World Journal of Advanced Research and Reviews
eISSN: 2581-9615 CODEN (USA): WJARAI
Cross Ref DOI: 10.30574/wjarr
Journal homepage: https://wjarr.com/

(RESEARCH ARTICLE)

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Performance of the 12th bread wheat yield consortium conducted in the Yaqui Valley, Sonora, Mexico, during the 2024-2025 crop season

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World Journal of Advanced Research and Reviews, 2025, 27(02), 1676-1687

Publication history: Received on 15 July 2025; revised on 20 August 2025; accepted on 23 August 2025

Article DOI: https://doi.org/10.30574/wjarr.2025.27.2.3036

Abstract

Thirty eight advanced bread wheat lines and commercial cultivar Borlaug 100 F2014, were evaluated for grain yield field performance in the Yaqui Valley, Sonora, Mexico, during the crop season 2024-2025. The sowing date was December 6, 2024, with a seed density of 100 kg ha^{-1} in 2 beds 2 m long with two rows and 0.80 m apart, with three replications. Average daily temperature (°C), maximum, minimum, relative humidity, rainfall, heat and cold units were recorded from December 15, 2024 to May 15, 2025. The variables evaluated were: plant height (cm), a thousand grain weight (g), and grain yield (g) per plot. The average plant height of the group was 76.7 cm with a range of 68.3 to 86.6; the tallest lines were MEX94.27.1.20/3/SOKOLL//ATTILA/3*BCN/4/PUB94.15.1.12/WBLL1/5/MUCUY with 86.6 cm, and SOKOLL/WBLL1/4/MUTUS//KIRITATI/2*TRCH/3/WHEAR/KRONSTADF2004/5/WBLL1*2/SHAMA//BAJ#1*2/3/BORL14 with 85 cm, while the shortest one was the sister line UP2338*2/VIVITSI/3/FRET2/TUKURU//FRET2/4/MISR1/5/TUKURU//BAV92/RAYON*2/3/PVN/6/MUCUY (PTHW20Y 00007S-0Y-099Y-0B-8Y-0B) with 68.3 cm. The average a thousand grain weight of the group was 50.8 g, with a range of 44.0 to 58.4 g; the line QUAIU*2/KINDE/6/PREMIO/4/CROC_1/AE.SQUARROSA(205)//KAUZ/3/PIFED/5/2*BORL14 showed the highest weight with 58.4 g. The average grain weight per plot of the group was 497.7 g, with a range of 410.7 to 575.3; lines with the highest grain weight were PUB94.15.1.12/WBLL1/4/ MEX94.27.1.20/3/SOKOLL//ATTILA/3*BCN/7/VEE/MJI//2*TUI/3/PASTOR/4/BERKUT/5/BAVIS/6/BORL14 with 575.3 g, and sister line WBLL1//YANGLINGSHAANXI/ESDA/3/ROLF07/6/SUP152/BAJ#1/4/BAJ#1/3/KIRITATI//ATTILA*2/PASTOR/5/SUP152/BAJ#1 (PTSS20Y00351S-0B-099Y-099M-1Y-0B) with 572 g, which correspond to 7.19, and 7.15 t ha^{-1}, respectively. The average temperature was 18.7 °C with a maximum of 40.2 °C and a minimum of 2.8 °C; the average relative humidity was 49.5 %; there were 0.1 mm of precipitation, and the number of heat and cold units was 413 and 643, respectively.

Keywords: Bread Wheat; *Triticum Aestivum*; Grain Yield; 12th WYCYT

1. Introduction

Maize (*Zea mays* L.) ranks as the most important cereal worldwide, followed by wheat (*Triticum* spp.) and rice (*Oryza sativa* L.) [1]. Wheat is notable for its adaptability, high grain yield potential, broad range of uses, and nutritional value, contributing to approximately 21 % of the global food supply [2]. It holds the largest share of cultivated land among crops, covering 222 million hectares worldwide, including 50 million hectares in developing countries. Notably, about

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half of this area is cultivated under rainfed conditions, often characterized by erratic rainfall, poor soil fertility, and extreme temperatures. Under such circumstances, drought remains one of the primary constraints to wheat production [3]. In Mexico, wheat ranks among the top five most important crops. It is primarily cultivated during the fall-winter season in the northern and northwestern regions, while in the central region, it is sown during the spring-summer season. The majority of wheat production is concentrated in five states -Sonora, Baja California, Sinaloa, Guanajuato, and Chihuahua- which together account for approximately 92 % of the country's total output [4]; over 90 % of this production takes place under irrigated conditions. In Sonora, most wheat production occurs in the southern region, primarily in the Yaqui Valley and, to a lesser extent, the Mayo Valley. Both valleys have arid climates with low humidity throughout most of the year and are recognized globally as key reference points for wheat production [5]. However, southern Sonora faces significant challenges due to limited water availability [6], and agriculture in the region relies heavily on dam-supplied irrigation systems [7]. This scarcity of natural water resources is also a critical issue in other major wheat-producing regions, such as the Bajío. As a result, both areas are classified within hydrological regions experiencing high water stress [8], and projections indicate the need to consider future scenarios of even greater scarcity [9]. At the national level, wheat production in Mexico is categorized by wheat type. Sonora and Baja California are primarily known for producing durum wheat, while states like Guanajuato and Jalisco focus more on bread wheat, characterized by medium to strong gluten content [10]. In Sonora, only about 20 % of the wheat-growing area is planted with bread wheat cultivars [11], largely because durum wheat has historically demonstrated higher yield potential in the region [12] and greater resistance to Karnal bunt [13,14]. Given this context, the development of new bread wheat cultivars with improved yield potential, industrial quality, and disease resistance is essential. Such efforts could expand the area dedicated to bread wheat cultivation and help reduce Mexico's dependence on imports, which exceeded 5 million tons in 2023 [15]. The bread wheat yield consortium (WYCYT) is a network of field trials designed to enhance the yield potential of spring wheat by strategically combining physiological traits related to both source and sink capacity [16]. These trials have been phenotyped across key wheat-producing mega-environments through the International Wheat Improvement Network (IWIN) and the Cereal Systems Initiative for South Asia (CSISA). In total, the trials have been conducted across 136 environments (site-year combinations) in major spring wheat-growing countries, including Bangladesh, China, Egypt, India, Iran, Mexico, Nepal, and Pakistan. The objective of this work was to evaluate the field performance of a set of 38 advanced bread wheat lines during the crop season fall-winter 2024-2025.

2. Materials and methods

Thirty eight advanced bread wheat lines that comprised the 12th bread wheat yield consortium (WYCYT), which included eight groups of sister lines (lines 2, 17, and 38; 3 and 33; 4 and 20; 5 and 31; 6 and 34; 8 and 14; 26, 27 and 32; 23 and 29) (Table 1) selected at the International Maize and Wheat Improvement Center (CIMMYT), based on their yield potential, were evaluated at the Norman E. Borlaug Experimental Station (CENEB) which belongs to the National Institute for Forestry, Agriculture, and Livestock Research (INIFAP). This experimental station is located in block 910 of the Yaqui Valley at 27°22´04.64´´ latitude north and 109°55´28.26´´ longitude west, 37 masl, in a clay soil with pH 7.8. The climate is warm [BW (h)] and extreme warm and dry [BS (h)], according to Köppen classification modified by García [17]. Commercial bread wheat cultivar Borlaug 100 F2014 [18] was used as check. This cultivar is the bread wheat most used by farmers in southern Sonora; during the 2019-2020 wheat season, 94,865.61 ha of bread wheat were planted, with 88.9 % of the area covered by this cultivar [19]. In 2020-2021, 42,694.86 ha were established, of which 86.38 % was planted with Borlaug 100 F2014 cultivar [20]. In the 2021-2022 season, 40,376.46 ha were planted with bread wheat, and 91.7 % of this used the same cultivar [21]. In 2022-2023, 59,232.56 ha were established, with 99.7 % covered by Borlaug 100 F2014 [22]. Finally, in 2023-2024, 52,534.276 ha were planted, with 70.6 % of the area using this cultivar [23]. Borlaug 100 F2014 has demonstrated stable yields. It is moderately susceptible to partial bunt (*Tilletia indica* Mitra), but shows resistance to both leaf rust (*Puccinia triticina* Eriks.) and to yellow or stripe rust (*Puccinia striiformis* Westend. f. sp. *tritici* Eriks.). Although bread wheat cultivar CIANO M2018 was released in 2018 and outperformed Borlaug 100 F2014 in experimental trials between the 2017-2018 and 2019-2020 seasons, yielding 1.58 and 6.27 % more grain under two and four complementary irrigations, respectively [24], it was grown on only 3,798 ha in southern Sonora during the 2022-2023 season [22]. However, by 2023-2024, its cultivation area had expanded significantly to 15,157 ha [23].

Table 1 Advanced bread wheat lines of the 12th bread wheat yield consortium and commercial cultivar Borlaug 100 F2014, sown on December 6, 2024, at the Norman E. Borlaug Experimental Station, in the Yaqui Valley, Sonora, Mexico

No.	Pedigree and selection history
1	CMH79A.955/4/AGA/3/4*SN64/CNO67//INIA66/5/NAC/6/RIALTO/7/SOKOLL/WBLL1/8/VEE/MJI//2*TUI/3/ PASTOR/4/BERKUT/5/BAVIS/6/BORL14 PTSS21Y00266S-0M-099Y-0B-4Y-0B
2	UP2338*2/VIVITSI/3/FRET2/TUKURU//FRET2/4/MISR 1/5/TUKURU//BAV92/RAYON*2/3/PVN/6/MUCUY PTHW20Y00007S-0Y-099Y-0B-8Y-0B
3	MEX94.27.1.20/3/SOKOLL//ATTILA/3*BCN/4/PUB94.15.1.12/WBLL1/5/MUCUY/6/FRET2*2/BRAMBLING//BECARD/3/WBLL1*2/BRAMBLING PTSS21Y00295S-0B-099Y-0B-5Y-0B
4	WBLL1//YANGLING SHAANXI/ESDA/3/ROLF07/6/SUP152/BAJ#1/4/BAJ#1/3/KIRITATI//ATTILA*2/ PASTOR/5/SUP152/BAJ #1 PTSS20Y00351S-0B-099Y-099M-1Y-0B
5	FRET2/KUKUNA//FRET2/3/TAM200/TUI/4/FRET2*2/SHAMA/5/WBLL1/KUKUNA//TACUPETOF2001/3/ UP2338*2/VIVITSI/6/PREMIO/4/CROC_1/AE.SQUARROSA (205)//KAUZ/3/PIFED/5/2*BORL14 PTSS21Y00055S-0B-099Y-0B-7Y-0B
6	68.111/RGB-U//WARD RESEL/3/STIL/4/AE.SQUARROSA(630)/5/BORL14/6/COPIO/7/KANCHAN*2/ JUCHI//2*BORL14 PTSS21Y00210S-0M-099Y-099M-3Y-0B
7	SOKOLL/3/PASTOR//HXL7573/2*BAU/4/WBLL4//OAX93.24.35/WBLL1/5/MUTUS*2/CHONTE/6/ SUP152/BAJ#1//TRCH/HUIRIVIS #1/3/SUP152/BAJ #1 PTSS20Y00323S-0B-099Y-099M-4Y-0B
8	SOKOLL/3/PASTOR//HXL7573/2*BAU/4/SOKOLL/WBLL1/5/PIHA//WORRAKATTA/2*PASTOR/3/PRL/2*PASTOR/6/SNTL/3/KACHU//WBLL1*2/BRAMBLING PTSS21Y00235S-0M-099Y-099M-9Y-0B
9	NINGA #1 CMSA11Y00507S-099Y-099M-099NJ-099NJ-19WGY-0B
10	NADI #1 CMSS06B00734T-099TOPY-099ZTM-099Y-099M-5WGY-0B
11	PASTOR//HXL7573/2*BAU/3/WBLL1/4/BORL14/5/CHIPAK PTSS21Y00142S-0M-099Y-099M-2Y-0B
12	BORLAUG100 F2014 CMSS06Y00605T-099TOPM-099Y-099ZTM-099Y-099M-11WGY-0B-0MEX
13	JNRB.5/PIFED/5/BJY/COC//PRL/BOW/3/SARA/THB//VEE/4/PIFED/6/BORL14 PTSS19Y00239S-0M-0Y-099B-34Y-0B
14	SOKOLL/3/PASTOR//HXL7573/2*BAU/4/SOKOLL/WBLL1/5/PIHA//WORRAKATTA/2*PASTOR/3/PRL/2*PASTOR/6/SNTL/3/KACHU//WBLL1*2/BRAMBLING PTSS21Y00235S-0M-099Y-099M-4Y-0B
15	SOKOLL/WBLL1/4/MUTUS//KIRITATI/2*TRCH/3/WHEAR/KRONSTAD F2004/5/WBLL1*2/SHAMA//BAJ #1*2/3/BORL14 PTSS20Y00390S-0B-099Y-099M-2Y-0Y-0B
16	SOKOLL/3/PASTOR//HXL7573/2*BAU/5/CROC_1/AE.SQUARROSA (205)//BORL95/3/PRL/SARA// TSI/VEE#5/4/FRET2/6/BORL14*2//BECARD/QUAIU #1 PTSS21Y00223S-0M-099Y-099M-3Y-0B
17	UP2338*2/VIVITSI/3/FRET2/TUKURU//FRET2/4/MISR 1/5/TUKURU//BAV92/RAYON*2/3/PVN/6/MUCUY PTHW20Y00007S-0Y-099Y-0B-3Y-0B
18	QUAIU*2/KINDE/4/FRET2*2/BRAMBLING//BECARD/3/WBLL1*2/BRAMBLING PTSS17Y00171S-0B-099Y-099B-24Y-0B-0Y
19	MEX94.27.1.20/3/SOKOLL//ATTILA/3*BCN/4/PUB94.15.1.12/WBLL1/6/KACHU/SAUAL/4/VARIS/MISR 2/3/FRET2/KUKUNA//FRET2/5/KACHU/SAUAL PTSS19Y00213S-0M-0Y-099M-24Y-0B
20	WBLL1//YANGLING SHAANXI/ESDA/3/ROLF07/6/SUP152/BAJ #1/4/BAJ #1/3/KIRITATI//ATTILA*2 /PASTOR/5/SUP152/BAJ #1 PTSS20Y00351S-0B-099Y-099M-3Y-0B
21	MEX94.27.1.20/3/SOKOLL//ATTILA/3*BCN/4/PUB94.15.1.12/WBLL1/5/MUCUY

	PTSS14Y00328S-0B-099Y-099B-19Y-020Y
22	QUAIU*2/KINDE/6/PREMIO/4/CROC_1/AE.SQUARROSA (205)//KAUZ/3/PIFED/5/2*BORL14 PTSS21Y00240S-0M-099Y-0B-6Y-0B

23	CROC_1/AE.SQUARROSA(205)//BORL95/3/PRL/SARA//TSI/VEE#5/4/FRET2/5/CIRO16/6/CROC_
	1/AE.SQUARROSA (224)//OPATA/3/PUB94.15.1.12/WBLL1
	PTHW20Y00051S-0Y-099Y-0B-6Y-0B

24	SOKOLL CMSS97M00316S-0P20M-0P20Y-43M-010Y
25	68.111/RGB-U//WARD/3/FGO/4/RABI/5/AE.SQUARROSA (878)/6/ATTILA*2/PBW65//MURGA/7/ BORL14/8/NADI#1*2/3/MUTUS/AKURI #1//MUTUS PTSS21Y00114S-0M-099Y-099M-3Y-0B
26	PASTOR//HXL7573/2*BAU/3/WBLL1/4/BORL14/6/PREMIO/4/CROC_1/AE.SQUARROSA (205)//KAUZ/3/PIFED /5/2*BORL14 PTSS21Y00166S-0M-099Y-0B-7Y-0B
27	PASTOR//HXL7573/2*BAU/3/WBLL1/4/BORL14/6/PREMIO/4/CROC_1/ AE.SQUARROSA(205)//KAUZ/3/ PIFED /5/2*BORL14 PTSS21Y00166S-0M-099Y-0B-2Y-0B
28	PUB94.15.1.12/WBLL1/4/MEX94.27.1.20/3/SOKOLL//ATTILA/3*BCN/7/VEE/MJI//2*TUI/3/PASTOR/4/ BERKUT/5/BAVIS/6/BORL14 PTSS21Y00162S-0M-099Y-099M-6Y-0B

29	CROC_1/AE.SQUARROSA(205)//BORL95/3/PRL/SARA//TSI/VEE#5/4/FRET2/5/CIRO16/6/CROC1/
	AE.SQUARROSA (224)//OPATA/3/PUB94.15.1.12/WBLL1
	PTHW20Y00051S-0Y-099Y-0B-1Y-0B

30	NAINA #1 CMSS11B00910T-099TOPY-099M-099NJ-099NJ-37WGY-0B
31	FRET2/KUKUNA//FRET2/3/TAM200/TUI/4/FRET2*2/SHAMA/5/WBLL1/KUKUNA//TACUPETO F2001 /3/UP2338*2/VIVITSI/6/PREMIO/4/CROC_1/AE.SQUARROSA (205)//KAUZ/3/PIFED/5/2*BORL14 PTSS21Y00055S-0B-099Y-0B-10Y-0B
32	PASTOR//HXL7573/2*BAU/3/WBLL1/4/BORL14/6/PREMIO/4/CROC_1/AE.SQUARROSA(205)//KAUZ/3/ PIFED/5/2*BORL14 PTSS21Y00166S-0M-099Y-0B-9Y-0B
33	MEX94.27.1.20/3/SOKOLL//ATTILA/3*BCN/4/PUB94.15.1.12/WBLL1/5/MUCUY6/FRET2*2/BRAMBLING //BECARD/3/WBLL1*2/BRAMBLING PTSS21Y00295S-0B-099Y-0B-3Y-0B
34	68.111/RGB-U//WARDRESEL/3/STIL/4/AE.SQUARROSA (630)/5/BORL14/6/COPIO/7/KANCHAN*2/JUCHI //2*BORL14 PTSS21Y00210S-0M-099Y-099M-2Y-0B
35	KS940935.7.1.2/2*PASTOR/4/FRAME//MILAN/KAUZ/3/PASTOR/5/KUTZ PTSS17Y00001S-0B-099Y-099M-6Y-0Y
36	SHORTENEDSR26TRANSLOCATION//2*WBLL1*2/KKTS/3/BECARD/6/PREMIO/4/CROC_1/ AE.SQUARROSA(205)//KAUZ/3/PIFED/5/2*BORL14 PTSS21Y00054S-0B-099Y-0B-2Y-0B
37	SUP152//PUB94.15.1.12/WBLL1/3/MUCUY/4/KABILU #1 PTSS21Y00258S-0M-099Y-0B-7Y-0B
38	UP2338*2/VIVITSI/3/FRET2/TUKURU//FRET2/4/MISR 1/5/TUKURU//BAV92/RAYON*2/3/PVN/6/ MUCUY PTHW20Y00007S-0Y-099Y-0B-7Y-0B

39	CROC_1/AE.SQUARROSA(224)//OPATA/3/PUB94.15.1.12/WBLL1/7/C80.1/3*BATAVIA//2*WBLL1/5/
	REH/HARE//2*BCN/3/CROC_1/AE.SQUARROSA (213)//PGO/4/HUITES/6/FRANCOLIN#1/BLOUK #1
	PTHW20Y00180S-0Y-099Y-0B-4Y-0B

The sowing date was December 6, 2023, with a density of 100 kg ha^{-1}. Plots consisted of 2 beds 2 m long, with two rows and 0.80 m apart, with three replications. Fertilization consisted of 150 kg ha^{-1} of urea before sowing. An irrigation was applied for seed germination and three complementary irrigation were applied during the season; before the first complementary irrigation, 100 kg ha^{-1} of urea were applied, and other 100 kg ha^{-1} of urea were applied before the second complementary irrigation. During crop development, broad leaf weeds were controlled with herbicides, Full-mina 4 (Dimethylamine salt of 2,4-Dichlorophenoxyacetic acid) [25] and Starane Ultra (Fluroxypyr methyl) (300 mL ha^{-1}) [26] during the tillering stage (stage 24, Zadoks *et al*.[27], and for narrow leaf weeds, Axial XL (Pinoxaden + Cloquintocet-

mexyl) (400 mL ha^{-1}) [28] during stem elongation (stage 35, Zadoks). For control of the green aphid (*Schizaphis graminum* Rondani), the fabric conditioner Suavitel (1 mL L^{-1}) was applied during the flowering (stage 65, Zadoks). The daily average temperature (°C), the maximum and minimum, relative humidity, the number of cold and heat units, and precipitation were recorded from December 15, 2024 to May 15, 2025 by the weather station CIANO-910, located in block 910 in the Yaqui Valley [29]; this station belongs to the automated weather station network of Sonora [30]. Cold units were calculated as the temperature > 0.1 °C to < 10 °C that occurs in a given hour, and the heat units as the number of hours with temperature above 30 °C [31]. The variables evaluated were: plant height (cm), a thousand grain weight (g), and grain yield (g) per plot, after harvesting 0.8 m^2 from each plot with a sickle, and threshing was carried out with a Pullman stationary thresher.

3. Results and discussion

The range of the average temperature during the period of evaluation was 14.9-23.9 °C (Figure 1), while for the maximum temperature it was 30.9-40.2 °C and 2.8-9.8 °C for the minimum temperature. The occurrence of temperatures above 30 °C were more consistent from March 16 (Figure 2) to May 15, where 80.1 % of the accumulated heat units (413) was recorded during that period of the evaluation, although there were some days when the temperature reached 30 °C for 1 or several hours, like December 18 (1 hour), 19 (3), 20 (4), 21 (2), 22 (3), 23 (1), 24 (2), 29 (1), 30 (2), January 2 (1), 3 (3), February 2 (4), 3 (5), 5 (4), 6 (4), 7 (5), 8 (4), 10 (2), 14 (2), 19 (3), 22 (2), 23 (3), 24 (5), 25 (5), 27 (2), 28 (5), March 2 (1), 5 (2), and 9 (1). This condition hindered proper plant development. Unlike the 2023-2024 crop season, when maximum grain yield reached 8.4 t ha^{-1} and the group average exceeded 7 t ha^{-1} [32], the current evaluation recorded a maximum yield of 7.57 t ha^{-1} (in one replicate of line No. 22), with a group average of 6.22 t ha^{-1}. Likewise, during the 2023-2024 crop season, the group's average plant height was 101 cm, ranging from 95 to 106 cm; in contrast, for the 2024-2025 season, the average height decreased to 76.7 cm, with a range between 68.3 and 86.6 cm. Heat stress triggers significant physiological and morphological changes in plants, including reduced seed germination and seedling growth, decreased cell turgidity, and lower water-use efficiency [33]. During the period of evaluation, the accumulation of cold units (CU) was detected from December 15, 2024 to even May 1, 2025, with a total of 613, being more prevalent up to March 22; therefore, 93.7 % of the total accumulated CU (613) was recorded during that period of the evaluation. The accumulation of CU per week was as following: during the week of December 15-21 there were 58 CU, 48 in December 22-28, 49 in December 29-January 4, 48 in January 5-11, 50 in January 12-18, 56 in January 19-25, 61 in January 26-February 1, 49 in February 2-8, 26 in February 9-15, 54 in February 16-22, 16 in February 23-March 1, 24 in March 2-8, 39 in March 9-15, and 25 in March 16-22 (Figure 2). All stages of wheat plant phenology are sensitive to temperature fluctuations, where elevated temperatures enhance the plant's metabolic activity and accelerate physiological processes that drive its growth and development [34].

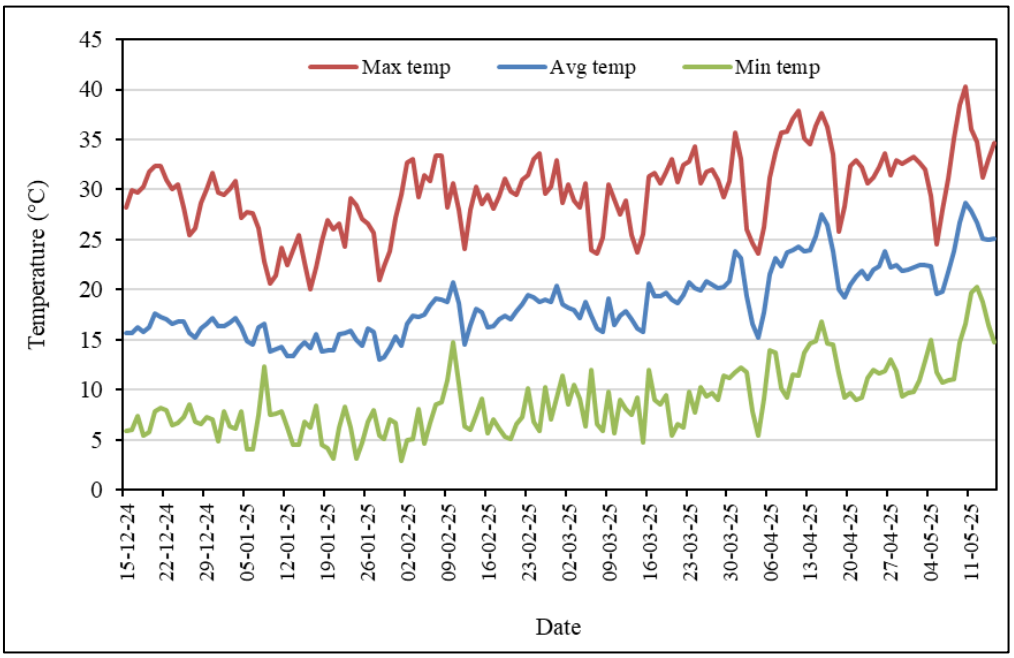

Figure 1 Average temperatures from December 15, 2024 to May 15, 2025, recorded from the weather station CIANO-910, at the Norman E. Borlaug Experimental Station in the Yaqui Valley, Sonora, Mexico, during the crop season 2024-2025

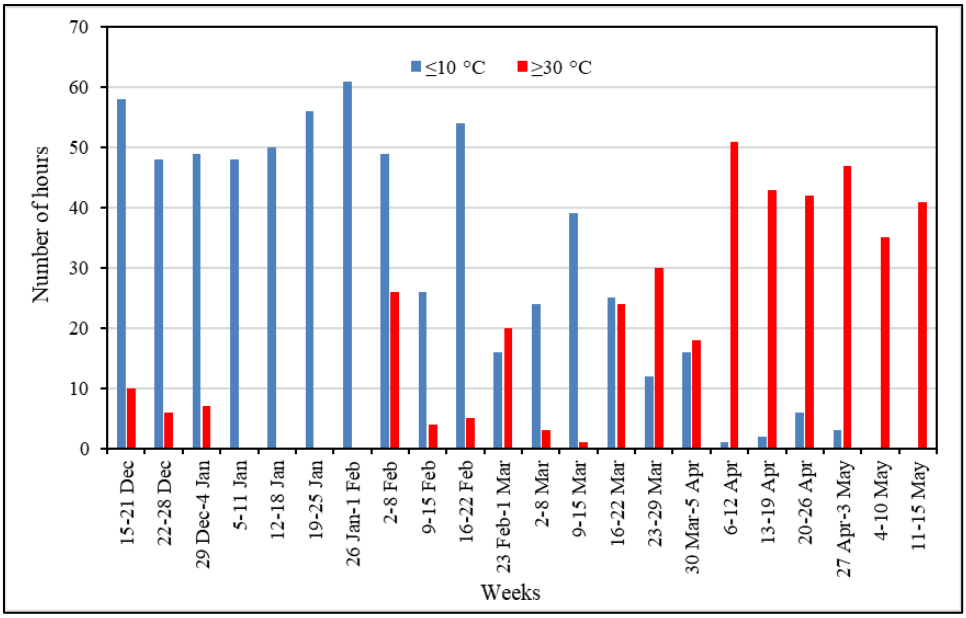

Figure 2 Number of cold and heat units accumulated from December 15, 2024 to May 15, 2025, recorded from the weather station CIANO-910, at the Norman E. Borlaug Experimental Station in the Yaqui Valley, Sonora, Mexico, during the crop season 2024-2025

The wheat plant also needs the accumulation of CU to extend its biological cycle, which typically results in higher grain yield [31]. In Southern Sonora, the recommended wheat sowing date is from November 15 to December 15. Sowing after this window often leads to poor tillering and increased exposure to heat stress [35]. The average height of the group was 76.7 cm with a range of 68.3 to 86.7 cm (Figure 3). The tallest lines were MEX94.27.1.20/3/SOKOLL//ATTILA/3*BCN/4/PUB94.15.1.12/WBLL1/5/MUCUY (line No. 21) with 86.6 cm, and SOKOLL/WBLL1/4/MUTUS//KIRITATI/2*TRCH/3/WHEAR/KRONSTADF2004/5/WBLL1*2/SHAMA//BAJ#1*2/3/BORL14 (No. 15) with 85 cm, while the shortest one was the sister line UP2338*2/VIVITSI/3/FRET2/TUKURU//FRET2/4/MISR1/5/TUKURU//BAV92/RAYON*2/3/PVN/6/MUCUY (PTHW20Y00007S-0Y-099Y-0B-8Y-0B, No. 2) with 68.3 cm. Cultivar Borlaug 100 F2014 (No. 12) showed a height of 71.7 cm, slightly below the group average. Plant height in wheat can influence susceptibility to lodging, as taller plants are generally more prone to this issue. Lodging refers to the irreversible bending or collapse of plant stems from their upright position, typically caused by wind pressure on the shoots and soil weakening from rain or irrigation, which diminishes root anchorage [36].

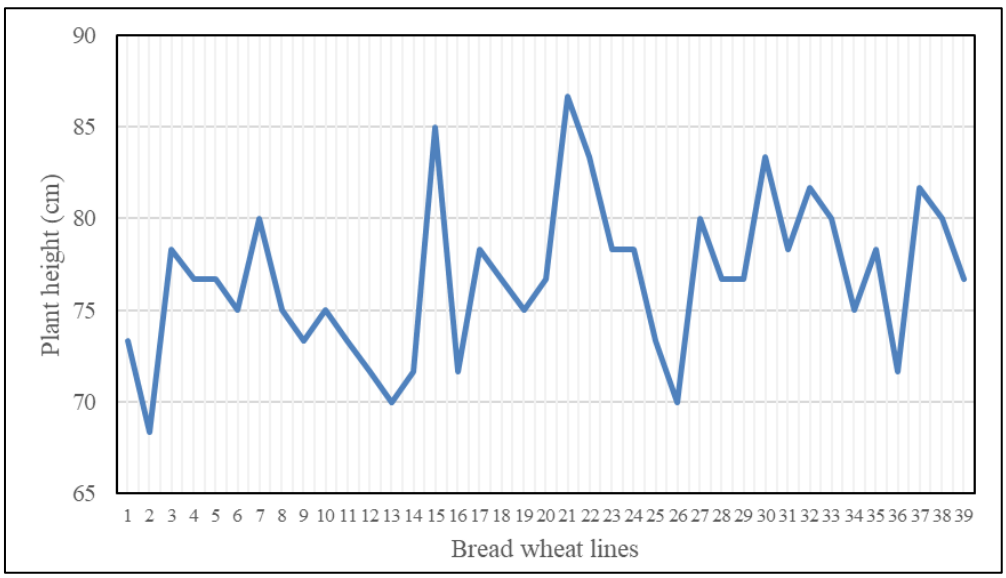

Figure 3 Average plant height of bread wheat cultivar Borlaug 100 F2014 (12), and 38 advanced bread wheat lines, at the Norman E. Borlaug Experimental Station in the Yaqui Valley, Sonora, Mexico, during the crop season 2024-2025

Yield losses in wheat due to lodging can range between 7 and 80 % [37], often accompanied by a decline in bread-making quality [36]. In the context of efforts to boost grain yield to meet growing global food demands [38], and with initiatives like the International Wheat Yield Partnership investing in this goal, preserving lodging resistance will be crucial to safeguard increased productivity. The average thousand grain weight (TGW) of the group was 50.8 g; the line QUAIU*2/KINDE/6/PREMIO/4/CROC_1/AE.SQUARROSA(205)//KAUZ/3/PIFED/5/2*BORL14 (No. 22) showed the highest weight with 58.3 g, a 7.5 g difference above the average, followed by SOKOLL/3/PASTOR//HXL7573/2*BAU/5/ CROC_1/AE.SQUARROSA(205)//BORL95/3/PRL/SARA//TSI/VEE#5/4/FRET2/6/ BORL14*2//BECARD/QUAIU #1 (No. 16), and NAINA #1 (No. 30), both with 56. 8 g (Figure 4). Lines with the lowest a TGW were SUP152// PUB94.15.1.12/WBLL1/3/MUCUY/4/KABILU #1 (No. 37) and SOKOLL/WBLL1/4/MUTUS//KIRITATI/2*TRCH/3/ WHEAR/KRONSTADF2004/5/WBLL1*2/SHAMA//BAJ#1*2/3/BORL14 (No. 15) with 45.3 and 44.0 g, respectively, while cultivar Borlaug 100 F2014 (No. 12) was below the average value with 50.2 g.

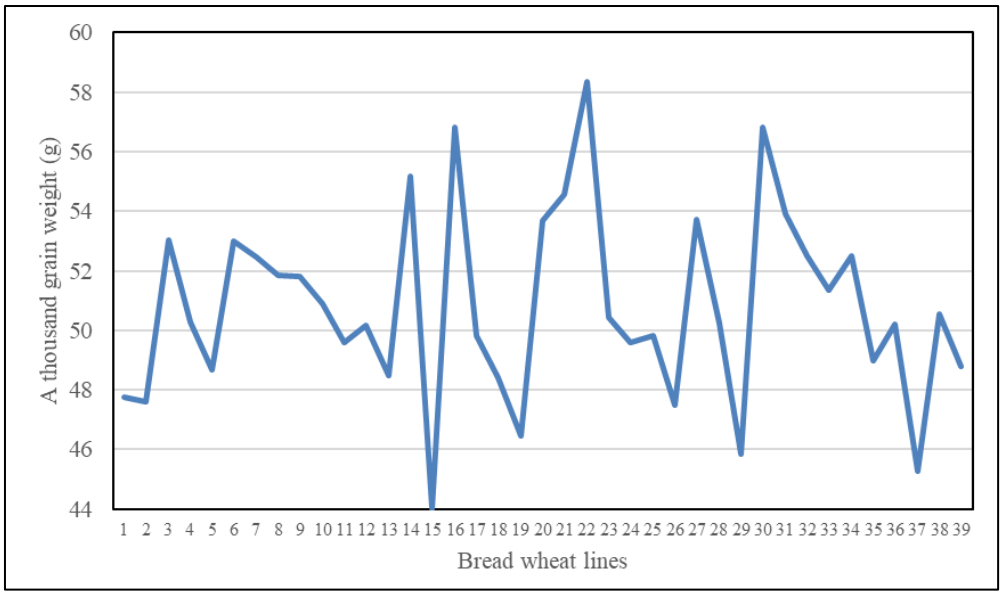

Figure 4 Average a thousand grain weight of bread wheat cultivar Borlaug 100 F2014 (12), and 38 advanced bread wheat lines, at the Norman E. Borlaug Experimental Station in the Yaqui Valley, Sonora, Mexico, during the crop season 2024-2025

According to Baillot *et al*. [39], the TGW is one of the components that determine the grain yield in wheat; it represents the average value of the individual grain weight, which depends on its position within the ear and its position within the spikelet. It measures the mass of the wheat kernel and is an essential parameter for the selection of cultivars with the best physical and physiological seed quality. Generally, higher TGW values are positively related to potential flour extraction or yield [40], because this property is closely related to grain size and proportion of endosperm to germ and pericarp tissues [41]. Wheat breeders and flour millers employ this method as a complement to test weight to better describe wheat kernel composition and potential flour extraction [42]. TGW is a key trait in wheat breeding due to its phenotypic stability and moderately high heritability, typically ranging from 0.6 to 0.8; this makes TGW a reliable and practical target for selection aimed at increasing grain yield [43,44,45]. For instance, a linear regression analysis of over 1,850 Chinese wheat cultivars released since the 1920s showed that the average TGW rose from 30.16 g in the 1920s to 38.43 g in the 2010s. During the same period, average grain yield increased from 2.01 to 6.58 t ha^{-1}, highlighting the substantial role of TGW improvement in boosting overall yield [46]. For grain yield per plot, the average yield of the group was 497.7 g with a range of 410.7 to 575.3 (Figure 5).

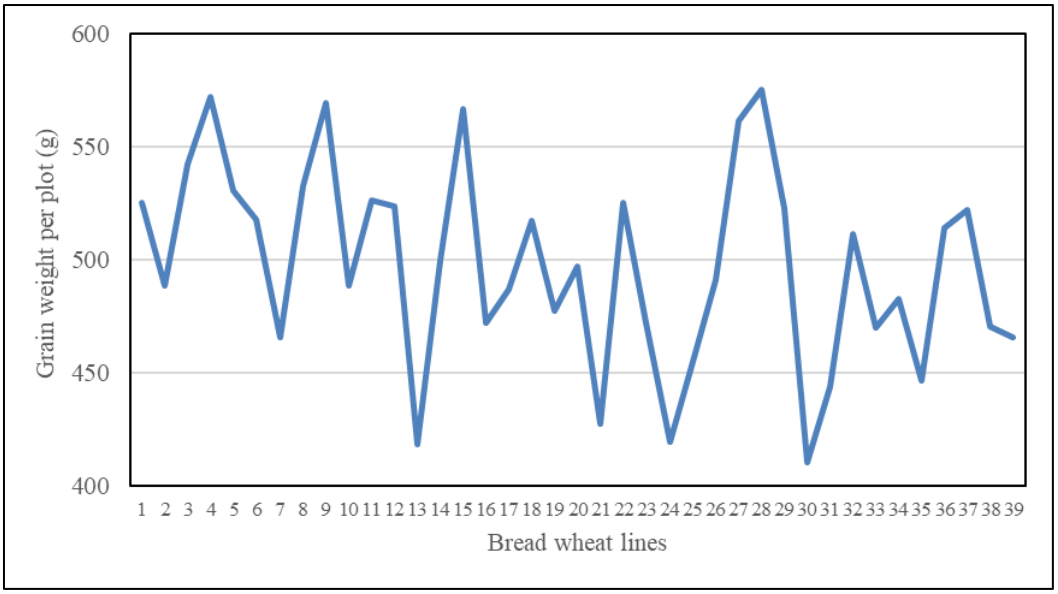

Figure 5 Average grain weight per plot of bread wheat cultivar Borlaug 100 F2014 (12), and 38 advanced bread wheat lines, at the Norman E. Borlaug Experimental Station in the Yaqui Valley, Sonora, Mexico, during the crop season 2024-2025

Cultivar Borlaug 100 F2014 showed an average grain yield above the group average with 524 g, while line PUB94.15.1.12/WBLL1/4/MEX94.27.1.20/3/SOKOLL//ATTILA/3*BCN/7/VEE/MJI//2*TUI/3/PASTOR/4/BERKUT/5/BAVIS/6/BORL14 (No. 28) showed the highest yield with 575.3 g, followed by sister line WBLL1//YANGLINGSHAANXI/ESDA/3/ROLF07/6/SUP152/BAJ#1/4/BAJ#1/3/KIRITATI//ATTILA*2/PASTOR/5/SUP152/BAJ#1 (PTSS20Y00351S-0B-099Y-099M-1Y-0B, No. 4) with 572 g, which correspond to 6.55, 7.19, and 7.15 t ha^{-1}, respectively. The TGW of Borlaug 100 F2014 and the two lines was below the average value of the group. Other high-yielding lines were NINGA #1 (No. 9), SOKOLL/WBLL1/4/MUTUS//KIRITATI/2*TRCH/3/WHEAR/KRONSTADF2004/5/WBLL1*2/SHAMA//BAJ#1*2/3/BORL14 (No. 15), and sister line PASTOR//HXL7573/2*BAU/3/WBLL1/4/BORL14/6/PREMIO/4/CROC_1/AE.SQUARROSA(205)//KAUZ/3/PIFED/5/2*BORL14 (PTSS21Y00166S-0M-099Y-0B-2Y-0B, No. 27) with 7.12, 7.08, and 7.02 t ha^{-1}, respectively. There were 11 lines with higher grain yield than Borlaug 100 F2024, and although it was reported that this cultivar produced a grain yield of 8.79 t ha^{-1} under full irrigation (four complementary irrigations) [47], in our evaluation it was short by 2.24 t ha^{-1}. According to García [48], wheat yield is primarily determined by the number of grains per unit area and their individual weight. While the number of grains has a strongly correlation with total yield and is largely influenced by agronomic practices, grain weight is more affected by climatic conditions during the grain-filling stage. In contrast, Estrada-Campuzano *et al*. [49] emphasize that grain weight – defined during the period from flowering to physiological maturity – is one of the numerical components of yield and is susceptible to both biotic and abiotic stresses. However, Peltonen-Sainio *et al*. [50] reported that grain weight is not directly correlated with yield. Despite this, some germplasm combinations developed by the International Maize and Wheat Improvement Center express high yields with high grain weight [51].

4. Conclusion

The average plant height of the group was 76.7 cm with a range of 68.3 to 86.6; the tallest lines were MEX94.27.1.20/3/SOKOLL//ATTILA/3*BCN/4/PUB94.15.1.12/WBLL1/5/MUCUY with 86.6 cm, and SOKOLL/WBLL1/4/MUTUS//KIRITATI/2*TRCH/3/WHEAR/KRONSTADF2004/5/WBLL1*2/SHAMA//BAJ#1*2/3/BORL14 with 85 cm, while the shortest one was the sister line UP2338*2/VIVITSI/3/FRET2/TUKURU//FRET2/4/MISR1/5/TUKURU//BAV92/RAYON*2/3/PVN/6/MUCUY (PTHW20Y 00007S-0Y-099Y-0B-8Y-0B) with 68.3 cm.

The average a thousand grain weight of the group was 50.8 g, with a range of 44.0 to 58.4 g; the line QUAIU*2/KINDE/6/PREMIO/4/CROC_1/AE.SQUARROSA(205)//KAUZ/3/PIFED/5/2*BORL14 showed the highest weight with 58.4 g.

The average grain weight per plot of the group was 497.7 g, with a range of 410.7 to 575.3; lines with the highest grain weight were PUB94.15.1.12/WBLL1/4/MEX94.27.1.20/3/SOKOLL//ATTILA/3*BCN/7/VEE/MJI//2*TUI/3/PASTOR/4/BERKUT/5/BAVIS/6/BORL14 with 575.3 g, and sister line WBLL1//YANGLINGSHAANXI/ESDA/3/ROLF07/6/

SUP152/BAJ#1/4/BAJ#1/3/KIRITATI//ATTILA*2/PASTOR/5/SUP152/BAJ#1 (PTSS20Y 00351S-0B-099Y-099M-1Y-0B) with 572 g, which correspond to 7.19, and 7.15 t ha^{-1}, respectively.

The average temperature was 18.7 °C with a maximum of 40.2 °C and a minimum of 2.8 °C; the average relative humidity was 49.5 %; there were 0.1 mm of precipitation, and the number of heat and cold units was 413 and 643, respectively.

Compliance with ethical standards

Acknowledgments

This research was financially supported by the Mexican National Institute for Forestry, Agriculture, and Livestock Research (INIFAP).

Disclosure of conflict of interest

The authors declare that No conflict of interest.

References

[1] FAOSTAT (Statistical Services of the Food and Agriculture Organization of the United Nations). 2020. Food and agriculture data. Production. https://www.fao.org/faostat/es/#data/QCL. Accessed on September 20, 2022.

[2] FAOSTAT (Statistical Services of the Food and Agriculture Organization of the United Nations). 2024. FAO briefing note on cereal supply and demand. WorldFoodSituation website: https://www.fao.org/worldfoodsituation/csdb/es/. Accessed on February 17, 2024.

[3] CIMMYT (International Maize and Wheat Improvement Center). 2019. The use of "synthetic hexaploid wheat" derived from Aegilops plants adds diversity and resilience to modern bread wheat. Available at: https://www.cimmyt.org/es/noticias/el-usodel-trigo-hexaploide-sintetico-derivado-de-plantas-aegilops-agrega-diversidad-yresilencia-al-trigo-harinero-moderno/.

[4] DGSIAP (General Directorate of the Agri-Food and Fisheries Information Service). 2024. Progress of sowing and harvesting. National summary by state. Wheat grain. Fall-winter season. Irrigation + rainfed. Available at: https://nube.agricultura.gob.mx/avance_agricola/. Accessed on June 5, 2025.

[5] Beltrán Ontamucha JA. 2019. Yaqui Valley and Mayo Valley, a historic commitment to science. Centro Internacional de Mejoramiento de Maíz y Trigo. https://idp.cimmyt.org/valle-del-yaqui-y-valle-del-mayo-una-apuesta-historica-por-la-ciencia/. Accessed on August 25, 2024.

[6] Calderón PE. 2017. The Yaquis and flooding of the river. A history of the hydraulic control of the Yaqui River. Culturales 1(2):67-106. Available at: https://www.scielo.org.mx/scielo.php?script=sci_ arttext&pid=S1870-11912017000300067.

[7] Torres-Cruz MM, Fuentes-Dávila G, and Félix-Valencia P. 2023. Prevailing temperatures and cold units in the Yaqui and Mayo Valleys, Mexico, during the 2021-2022 fall-winter crop season. World Journal of Advanced Research and Reviews 19(02):816-821. DOI: https://doi.org/10.30574/wjarr.2023.19.2.1639.

[8] CONAGUA (National Water Commission). 2015. Statistics on Water in Mexico. Editionhttp://www.conagua.gob.mx/CONAGUA07/Publicaciones/Publicaciones/EAM2015-ing.pdf.

[9] Herrera-Pantoja M, and Hiscock KM. 2015. Projected impacts of climate change on water availability indicators in a semi-arid region of central Mexico. Environmental Science and Policy 54(12):81-89. https://doi.org/10.1016/j.envsci.2015.06.020.

[10] FIRA (Trusts Established in Relation to Agriculture). 2014. Agri-Food Panorama: Wheat. Diesses 1(1):15-25. http://www.equalrightstrust.org/ertdocumentbank/Pages from Declaration perfect principle.pdf.

[11] SIAP (Agri-Food and Fisheries Information Service). 2023. Statistical yearbook of agricultural production. Agri-food and Fisheries Information Service, SADER (Ministry of Agriculture and Rural Development). Mexico, D.F. available at: https://nube.siap.gob.mx/cierreagricola/.

[12] Rosas-Jáuregui IA, Fuentes-Dávila G, Félix-Fuentes JL, Ortiz-Avalos AA, and Cortés-Jiménez JM. 2023. Determination of yield components in four durum wheat cultivars during the fall-winter 2020-2021 agricultural

season in the Yaqui Valley, Sonora, Mexico. Brazilian Journal of Animal and Environmental Research 6(3):2736-2746. DOI: 10.34188/bjaerv6n3-060.

[13] Fuentes-Davila G, Rajaram S, Pfeiffer WH, Abdalla O, Van-Ginkel M, Mujeeb-Kazi A, and Rodriguez-Ramos R. 1993. Results of artificial inoculations of the 5th Selection Nursery for Resistance to *Tilletia indica* Mitra. Revista Mexicana de Micología 9:57-65.

[14] Fuentes-Dávila G, Rosas-Jáuregui IA, Félix-Fuentes JL, Félix-Valencia P, Borbón-Gracia A. and Torres-Cruz MM. 2023. Reaction of durum wheat cultivars and advanced lines to partial bunt (Tilletia indica). Brazilian Journal of Animal and Environmental Research 6(2):1391-1402. DOI: 10.34188/bjaerv6n2-036.

[15] SIAP (Agri-Food and Fisheries Information Service). 2024. Monthly scenario of agri-food producers. Strategic analysis department. chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.gob.mx/cms/uploads/attachment/file/938471/Trgo_Panificable_Julio.pdf. Accessed on November 1, 2024.

[16] SIDALC (Agricultural Information Services Alliance). 2024. 1st Wheat Yield Collaboration Yield Trial https://sidalc.net/search/Record/dat-cimmyt-1152910548295/Similar. Accessed on February 15, 2024.

[17] García E. 2004. Modifications to the Köppen climate classification system. Institute of Geography of the National Autonomous University of Mexico. Book Series number 6. México, D.F. 90 p. Available at: http://www.publicaciones.igg.unam.mx/index. php/ig/catalog/view/83/82/251-1.

[18] Camacho-Casas MA, Chávez-Villalba G, Fuentes-Dávila G, Figueroa-López P, Huerta-Espino J, Villaseñor-Mir HE, y Ortiz-Monasterio JI. 2017. Borlaug 100: variety of bread wheat for northwest Mexico. Technical Brochure No. 100. Norman E. Borlaug Experimental Station, INIFAP. Ciudad Obregón, Sonora, México. 32 p.

[19] CESAVESON (Plant Health Committee of the State of Sonora). 2020. Area with planting permit by variety. Available at: https://osiap.org.mx/senasica/quienes-estado/sonora/Agricola.

[20] CESAVESON (Plant Health Committee of the State of Sonora). 2021. Area with planting permit by variety. Available at: https://osiap.org.mx/senasica/quienes-estado/sonora/Agricola.

[21] CESAVESON (Plant Health Committee of the State of Sonora). 2022. Area with planting permit by variety. Available at: https://osiap.org.mx/senasica/quienes-estado/sonora/Agricola.

[22] CESAVESON (Plant Health Committee of the State of Sonora). 2023. Area with planting permit by variety. Available at: https://osiap.org.mx/senasica/quienes-estado/sonora/Agricola.

[23] CESAVESON (Plant Health Committee of the State of Sonora). 2024. Area with planting permit by variety. Available at: https://osiap.org.mx/senasica/quienes-estado/sonora/Agricola.

[24] Chávez-Villalba G, Borbón-Gracia A, Díaz-Cisneros HL, Alvarado-Padilla JI, Huerta-Espino J, García-León E, and Fuentes-Dávila G. 2021. CIANO M2018: New bread wheat variety for northewestern Mexico. Revista Fitotecnia Mexicana 44(3):477-479. DOI: https://doi.org/10.35196/rfm.2021.3.477.

[25] Dow AgroSciences. 2024. Full-Mina 4. Technical Sheet. Available at: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.corteva.co/content/dam/dpagco/corteva/la/mx/es/products/files/DF-label-FullMina4.pdf.

[26] Corteva Agriscience México. 2024. Technical Sheet. Available at: https://www.corteva.mx/ productos-y-soluciones/proteccion-de-cultivos/starane-ultra.html.

[27] Zadoks JC, Chang TT, and Konzak CF. 1974. A decimal code for the growth stages of cereals. Weed Research 14:415-421. https://doi.org/10.1111/j.1365-3180. 1974.tb01084.x

[28] SYNGENTA México. 2024. Axial XL. Technical Sheet. Available at: https://www.syngenta.com.mx/sites/g/files/zhg501/f/media/2019/09/07/axial_xl.pdf?token=1567883834.

[29] Torres-Cruz MM, Fuentes-Dávila G, and Felix-Valencia P. 2021. Prevailing temperatures, cold and heat units in the Yaqui and Mayo Valleys, Mexico, during the 2019-2020 wheat season. International Journal of Agriculture, Environment and Bioresearch 6(4):1-6. https://doi.org/10.35410/IJAEB.2021.5647.

[30] REMAS (Network of Automatic Meteorological Stations of Sonora). 2024. Descargar datos. http://www.siafeson.com/remas/. Accessed on July 24, 2024.

[31] Félix-Valencia P, Ortíz-Enríquez JE, Fuentes-Dávila G, Quintana-Quiróz JG. y Grageda-Grageda J. 2009. Cold hours in relation to wheat yield: production areas of the state of Sonora. INIFAP, Northwest Regional Research Center,

Yaqui Valley Experimental Station. Technical Brochure No. 63. Cd. Obregón, Sonora, México. 40 p. ISBN 978-607-425-159-3.

[32] Rosas-Jáuregui IA, Fuentes-Dávila G, Félix-Fuentes JL, Torres-Cruz MM, and Ortiz-Avalos AA. 2024. Performance of the 11th bread wheat yield consortium established in the Yaqui Valley, Sonora, Mexico, during the 2023-2024 crop season. Magna Scientia Advanced Research and Reviews 12(02):293-303. https://doi.org/10.30574/msarr.2024.12.2.0208.

[33] Akter N, and Rafiqui IM. 2017. Heat stress effects and management in wheat. A review. Agronomy for Sustainable Development 37:37(1-17). DOI: 10.1007/s13593-017-0443.9.

[34] Moreno Dena JM, Salazar Solano V, y Rojas Rodríguez IS. 2018. Economic impacts of cold hours on wheat production in Sonora, Mexico. Entreciencias: diálogos en la sociedad del conocimiento: 6(16):15-29. https://doi.org/10.22201/enesl.20078064e.2018. 16.63206.

[35] Figueroa-López P, Fuentes-Dávila G, Cortés-Jiménez JM, Tamayo-Esquer LM, Félix-Valencia P, Ortiz-Enríquez JE, Armenta-Cárdenas I, Valenzuela-Herrera V, Chávez-Villalba G, and Félix-Fuentes JL. 2011. Guide to produce wheat in southern Sonora. INIFAP, Northwest Regional Research Center, Norman E. Borlaug Experimental Field. Brochure for Producers No. 39. Cd. Obregón, Sonora, México. 63 p. ISBN: 978-607-425-518.8.

[36] Berry PM, Sterling M, Spink JH, Baker C J, Sylvester-Bradley R, Mooney SJ, and Ennos AR. 2004. Understanding and reducing lodging in cereals. Advances in Agronomy 84(04):215-269. https://doi.org/10.1016/S0065-2113(04)84005-7.

[37] Berry PM, and Spink J. 2012. Predicting yield losses caused by lodging in wheat. Field Crops Research 137:19-26. https://doi.org/10.1016/j.fcr.2012.07.019.

[38] Reynolds M, Foulkes J, Furbank R, Griffiths S, King J, Murchie E, Parry M, and Slafer G. 2012. Achieving yield gains in wheat. Plant, Cell and Environment 35:1799-1823.https://doi.org/10.1111/j.1365-3040.2012.02588.x.

[39] Baillot N, Girousse C, Allard V, Piquet-Pissaloux A, Le Gouis J. 2018. Different grain-filling rates explain grain-weight differences along the wheat ear. PLOS ONE 13(12):e0209597. https://doi.org/10.1371/journal.pone.0209597.

[40] Gutiérrez-García AS, Carballo-Carballo A, Mejía-Contreras JA, Vargas-Hernández M, Trethowan R, Villaseñor-Mir HE. 2006. Characterization of bread wheat using seed physical and physiological quality parameters. Technical Agriculture in Mexico 32:45-55.

[41] Serna-Saldívar SO. 2010. Cereal grains: Properties, processing and nutritional attributes. CRC Press, Taylor and Francis Group. Boca Raton, Florida, USA. 752 p. https://doi.org/10.1201/9781439882092.

[42] U.S. Wheat Associates. 2007. Overview of U.S. wheat inspection of wheat and flour testing methods: A guide to understanding wheat and flour quality: Version 2. 72 p. wheat Marketing Center, Inc. Portland, Oregon, USA. Available at: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://uswheat.org/ wp-content/uploads/2024/07/Wheat-and-Flour-Testing-Methods-Book.pdf.

[43] Wang L, Ge H, Hao C, Dong Y, and Zhang X. 2012. Identifying loci influencing 1,000-kernel weight in wheat by microsatellite screening for evidence of selection during breeding. PLoS One 7:e29432. doi: 10.1371/journal.pone.0029432.

[44] Avni R, Oren L, Shabtay G, Assili S, Pozniak C, Hale I, Ben-David R, Peleg Z, and Distelfeld A. 2018. Genome based meta-QTL analysis of grain weight in tetraploid wheat identifies rare alleles of GRF4 associated with larger grains. Genes 9:636. doi: 10.3390/genes9120636.

[45] Duan X, Yu H, Ma W, Sun J, Zhao Y, Yang R, Ning T, Li Q, Liu Q, Guo T, Yan M, Tian J, Chen J. 2020. A major and stable QTL controlling wheat thousand grain weight: identification, characterization, and CAPS marker development. Molecular Breeding 40:68. doi: 10.1007/s11032-020-01147-3.

[46] Qin X, Zhang F, Liu C, Yu H, Cao B, Tian S, Liao Y, Siddique HM. 2015. Wheat yield improvements in China: past trends and future directions. Field Crops Research 177:117-124. doi: 10.1016/j.fcr.2015.03.013.

[47] Díaz-Ceniceros HL, Borbón-Gracia A, Fuentes-Dávila G, Chávez-Villalba G, Villaseñor-Mir HE, Martínez-Cruz E, and Hortelano-Santa Rosa R. 2021. Evaluation of elite bread wheat lines from the 16th National Bread Wheat Trial in southern Sonora, Mexico. Annual Wheat Newsletter 67:33-35. Available at: https://krex.k-state.edu/server/api/core/bitstreams/7fa8aef6-7377-4265-8162-0592c8333703/content.

[48] García A. 2017. Sowing density in wheat. Revista INIA 6(49):17-22. Available at: http://www.ainfo.inia.uy/digital/bitstream/item/6965/1/revista-INIA-49.p17-22.pdf.

[49] Estrada-Campuzano G, Miralles DJ, and Slafer GA. 2008. Genotypic variability and response to water stress of pre- and post-anthesis phases in triticale. European Journal of Agronomy 28(3):171- 177. doi:10.1016/j.eja.2007.07.005.

[50] Peltonen-Sainio P, Kangas A, Salo Y, and Jauhiainen L. 2007. Grain number dominates grain weight in temperate cereal yield determination: evidence based on 30 years of multi-location trials. Field Crops Research 100(2-3):179-188. DOI:10.1016/j.fcr.2006.07.002.

[51] Rattey A, Shorter R, Chapman S, Dreccer F, and Herwaarden A. 2009.Variation for and relationships among biomass and grain yield component traits conferring improved yield and grain weight in an elite wheat population grown in variable yield environments. Crop and Pasture Science 60(8):717-729. https://doi.org/10.1071/CP08460.