 28. The plants of each experimental unit were harvested manually cutting plants from the base of the stem using sickles. The plants were harvested in 3 m of two central furrows with a separation of 0.45 m between them, resulting in an area of 1.35 m^2. Samples were placed in kraft paper bags, identified and then transported to the multipurpose agronomic laboratory, where they were evaluated for development and performance traits.

Development and performance traits

Plant height

The measurement was made in 10 plants per replicate using a flexometer. The height was taken from the base of the stem to the tip of the inflorescence and reported in centimeters (cm).

Number of leaves per plant

Total number of leaves were counted in ten plants per replicate from the stem to the inflorescence including the flag leaf.

Number of tillers per plant

The tillers were counted in ten plants per replicate counting the number of secondary stems. The determination was carried out when flowering exceeded 50 %.

Spike length

The length of the spikes of ten plants per replicate were measured from the base to the apex of the terminal spikelet using a ruler and reported in centimeters (cm).

Number of spikelets per spike

The number of spikelets in ten spikes per replicate were counted.

Number of grains per spike

The number of grains in ten spikes per replicate were counted.

Thousand grain weight

One thousand grains clean and free of damage were counted per replicate, the weight was recorded using a balance (Truper® model 102317, Mexico) and the results were expressed in grams (g).

Forage Yield

Plants from 1 m^2 of central furrow per replicate were cut and weighted in a balance (Torrey® model L-EQ 10/20, Mexico), data were converted and reported as ($t.ha^{-1}$).

Grain yield per hectare

Plants used in forage yield were threshed using a craft electric thresher and the clean grains were weighed in a balance (Torrey® model L-EQ 10/20, Mexico), data were converted and reported as ($t.ha^{-1}$).

Days to physiological maturity

It was determined counting from the day of sowing until the day where 90 % of the plants per replicate lost chlorophyll and turned yellow.

Grain moisture

The evaluation of grain moisture was carried out according to Gutheil *et al*. (1984) using a electronic moisture tester (Steinlite® model RCT, USA) and results were reported as percentage (%).

Production and physical characterization of wheat flour

Production of wheat flour

One kilogram of grain free of impurities was considered. Grains of each bread were milled using an electric experimental mill by passing the material through the mill twice. Subsequently, each sample was passed through a physical testing sieve with #30 mesh (595 µm) and flour yield was reported as percentage (%).

Flour color

Flour color parameters were obtained using a colorimeter (Minolta® model CR-20, Japan). A petri dish was filled with 100 g of wheat flour and chromatic parameters were obtained using CIELAB (L^*, a^*, b^*) and CIELCH (L^*, C^*, h) color systems, where L^* defines lightness (0= black, 100= white), a^* indicate red (positive a^*) or green value (negative a^*) and b^* indicate yellow (positive b^*) or blue value (negative b^*). In addition, C^* (chroma) saturation level of h and h (hue angle 0°= red, 90°= yellow, 180°= green and 270°= blue) were also reported, according to Commission Internationale De L'ecleirage (CIE, 2004). Color view was obtained by online software ColorHexa (ColorHexa, 2023) color converter using L^*, C^* and h values.

Dough extensibility

Dough extensibility was measured using a texturometer (TA.XT plus Stable Micro Systems, UK) and the Kieffer dough and gluten extensibility kit according to Dunnewind *et al*. (2003). Maximum force (N) and distance (mm) of extensibility test were obtained at 30, 60 and 90 min after preparation of dough.

Industrial quality evaluation of bread wheat

Breadmaking process

The Bread preparation was done by using 200 g of flour, 6 g of yeast and 3 g of salt, while water used was 140 mL for BW1, 145 mL for BW3 and 150 mL for BW2 and BW4. Solid ingredients were mixed in a mixer (KitchenAid model KSM7586PSR, USA) at speed 1 for 1 min, after that, water was added and mixed for 10 min at speed 4. Later, dough was divided in 4 pieces of 85 g and they were placed in steel mini loaf pans (9.5 x 5.7 x 3.2 cm), left for fermentation at 35.5 °C for 30 min, afterwards baking at 200 °C for 30 min in a rotary gas oven (Century Model 20, Mexico) and finally bread pieces were cooled at room temperature.

Physicochemical evaluation of bread

Physicochemical evaluations were conducted according to according to Niño-Medina *et al*. (2017) with minor modifications. The height of bread was measured with a Vernier caliper (Steren model HER-411, Mexico) on the central part of the bread pieces, and it was reported in millimeters (mm). The weight loss (WL) was obtained with the next equation (Eq. 1):

$$\mathrm{WL} = \frac{\mathrm{WBB} - \mathrm{WAB}}{\mathrm{WBB}} * 100 \qquad \text{(Eq. 1)}$$

where: WBB= weight before baking and WAB= weight after baking. Hardness was evaluated with a texture analyser (Stable Micro Systems TA.XT.Plus, UK) using a compression plate of 75 mm diameter and a compression distance to 30 % of the bread height. Chromatic evaluation was done in the bread crust of the bread pieces using a colorimeter (Minolta model CR-20, Japan) and chromatic parameters were obtained using CIELAB (L^*, a*, b*) and CIELCH (L^*, C^*, h) color systems where L^* defines Lightness (0= black and 100= white), a^* indicate red (positive a^*) or green value (negative a^*) and b^* indicate yellow (positive b^*) or blue value (negative b^*). In addition, C^* (Chroma) saturation level of h and h (hue angle 0°= red, 90°= yellow, 180°= green and 270°= blue) were also reported according to Commission Internationale De L'ecleirage (CIE, 2004). Color view was obtained by online software ColorHexa (ColorHexa, 2023) color converter using L^*, C^* and h values.

Statistical analysis

The statistical analysis was conducted using Minitab software 14.0 (Minitab, 2023). In addition, comparison among genotypes was conducted using a randomized complete block design model. A multiple comparison of means was performed using the Tukey test ($p \leq 0.05$).

Results and discussion

Development and performance traits parameters in bread wheat (*Triticum aestivum* L.) genotypes are shown in table 2. The PH and NLP per plant are critical variables that impact the yield. There was no statistical difference between genotypes for PH and NLP variables. Our results show plant heights below the range of 84 to105 cm observed by Noriega-Carmona *et al*. (2019) whom evaluated the effect of sowing date in 34 wheat genotypes developed in Guanajuato, Mexico. The NTP showed statistically significant difference ($p \leq 0.05$) among the genotypes. Our results are similar with those reported by Huanca *et al*. (2016) whom also reported an average of four tillers per plant in 15 wheat bread genotypes in Totora, Peru.

Significant statistical difference ($p \leq 0.05$) between genotypes were observed in SL, which is below the 13.74 to 15 cm range reported by Plana *et al*. (2006) for two bread wheat genotypes cultivated in La Habana, Cuba. The NSS data indicates a significant statistical difference ($p \leq 0.05$) between bread wheat genotypes, but our results are below to those reported by Ortega *et al*. (2004) whom found values between 19 and 22 NSS in 16 wheat bread genotypes developed in Cordoba, Argentina. The NGS resulted with a significant statistical difference ($p \leq 0.05$) among genotypes and are closely resemble to those reported by Solis-Moya *et al*. (2004) with 42 to 57 grains per spike in 6 genotypes developed in Guanajuato, Mexico.

Table 2. Growth parameters in bread wheat (*Triticum aestivum* L.) genotypes.

Genotype	PH	NLP	NTP	SL	NSS	NGS
BW1	73.63 ± 1.16^{a}	3.58 ± 0.22^{a}	3.08 ± 0.33^{b}	9.63 ± 0.30^{b}	15.98 ± 0.43^{b}	43.50 ± 2.85^{b}
BW2	74.30 ± 5.45^{a}	3.79 ± 0.41^{a}	2.68 ± 0.22^{b}	9.06 ± 0.31^{b}	15.33 ± 1.19^{b}	44.98 ± 4.16^{b}
BW3	70.93 ± 10.72^{a}	3.88 ± 0.13^{a}	2.60 ± 0.44^{b}	9.00 ± 0.27^{b}	15.70 ± 1.56^{b}	42.10 ± 3.16^{b}
BW4	66.58 ± 4.92^{a}	3.90 ± 0.15^{a}	4.48 ± 0.44^{a}	11.10 ± 0.38^{a}	18.78 ± 0.91^{a}	55.65 ± 7.13^{a}

PH = plant height (cm), NLP = number of leaves per plant, NTP = number of tillers per plant, SL = spike length (cm), NSS = number of spikelets per spike, NGS = number of grains per spike. Different letters in columns indicate statistical difference p≤0.05 (n= 4).

Yield parameters and phenology of bread wheat are shown in table 3. The WTG showed a significant statistical difference among genotypes, BW3 was 1.17, 1.14 and 1.10 fold higher than BW1, BW2 and BW4, respectively in WTG. The WTG data obtained in this present study is higher than those reported by Martinez-Cruz *et al*. (2020), whom recorded 31 to 43 g in eight genotypes of wheat bread cultivated in Guanajuato, Mexico. The FH did not show significant statistical difference (p≥0.05) between genotypes.

In the GYH of bread wheat no significant differences were observed among genotypes. A study by Suaste-Franco *et al*. (2013) in Guanajuato, Mexico using two wheat bread genotypes showed a yield of 4.73 to 6.16 $t.ha^{-1}$ which is similar to that was found in the present study. Regarding the DPM, the results indicated ranges between 111.75 and 118 days, finding a significant difference among the genotypes, where the BW2 genotype stood out for obtaining the fewest number of days to reach maturity, followed by the control genotype BW1. Santa-Rosa *et al*. (2016) found different results in wheat cultivars planted under rainfed conditions in Coatepec, Mexico with data ranging from 120.6 to 132.2 in DPM.

The moisture and flour yield of bread wheat are shown in table 4. Moisture influences the wheat industrial performance, a range from 13.61 to 13.76 % obtained in this study did not show significant difference (p≥0.05) among genotypes (table 3).

According to Castillo and Chamorro (2009), the ideal grain moisture levels for producing high-quality wheat flour are between 13 % and 15 %, therefore, the grains produced in this study meet this range for storage and flour production.

The flour yield varied between 88.75 % to 97.28 %, showing a significant statistical difference (p≤0.05) among the genotypes (table 3). In addition, BW2 showed the highest yield, followed by BW4, BW1 and BW3. Although BW3 had the lowest yield, its average value is higher than flour yield reported by Rozo-Otega *et al*. (2021), whom obtained flour yield of 69 to 64 % in four genotypes developed in Argentina.

The chromatic parameters in bread wheat flours are shown in table 5. Regarding flour color, luminosity (*L**) values ranged from 83.49 to 88.74, with the BW4 genotype having the highest value, indicating a significant difference (p≤0.05) between genotypes. The values on the a* ranged from 2.64 to 3.53, indicating a significant statistical difference between genotypes (p≤0.05). In addition, the b* axis values ranged from 11.10 to 13.43, indicating a significant difference between genotypes (p≤0.05).

The chroma *C** factor ranged from 11.41 to 13.75 with a significant difference (p≤0.05) between genotypes, with the BW3 genotype obtaining the highest value. Moreover, the Hue angle *h** has

Table 3. Yield parameters and phenology of bread wheat (*Triticum aestivum* L.) genotypes.

Genotype	WTG	FH	GYH	DPM
BW1	48.25 ± 2.37^{b}	9.35 ± 2.43^{a}	4.89 ± 1.15^{a}	116.75 ± 1.26^{a}
BW2	49.75 ± 3.84^{b}	11.76 ± 0.64^{a}	5.04 ± 1.21^{a}	111.75 ± 1.26^{b}
BW3	56.75 ± 2.54^{a}	9.73 ± 1.14^{a}	4.62 ± 1.01^{a}	117.00 ± 0.82^{a}
BW4	51.25 ± 0.99^{ab}	12.25 ± 1.30^{a}	6.42 ± 1.29^{a}	118.00 ± 0.82^{a}

WTG = weight of a thousand grains (g), FH = forage per hectare ($t.ha^{-1}$), GYH = grain yield per hectare ($t.ha^{-1}$), DPM = days to physiological maturity. Different letters in columns indicate statistical difference p≤0.05 (n= 4).

Table 4. Moisture and flour yield of bread wheat (*Triticum aestivum* L.) genotypes.

Genotype	Grain moisture (%)	Flour yield (%)
BW1	13.61 ± 0.30^{a}	93.16 ± 0.40^{c}
BW2	13.76 ± 0.25^{a}	97.28 ± 0.66^{a}
BW3	13.72 ± 0.37^{a}	88.75 ± 0.79^{d}
BW4	13.61 ± 0.37^{a}	95.29 ± 0.67^{b}

Different letters in columns indicate statistical difference p≤0.05 (n= 4).

Table 5. Chromatic parameters in bread wheat (*Triticum aestivum* L.) flours.

Genotype	L*	a*	b*	C*	h*	Color view
BW1	86.69 ± 0.50^{b}	2.88 ± 0.13b^{c}	11.38 ± 0.21^{b}	11.74 ± 0.21^{b}	75.91 ± 0.34^{ab}	
BW2	86.43 ± 0.39^{b}	2.94 ± 0.11^{b}	11.38 ± 0.19^{b}	11.75 ± 0.20^{b}	75.50 ± 0.36^{b}	
BW3	83.49 ± 0.56^{c}	3.53 ± 0.13^{a}	13.43 ± 0.19^{a}	13.78 ± 0.09^{a}	75.15 ± 0.40^{b}	
BW4	88.74 ± 0.15^{a}	2.64 ± 0.05^{c}	11.10 ± 0.17^{b}	11.41 ± 0.19^{a}	76.56 ± 0.11^{a}	

Different letters in columns indicate statistical difference (p≤0.05) (n= 4). *L**=Lightness (0=black, 100=white), a*=red (positive a*) or green (negative a*), b*=yellow (positive b*) or blue (negative b*). *C**=saturation level of *h**, *h**=hue angle, 0°=red, 90°=yellow, 180°=green, 270°=blue.

This scientific publication in digital format is a continuation of the Printed Review: Legal Deposit pp 196802ZU42, ISSN 0378-7818.

values ranging from 75.15 to 76.56, indicating a significant difference (p≤0.05) between genotypes (table 4).

In this study, these ranges are different from those reported by Montoya-López *et al*. (2012), who evaluated the color in commercial wheat flours with prior bleaching, obtaining an average luminosity L^* of 92.01, an average C^* of 9.79, and average h^* of 86.74. Moreover, Oliver *et al*. (1992) used two colorimeters to measure flour from white spring wheat and observed minimal variations in the measurements. The average L^* value obtained using the HunterLab colorimeter (D25-9SM) was 91.73, ranging from 90.95 to 92.95. The Minolta colorimeter (CR 200) yielded an average value of 91.33, with values ranging from 90.35 to 92.55. These results are also higher than our data.

According to Rodriguez-Sandoval *et al*. (2005), food texture is crucial for consumer acceptance and approval. The textural properties of a food are the group of physical characteristics that depend on the structural elements of the material and are related to deformation, integration, and flow owing to the application of a force.

An important property of the food that is associated with the texture is the rheological behavior; therefore, when conducting this analysis on the dough extensibility, the strength results at 30 min did not show a significant statistical difference among genotypes, obtaining data from 0.17 N to 0.25 N, whereas at 60 min, there was a significant statistical difference (p≤0.05) where BW1 required a force of 0.42 N, unlike BW4 that required 0.30 N. At 90 min, values ranged from 0.39 to 0.65 N, showing statistical difference (p≤0.05) with the genotypes being BW4 the lower in this parameter (table 6).

A good average height and texture of the bread are possible because wheat has a group of proteins (gliadins and glutenins) that, in the presence of water, hydrate and interact to form gluten, allowing the dough to retain the gas produced during the fermentation. Therefore, a strong and extensible gluten allows the preparation of doughs with good gas retention capacity during fermentation, which can expand, giving rise to breads with a high volume, soft, and spongy crumb (Robles-Sosa *et al*., 2005).

Table 7 presents the results of height (mm), percentage of weight loss during baking, and bread hardness (N) where the genotypes did not show a significant difference however, genotype BW3 is the one with the highest average in the three variables evaluated, reaching 52.19 mm in height, 12.50 % weight loss during baking, and 33.26 N in bread hardness.

The color of the bread crust

The weight loss results in baking are similar to the findings by Calvo-Carrillo *et al*. (2020), who reported an 11.84 % loss in wheat flour bread, and is lower than Vega *et al*. (2015), who reported a higher loss of 15.54 %.

During the bread-baking process, the color of the crust develops owing to caramelization, giving it a crispy and shiny texture. According to Mohammed *et al*. (2012), the luminosity value (L^*) plays a vital role in determining the commercial value owing to its direct impact.

BW4 presented the greatest range of luminosity, chroma, and hue angle. In addition, the genotype that showed the lowest ranges in the a^* and b^*, resulting in a lighter visible shade compared with BW1 (Table 8). Our research findings align with those of Domínguez Zarate *et al*. (2019), who reported similar values in boxed bread made from wheat flour, with a luminosity of 67.80.

Table 6. Bread wheat dough extensibility (*Triticum aestivum* L.).

Parameter	Time (min)	Genotype			
		BW1	BW2	BW3	BW4
Force (N)	30	0.25 ± 0.06^{a}	0.25 ± 0.04^{a}	0.23 ± 0.05^{a}	0.17 ± 0.02^{a}
	60	0.42 ± 0.09^{a}	0.37 ± 0.02^{ab}	0.32 ± 0.06^{ab}	0.30 ± 0.03^{b}
	90	0.65 ± 0.10^{a}	0.52 ± 0.07^{b}	0.53 ± 0.08^{ab}	0.39 ± 0.04^{c}
Rupture (mm)	30	75.13 ± 12.49^{ab}	61.29 ± 17.67^{ab}	57.97 ± 18.19^{b}	76.10 ± 14.57^{a}
	60	68.22 ± 9.15^{a}	48.70 ± 7.88^{b}	61.53 ± 7.00^{ab}	67.34 ± 8.05^{ab}
	90	42.21 ± 4.14^{b}	36.46 ± 3.17^{b}	41.81 ± 6.69^{b}	65.06 ± 9.38^{a}

Different letters in rows indicate statistical difference p≤0.05 (n= 4).

Table 7. Baking attributes and texture of bread obtained from *Triticum aestivum* L. genotypes.

Genotype	Height (mm)	Weight loss (%)	Hardness (N)
BW1	49.66 ± 0.39^{a}	10.74 ± 1.30^{a}	31.88 ± 0.79^{a}
BW2	49.91 ± 0.43^{a}	11.03 ± 1.30^{a}	31.86 ± 1.93^{a}
BW3	52.19 ± 2.13^{a}	12.50 ± 0.29^{a}	33.26 ± 0.18^{a}
BW4	49.47 ± 2.39^{a}	10.15 ± 1.30^{a}	32.43 ± 6.69^{a}

Different letters in columns indicate statistical difference p≤0.05 (n= 4).

Table 8. Chromatic parameters of bread crust obtained from *Triticum aestivum* L. genotypes.

Genotype	L^*	a^*	b^*	C^*	h^*	Color view
BW1	65.43 ± 2.38^{b}	7.94 ± 1.77^{a}	24.25 ± 1.96^{ab}	25.53 ± 2.39^{ab}	72.04 ± 2.51^{a}	
BW2	65.43 ± 0.33^{b}	7.99 ± 0.82^{a}	25.29 ± 1.46^{a}	26.55 ± 1.62^{a}	72.50 ± 0.75^{a}	
BW3	67.54 ± 0.78^{ab}	7.14 ± 0.36^{a}	23.14 ± 0.58^{ab}	24.25 ± 0.62^{ab}	72.80 ± 0.47^{a}	
BW4	68.55 ± 0.09b^{a}	6.05 ± 0.51^{a}	21.93 ± 1.03^{b}	22.76 ± 1.13^{b}	74.63 ± 0.56^{a}	

Different letters in columns indicate statistical difference p≤0.05 (n= 4). L^*= Lightness (0= black, 100= white), a*= red (positive a*) or green (negative a*), b*= yellow (positive b*) or blue (negative b*). C^*= saturation level of h^*, h^*= hue angle, 0°= red, 90°= yellow, 180°= green, 270°= blue.

This scientific publication in digital format is a continuation of the Printed Review: Legal Deposit pp 196802ZU42, ISSN 0378-7818.

Conclusions

BW4 had the highest values in yield and most of the yield components as spike length, number of spikelets per spike, number grains per spike, grain yield per hectare, forage per hectare. Regarding to the industrial quality, BW4 also had the lower weight loss and the higher luminosity in flour and bread crust, being the outstanding genotype among genotypes evaluated and a good option for producers of bread wheat aimed to industrial purposes.

Acknowledgements

Nydia del Carmen Ramírez-Cortez acknowledges to Consejo Nacional de Ciencia y Tecnología (CONACYT) for the Master of Science scholarship. Thanks to Programa de Apoyo a la Investigación Científica y Tecnológica 2022 de la Universidad Autónoma de Nuevo León (PAICYT-UANL) for the Project 64-CAT-2022 (Evaluación de las propiedades tecnológicas y nutraceúticas de trigos harineros (*Triticum aestivum* L.) y trigos cristalinos (*Triticum durum* L.) cultivados en La Ascensión Aramberri Nuevo León) awarded to Guillermo Niño-Medina.

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