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Performance of the 11th bread wheat yield consortium established in the Yaqui Valley, Sonora, Mexico, during the 2023-2024 crop season

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Abstract

Forty two advanced bread wheat lines and commercial cultivars Borlaug 100 F2014 and CIANO M2018, were evaluated for grain yield field performance in the Yaqui Valley, Sonora, Mexico, during the crop season 2023-2024. The sowing date was December 13, 2023, 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, 2023 to May 15, 2024. The variables evaluated were: days to heading, plant height (cm), a thousand grain weight (g), and grain yield (g) per plot. The average days for heading of lines was 71 with a range of 69 to 74. The average plant height of the group was 101 cm with a range of 95 to 106; the tallest lines were NAINA#1 and WBLL1/6/ATTILA*2/PBW65*2/5/REH/HARE//2*BCN/3/CROC_1/AE.SQUARROSA(213)//PGO/4/HUITES/7/CROC_1/AE.SQUARROSA(205)//BORL95/3/PRL/SARA//TSI/VEE#5/4/FRET2/5/CIRO16 with 106 cm, and the shortest the sister line SERI/BAV92//PUB94.15.1.12/WBLL1/3/BORL14 (PTSS19Y00217S-0M-0Y-099B-19Y-0B) with 95 cm. The average a thousand grain weight of the group was 58.1 g, with a range of 39.6 to 62.6 g; the sister line PRL/2*PASTOR//2*CIRO16/3/KUTZ (PTSS19Y00198S-0M-0Y-099M-24Y-0B) showed the highest weight with 62.6 g. The average grain weight per plot of the group was 492 g, with a range of 396 to 581; lines with the highest grain weight were sister line BAV92/SERI//BORL14 (PTSS19Y00287S-0M-0Y-099M-15Y-0B) with 581 g, RL6043/4*NAC//2*PASTOR/3/BCN/WBLL1/4/KUTZ with 567.3, NAINA #1 with 562, and SOKOLL with 546.7 g, which correspond to 7.27, 7.09, 7.03, and 6.83 t ha^{-1}, respectively. The average temperature was 17.9 °C with a maximum of 35.8 °C and a minimum of 1.6 °C; the average relative humidity was 60.8 %; there were 2.5 mm of precipitation, and the number of heat and cold units was 233 and 494, respectively

Keywords: Bread wheat; *Triticum aestivum*; Grain yield; Trial

1. Introduction

Wheat (*Triticum* spp.) is one of the crops most cultivated around the world for human consumption, but the main cereal worldwide is maize (*Zea mays* L.) followed by wheat and rice (*Oryza sativa* L.) [1]. This cereal has great adaptation, use, grain yield capacity, nutritional quality, and it covers at least 21 % of the world's food needs [2]. It occupies first place in terms of cultivated area with 222 million hectares worldwide and 50 million in developing countries; of this area, at least 50 % is managed under rainfed systems, with erratic rainfall, infertile soils and extreme heat or cold conditions,

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where drought is one of the main limiting factors of production [3]. In Mexico, it is among the five main crops produced. Wheat is sown in the fall-winter crop seasons in the northern and northwestern regions, as well as spring-summer sowing in the central region. The largest wheat production is concentrated in five states (Sonora, Baja California, Sinaloa, Guanajuato, and Chihuahua), which together represent around 92 % of the total national production [4]. More than 90 % of the wheat production is carried out under irrigated conditions [5]. Most wheat production in Sonora takes place in the southern part of the state in the Yaqui Valley and to a lesser extent in the Mayo Valley; both valleys have an arid climate and poor humidity for most of the year; they are considered a world reference in wheat production [6]; however, since Southern Sonora is prone to limitations in water availability [7], the agricultural area is irrigated with water from dams [8]. One of the limitations in the main wheat production areas such as southern Sonora and Bajío is their low natural water availability, which is why both regions are classified within the administrative hydrological regions with a high degree of stress [9], and that future scenarios of greater scarcity must be considered [10]. At the national level, production is divided according to the type of wheat cultivated. The states of Sonora and Baja California are best known for their production of durum wheat, while Guanajuato and Jalisco produce more bread wheat with medium-strong gluten [11]. Of the wheat area established in the state of Sonora, only 20 % is established with bread wheat cultivars [12], since historically, durum wheat cultivars have greater production potential in the area [13] and resistance to Karnal bunt [14,15]; therefore, the generation of new bread wheat cultivars with greater yield potential, industrial quality and tolerance to diseases is important, so that in the future the area sown with this type of cereal increases, with the consequent reduction in the importation of this type of wheat which in 2023 was above 5 million ton [16]. The Wheat Yield Collaboration Yield Trial (WYCYT) is a network of field trials that aims to increase the yield potential of spring wheat, through the strategic crossing of physiological traits related to source and sink potential in wheat [17]. These trials have been phenotyped in the major wheat-growing mega environments through the International Wheat Improvement Network (IWIN), and the Cereal System Initiative for South Asia (CSISA) network, which included a total of 136 environments (site-year combinations), in major spring wheat-growing countries such as Bangladesh, China, Egypt, India, Iran, Mexico, Nepal, and Pakistan. The objective of this work was to evaluate the field performance of a set of 42 advanced bread wheat lines during the crop season fall-winter 2023-2024.

2. Material and methods

Forty two advanced bread wheat lines that comprised the 11th Wheat Yield Collaboration Yield Trial (WYCYT), which included nine groups of sister lines (lines 1 and 14; 2 and 21; 3, 6, 8, 11, and 26; 7 and 20; 13 and 17; 23 and 32; 25 and 35; 28 and 37; and 31 and 34) (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 Garcia [18]. Commercial bread wheat cultivars Borlaug 100 F2014 [19] and CIANO M2018 [20] were used as checks. The first cultivar is the bread wheat most used by farmers in southern Sonora; in the 2019-2020 wheat season, 94,865.61 ha of bread wheat were established, of which 88.9 % of the area was covered by this cultivar [21]; in 2020-2021, 42,694.86 ha of bread wheat were established, of which 86.38 % of the area was covered by Borlaug 100 F2014 [22]; and in 2021-2022, of 40,376.46 ha established with bread wheat, 91.7 % of the area was covered by this same cultivar [23]. Borlaug 100 F2014 has shown yield stability, it is moderately susceptible to partial bunt (*Tilletia indica* Mitra), and resistant to leaf rust (*Puccinia triticina* Eriks.) and to yellow or stripe rust (*Puccinia striiformis* Westend. f. sp. *tritici* Eriks.). Although CIANO M2018 was released in 2018 and it was reported that in experimental trials during the 2017-2018 to 2019-2020 wheat seasons, it overcame Borlaug 100 F2014 in grain yield by 1.58 and 6.27 % with two and four auxiliary irrigations, respectively [24], it occupied only 6,718 ha in southern Sonora during the crop season 2023-2024 [25] .

Table 1 Advanced bread wheat lines of the 11th Wheat Yield Collaboration Yield Trial and commercial cultivars Borlaug 100 F2014 and CIANO M2018, sown on December 13, 2023, at the Norman E. Borlaug Experimental Station, in the Yaqui Valley, Sonora, Mexico

NO.	Pedigree and selection history
1.	SOKOLL/WBLL1/5/CROC_1/AE.SQUARROSA(205)//BORL95/3/PRL/SARA//TSI/VEE#5/4/FRET2/6/ KACHU/SAUAL//CIRO16 PTSS18Y00170S-0M-099Y-099M-38Y-0Y
2.	ALTAR 84/AE.SQUARROSA (237) /4/2*KIRITATI/WBLL1//2*BLOUK #1*2/3/KACHU #1/KIRITATI//KACHU

	PTSS20B00072T-099Y-099M-2Y-0B
3.	SOKOLL/3/KACHU/SAUAL//CIRO16 PTSS19Y00313S-0M-0Y-099M-4Y-0B
4.	KACHU/SAUAL*2/5/SERI.1B//KAUZ/HEVO/3/AMAD*2/4/KIRITATI/6/CIANO M2018 PTSS20Y00206S-0B-099Y-0B-8Y-0B
5.	BORLAUG100 F2014 CMSS06Y00605T-099TOPM-099Y-099ZTM-099Y-099M-11WGY-0B-0MEX
6.	SOKOLL/3/KACHU/SAUAL//CIRO16 PTSS19Y00313S-0M-0Y-099M-16Y-0B
7.	PRL/2*PASTOR//2*CIRO16/3/KUTZ PTSS19Y00198S-0M-0Y-099M-1Y-0B
8.	SOKOLL/3/KACHU/SAUAL//CIRO16 PTSS19Y00313S-0M-0Y-099M-7Y-0B
9.	SERI.1B*2/3/KAUZ*2/BOW//KAUZ/4/FRANCOLIN#1/5/MUNAL/6/KACHU#1/KIRITATI//KACHU/7/ CIANOM2018 PTSS20Y00252S-0B-099Y-099B-3Y-0B
10.	SUP152//PUB94.15.1.12/WBLL1/3/MUCUY/4/SAUAL/MUTUS*2//PICAFLOR #1 PTSS20Y00312S-0B-099Y-099M-5Y-0B
11.	SOKOLL/3/KACHU/SAUAL//CIRO16 PTSS19Y00313S-0M-0Y-099M-3Y-0B
12.	SOKOLL CMSS97M00316S-0P20M-0P20Y-43M-010Y
13.	SERI/BAV92//PUB94.15.1.12/WBLL1/3/BORL14 PTSS19Y00217S-0M-0Y-099B-8Y-0B
14.	SOKOLL/WBLL1/5/CROC_1/AE.SQUARROSA(205)//BORL95/3/PRL/SARA//TSI/VEE#5/4/FRET2/6/ KACHU/SAUAL//CIRO16 PTSS18Y00170S-0M-099Y-099M-45Y-0Y
15.	SOKOLL/WBLL1/4/2*PASTOR//HXL7573/2*BAU/3/WBLL1/5/SCOOP_1/AE.SQUARROSA(634)// KACHU/3/BAJ #1 PTSS20Y00477S-0B-099Y-0B-3Y-0B
16.	TUKURU//BAV92/RAYON/3/BORL14//BECARD/QUAIU #1 PTSS20Y00154S-0B-099Y-099M-5Y-0B
17.	SERI/BAV92//PUB94.15.1.12/WBLL1/3/BORL14 PTSS19Y00217S-0M-0Y-099B-19Y-0B
18.	CIANO M2018 CMSS12B00828T-099TOPY-099M-0SY-42M-0WGY
19.	BCN/WBLL1//ROLF07/4/SCOOP_1/AE.SQUARROSA (634)//KACHU/3/BAJ #1 PTSS20Y00473S-0B-099Y-0B-3Y-0B
20.	PRL/2*PASTOR//2*CIRO16/3/KUTZ PTSS19Y00198S-0M-0Y-099M-24Y-0B
21.	ALTAR 84/AE.SQUARROSA (237)/4/2*KIRITATI/WBLL1//2*BLOUK #1*2/3/KACHU #1/KIRITATI//KACHU PTSS20B00072T-099Y-099M-8Y-0B
22.	BCN/WBLL1//ROLF07/3/BORL14

	PTSS18Y00057S-0M-099Y-099M-55Y-0Y
23.	SORA/AE.SQUARROSA (617)/4/2*NADI#2//TRCH/HUIRIVIS #1/3/NADI#1 PTSS20B00071T-099Y-099M-10Y-0B
24.	MEX94.27.1.20/3/SOKOLL//ATTILA/3*BCN/4/PUB94.15.1.12/WBLL1/5/MUCUY PTSS14Y00328S-0B-099Y-099B-19Y-020Y
25.	WBLL1//YANGLING SHAANXI/ESDA/3/ROLF07/4/SAUAL/MUTUS*2//PICAFLOR #1 PTSS20Y00313S-1B-099Y-099M-4Y-0B
26.	SOKOLL/3/KACHU/SAUAL//CIRO16 PTSS19Y00313S-0M-0Y-099M-24Y-0B
27.	PANDORAINIA//WBLL1*2/BRAMBLING/6/UP2338*2/VIVITSI/3/FRET2/TUKURU//FRET2/4/MISR 1/5/TUKURU//BAV92/RAYON*2/3/PVN PTSS19Y00205S-0M-0Y-099B-15Y-0B
28.	BAV92/SERI//BORL14 PTSS19Y00287S-0M-0Y-099M-25Y-0B
29.	MEX94.15.34/4/PASTOR//HXL7573/2*BAU/3/WBLL1/5/BABAX/LR42//BABAX/3/ER2000/6/CROC_1/ AE.SQUARROSA (517)//KACHU/3/BAJ #1 PTSS20Y00460S-0B-099Y-099B-1Y-0B
30.	NINGA #1 CMSA11Y00507S-099Y-099M-099NJ-099NJ-19WGY-0B
31.	SUP152/BAJ #1/3/KACHU #1/KIRITATI//KACHU/4/BORL14 PTSS19Y00258S-0M-0Y-099M-26Y-0B
32.	SORA/AE.SQUARROSA (617)/4/2*NADI#2//TRCH/HUIRIVIS #1/3/NADI#1 PTSS20B00071T-099Y-099M-6Y-0B
33.	GARZA/BOY//AE.SQUARROSA (294)/4/2*SUP152/BAJ #1//TRCH/HUIRIVIS #1/3/SUP152/BAJ #1 PTSS20B00077T-099Y-0M-6Y-0B
34.	SUP152/BAJ #1/3/KACHU #1/KIRITATI//KACHU/4/BORL14 PTSS19Y00258S-0M-0Y-099M-6Y-0B
35.	WBLL1//YANGLING SHAANXI/ESDA/3/ROLF07/4/SAUAL/MUTUS*2//PICAFLOR #1 PTSS20Y00313S-1B-099Y-099M-1Y-0B
36.	NAINA #1 CMSS11B00910T-099TOPY-099M-099NJ-099NJ-37WGY-0B
37.	BAV92/SERI//BORL14 PTSS19Y00287S-0M-0Y-099M-15Y-0B

38.	WBLL1/6/ATTILA*2/PBW65*2/5/REH/HARE//2*BCN/3/CROC_1/AE.SQUARROSA (213)//PGO/4/HUITES
	/7/CROC_1/AE.SQUARROSA (205)//BORL95/3/PRL/SARA//TSI/VEE#5/4/FRET2/5/CIRO16
	PTSS18Y00178S-0M-099Y-099M-43Y-0Y

39.	CHIBIA//PRLII/CM65531/3/MISR2*2/4/HUW234+LR34/PRINIA//PBW343*2/KUKUNA/3/ROLF07 /5/KUTZ PTSS19Y00192S-0M-0Y-099M-2Y-0B
40.	REEDLING-GL5A_1/5/2*SOKOLL/3/PASTOR//HXL7573/2*BAU/4/MEX94.27.1.20/3/SOKOLL// ATTILA/3*BCN PTSS19B00020T-0Y-099M-11Y-0B
41.	RL6043/4*NAC//2*PASTOR/3/BCN/WBLL1/4/KUTZ

	PTSS16Y00013S-0B-099Y-099M-1Y-0B-0Y
42.	KABILU #1/CIANO M2018 PTSS20Y00253S-0B-099Y-099B-2Y-0B
43.	PASTOR//HXL7573/2*BAU/3/ATTILA/3*BCN/4/NAVJ07/6/CROC_1/AE.SQUARROSA(205)//BORL95 /3/PRL/SARA//TSI/VEE#5/4/FRET2/5/CIRO16 PTSS19Y00276S-0M-0Y-099M-4Y-0B
44.	CROC_1/AE.SQUARROSA (333)//2*KUTZ PTSS15B00034T-099Y-099M-23Y-0Y-020Y-0B

The sowing date was December 13, 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 and phosphorus were applied, and other 100 kg ha^{-1} of urea were applied before the second complementary irrigation. During crop development, broad leaf weeds were control with herbicides, Full-mina 4 (Dimethylamine salt of 2,4-Dichlorophenoxyacetic acid) [26] and Starane Ultra (Fluroxypyr methyl) (300 mL ha^{-1}) [27] during the tillering stage (stage 24, Zadoks *et al.*[28], and for narrow leaf weeds, Axial XL (Pinoxaden + Cloquintocet-mexyl) (400 mL ha^{-1}) [29] during stem elongation (stage 35, Zadoks). For control of the green aphid (*Schizaphis graminum* Rondani), the insecticide Muralla Max (Imidacloprid + Betacyfluthrin) (200 mL ha^{-1}) [30] was applied during 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, 2023 to May 15, 2024 by the weather station CIANO-910, located in block 910 in the Yaqui Valley [31]; this station belongs to the automated weather station network of Sonora [32]. 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 [33]. The variables evaluated were: days to heading, 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 17.9-24.8 °C (Figure 1), while for the maximum temperature it was 18.7-35.8 °C and 1.6-17.4 °C for the minimum temperature. The occurrence of temperatures above 30 °C were more consistent from April 14 (Figure 2) to May 15, where 87 % of the accumulated heat units (233) were recorded during the period of the study, although there were some days where the temperature reached 30 °C for 1 or several hours, like December 16 (2 hours), 17 (2), 18 (1), 22 (4), March 21 (3), 22 (4), 28 (1), April 3 (2), and 10 (6). However, it did not affect the proper development of plants since the maximum grain yield reached 8.4 t ha^{-1} and the average of the group more than 7. On the other hand, the accumulation of cold units (CU) started from December 15, 2023 up to April 29, 2024, with a total of 494. Wheat is a cool-season crop whose production is concentrated between latitudes 30-60 °N and 27-40 °S under different climatic areas, but it can be grown beyond these limits, with an optimum growth temperature of about 25 °C [34]. The accumulation of CU was more consistent after December 24, 2023; during the week of December 24-30 there were 53 CU, 48 in December 31-January 6, 75 in January 7-13, 52 in January 14-20, 12 in January 21-27, 22 in January 28-February 3, 37 in February 4-10, 44 in February 11-17, 22 in February 18-24, 10 in February 25-March 2, 10 in March 3-9, 23 in March 10-16, 19 in March 17-23, 18 in March 24-30, 5 in March 31-April 6, and 22 in April 7-13 (Figure 2). All stages of the wheat plant phenology are sensitive to changes of temperature; high temperatures favor a greater metabolic activity of the plant, as well as the speed up of the physiologic processes that determine its growth and development [35].

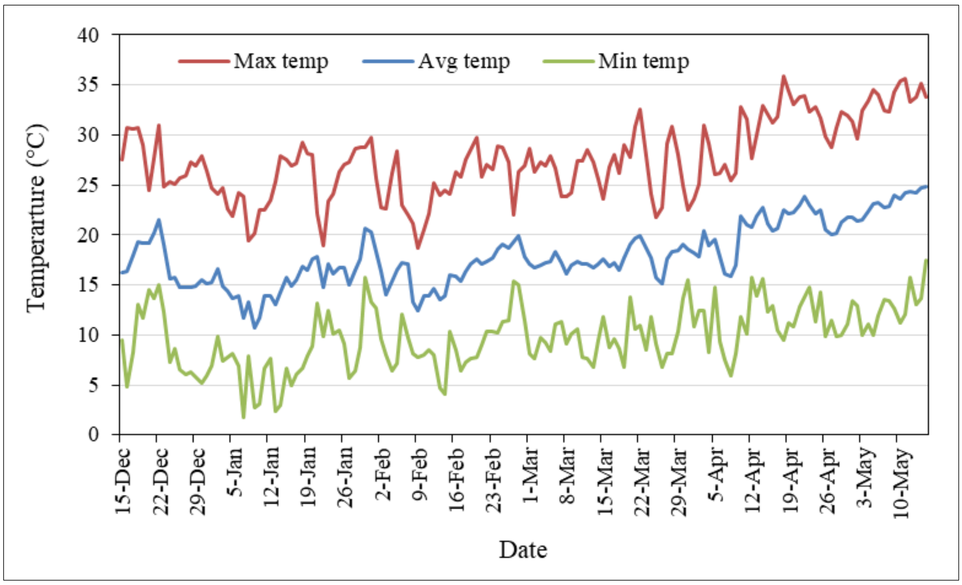

Figure 1 Average temperatures from December 15, 2023 to May 15, 2024, recorded from the weather station CIANO-910, at the Norman E. Borlaug Experimental Station in the Yaqui Valley, Sonora, Mexico, during the crop season 2023-2024

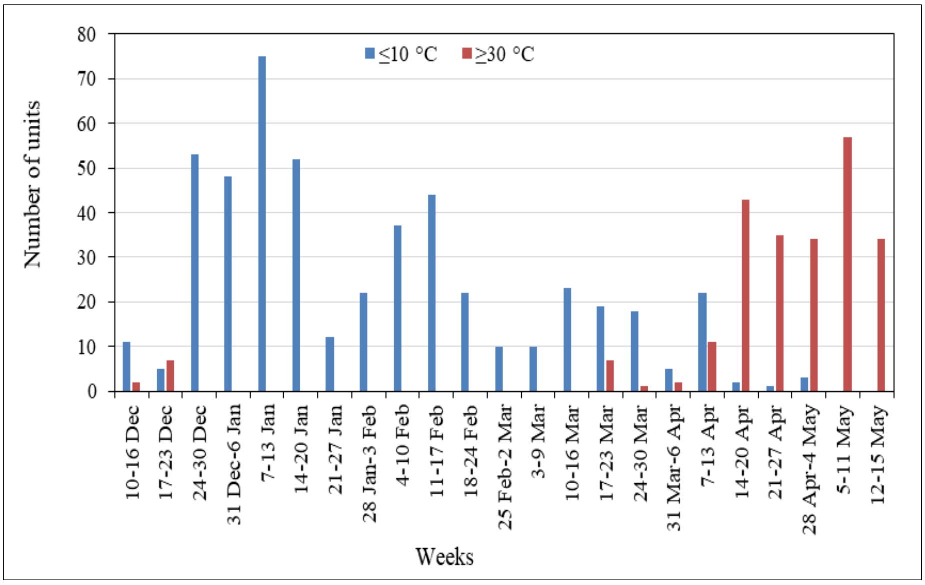

Figure 2 Number of cold and heat units accumulated from December 15, 2023 to May 15, 2024, recorded from the weather station CIANO-910, at the Norman E. Borlaug Experimental Station in the Yaqui Valley, Sonora, Mexico, during the crop season 2023-2024

The wheat plant also requires the accumulation of cold units, to prolong its biological cycle, which generally leads to a higher grain yield [33]. Recommended wheat sowing dates for southern Sonora are between November 15 to December 15; generally, if sowing is done later, plants will not tiller properly and will be expose to heat stress [36]. The average heading dates for the group of advanced lines and commercial cultivars Borlaug 100 F2014 and CIANO M2018 was 71 days with a range of 69 to 74; there were five early lines with 69 days and one late with 74 (SUP152//PUB94.15.1.12/WBLL1/3/MUCUY/4/SAUAL/MUTUS*2//PICAFLOR #1), although the day difference was rather small. The average plant height of the group was 101 cm (Figure 3), with a range of 95 to 106.

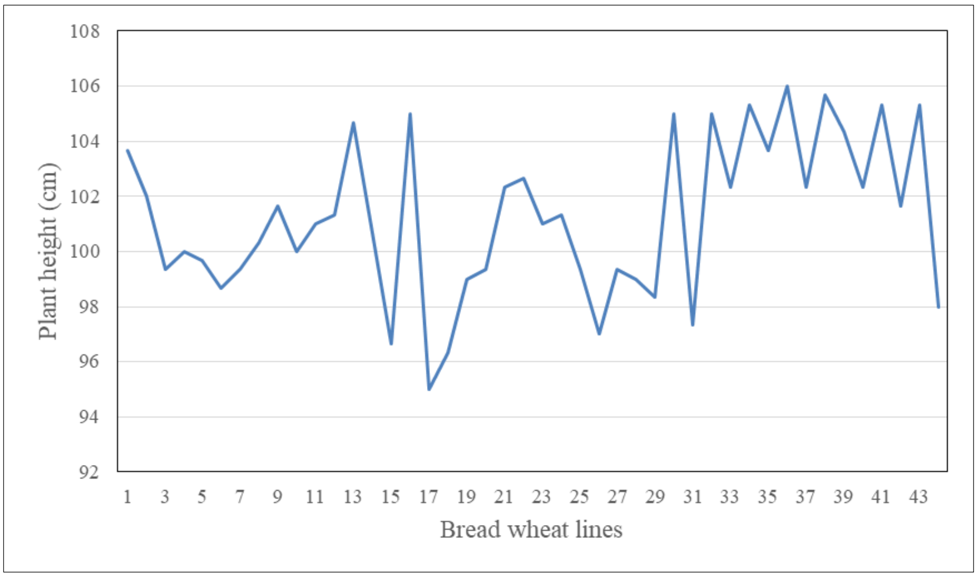

Figure 3 Plant height of bread wheat cultivars Borlaug 100 F2014 (5) and CIANO M2018 (18), and 42 advanced bread wheat lines, at the Norman E. Borlaug Experimental Station in the Yaqui Valley, Sonora, Mexico, during the crop season 2023-2024

The tallest lines were NAINA#1 (line No. 36) and WBLL1/6/ATTILA*2/PBW65*2/5/REH/HARE//2*BCN/3/ CROC_1/AE.SQUARROSA(213)//PGO/4/HUITES/7/CROC_1/AE.SQUARROSA(205)//BORL95/3/PRL/SARA//TSI/ VEE#5/4/FRET2/5/CIRO16 (No. 38) with 106 cm, and the shortest the sister line SERI/BAV92// PUB94.15.1.12/WBLL1/3/BORL14 (PTSS19Y00217S-0M-0Y-099B-19Y-0B, line No. 17) with 95 cm. Plant height in wheat may be related to lodging, since the tallest plants could have lodge problems. Lodging is defined as the permanent displacement of plant stems from their vertical position, as a result of wind acting on the shoot and rain or irrigation weakening the soil and reducing the anchoring force [37]. Wheat grain yield reductions due to lodging can range from 7-80 % [38], and are commonly accompanied by reductions in bread making quality [37]. In a scenario where the main objective is to increase grain yield to meet global food demands [39], and research initiatives such as the International Wheat Yield Partnership are investing in this, maintaining lodging resistance will be of utmost importance to protect higher productivity. Lines 3, 8, 13, 20, 28, 34, and 35 reached 30 % lodging. The average thousand grain weight of the group was 58.1 g; sister line PRL/2*PASTOR//2*CIRO16/3/KUTZ (PTSS19Y00198S-0M-0Y-099M-24Y-0B, No. 20) showed a 4.44 g difference above the average (62.6 g), followed by REEDLING-GL5A_1/5/2*SOKOLL/3/PASTOR// HXL7573/2*BAU/4/MEX94.27.1.20/3/SOKOLL//ATTILA/ 3*BCN (No. 40), sister line ALTAR84/AE.SQUARROSA(237) /4/2*KIRITATI/WBLL1//2*BLOUK#1*2/3/ KACHU#1/KIRITATI//KACHU (PTSS20B00072T-099Y-099M-8Y-0B, No. 21) and NINGA #1 (No. 30), and KABILU#1/CIANOM2018 (No. 42) with a weight of 61.5, 60.6, and 60.0 g, respectively, while cultivars Borlaug 100 F2014 reached the average value and CIANO M2018 showed a value below the average (Figure 4). According to Baillot *et al.* [40], the thousand grain weight 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. In regard to grain yield per plot, the average yield of the group was 492 g with a range of 396 to 581 (Figure 5). Cultivars Borlaug 100 F2014 and CIANO M2018 showed an average grain yield below the group average with 484.6 and 457.3, respectively, while sister line BAV92/SERI//BORL14 (PTSS19Y00287S-0M-0Y-099M-15Y-0B, No. 37) showed the highest yield with 581 g, which would be more than a ton than check cultivars; the thousand grain weight of this line was not the highest, but it remained above average. The other high-yielding lines were RL6043/4*NAC//2*PASTOR/3/BCN/WBLL1/4/KUTZ (No. 41), NAINA #1 (No. 36), SOKOLL (No. 12), and sister line WBLL1//YANGLINGSHAANXI/ESDA/3/ROLF07/4/SAUAL/MUTUS*2// PICAFLOR#1 (PTSS20Y00313S-1B-099Y-099M-4Y-0B, No. 25) with 7.09, 7.03, 6.83, and 6.7 t ha^{-1}, respectively. There were 20 lines with higher grain yield than Borlaug 100 F2024 and 32 higher than CIANO M2028. According to Díaz-Ceniceros *et al.* [41], cultivar Borlaug 100 F2014 produced a grain yield of 8.797 t ha^{-1} under full irrigation (four complementary irrigations). García [42] indicates that wheat yield is built from the number of grains per unit area and the weight of the grains. The number of grains achieved is closely related to the yield and is highly dependent on agronomic practices, while grain weight depends more on the climatic conditions during their formation.

Figure 4 Average a thousand grain weight of bread wheat cultivars Borlaug 100 F2014 (5) and CIANO M2018 (18), and 42 advanced bread wheat lines, at the Norman E. Borlaug Experimental Station in the Yaqui Valley, Sonora, Mexico, during the crop season 2023-2024

On the other hand, Estrada-Campuzano *et al*. [43] reported that one of the most important numerical components of yield is grain weight, which is defined during the period between flowering and physiological maturity, and can be affected by both biotic and abiotic stress. However, Peltonen-Sainio *et al*. [44] reported that grain weight is not associated with yield, but it has also been found that some germplasm combinations from the International Maize and Wheat Improvement Center express high yields with high grain weight [45].

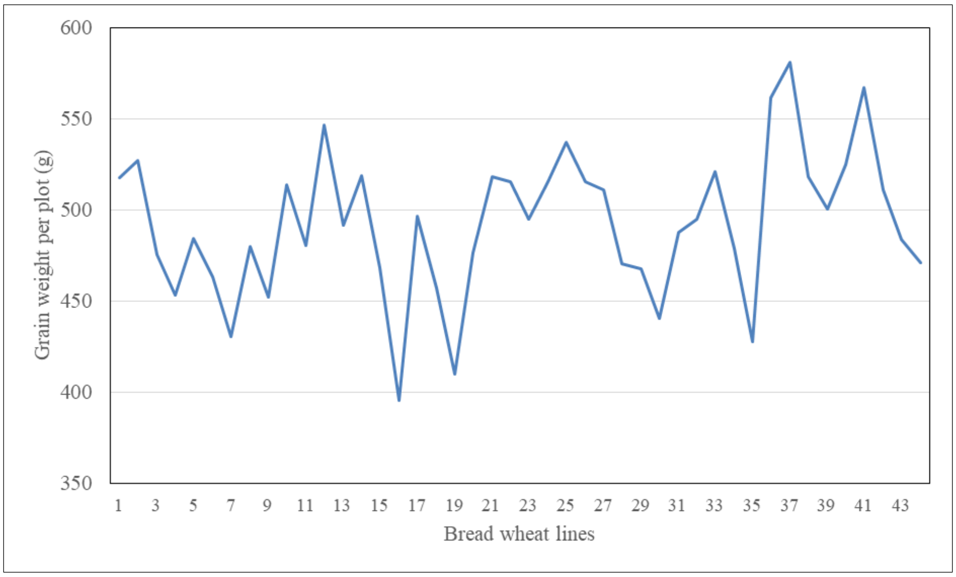

Figure 5 Average grain weight per plot of bread wheat cultivars Borlaug 100 F2014 (5) and CIANO M2018 (18), and 42 advanced bread wheat lines, at the Norman E. Borlaug Experimental Station in the Yaqui Valley, Sonora, Mexico, during the crop season 2023-2024

4. Conclusion

The average days for heading of forty two bread wheat advanced lines which included nine groups of sister lines, and commercial bread wheat cultivars Borlaug 100 F2014 and CIANO M2018l, was 71 with a range of 69 to 74.

The average plant height of the group was 101 cm with a range of 95 to 106; the tallest lines were NAINA#1 and WBLL1/6/ATTILA*2/PBW65*2/5/REH/HARE//2*BCN/3/CROC_1/AE.SQUARROSA(213)//PGO/4/HUITES /7/CROC_1/AE.SQUARROSA(205)//BORL95/3/PRL/SARA//TSI/VEE#5/4/FRET2/5/CIRO16 with 106 cm, and the shortest the sister line SERI/BAV92//PUB94.15.1.12/WBLL1/3/BORL14 (PTSS19Y00217S-0M-0Y-099B-19Y-0B) with 95 cm.

The average a thousand grain weight of the group was 58.1 g, with a range of 39.6 to 62.6 g; the sister line PRL/2*PASTOR//2*CIRO16/3/KUTZ (PTSS19Y00198S-0M-0Y-099M-24Y-0B) showed the highest weight with 62.6 g.

The average grain weight per plot of the group was 492 g, with a range of 396 to 581; lines with the highest grain weight per plot were sister line BAV92/SERI//BORL14 (PTSS19Y00287S-0M-0Y-099M-15Y-0B) with 581 g, RL6043/4*NAC// 2*PASTOR/3/BCN/WBLL1/4/KUTZ with 567.3, NAINA #1 with 562, and SOKOLL with 546.7 g, which correspond to 7.27, 7.09, 7.03, and 6.83 t ha^{-1}, respectively.

The average temperature was 17.9 °C with a maximum of 35.8 °C and a minimum of 1.6 °C; the average relative humidity was 60.8 %; there were 2.5 mm of precipitation, and the number of heat and cold units was 233 and 494, respectively.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare that No conflict of interest.

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