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Performance of bread wheat advanced lines under late sowing

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Abstract

Thirty two advanced wheat lines which included four groups of sister lines and the commercial bread wheat cultivar Borlaug 100 were sown on January 16 and 30, 2019, at the Norman E. Borlaug Experimental Station, in the Yaqui Valley, Sonora, Mexico. Plots consisted of 1 bed 2 m long with two rows and 0.80 m apart without replications, and a seed density of 100 kg ha^{-1}. Average daily temperature (°C), maximum, minimum, relative humidity, rainfall, heat and cold units were recorded from January 1 to May 15, 2019. The variables evaluated were: days to heading, plant height (cm), and grain weight in 20 spikes (g). The average days for heading of lines was 76 for the first sowing date and 73 for the second. The average plant height of the group for the first sowing date was 95 cm and 88 for the second; line W15.92/4/PASTOR//HXL7573/2*BAU/3/WBLL1/5/OAX92.2.5/6/BABAX/LR42//BABAX/3/ ER2000 was the tallest in the first date with 120 cm and with 115 in the second date. The average grain weight of the group in 20 spikes in the first sowing date was 55 g and 40.9 in the second; the line MEX94.15.34/4/PASTOR//HXL7573/2*BAU/3/WBLL1/5/ BABAX/LR42//BABAX/3/ER2000 showed the highest weight in the first and second dates with 71.1 g and 49.5, respectively. In the first date, the line W15.92/4/PASTOR//HXL7573/2*BAU/3/WBLL1/5/IWA8612414/6/BABAX/ LR42//BABAX/3/ER2000 showed the lowest grain weight in 20 spikes with 41.0 g, while in the second date, the sister line PBL94.14.30/4/PASTOR//HXL7573/2*BAU/3/WBLL1/5/BABAX/LR42//BABAX/3/ER2000 (PTSS12SHB 00003T-0TOPB-099Y-099B-7Y-020Y-0B) showed 25.6 g. The average temperature was 18.26 °C with a maximum of 35.2 °C and a minimum of 3.6 °C; the average relative humidity was 67.0 %; there were 13.1 mm of precipitation, and the number of heat and cold units was 146 and 293, respectively.

Keywords: Wheat; *Triticum* spp.; Grain yield; Stress

1. Introduction

Heat stress definition is based on the increment of temperature over a threshold level during a period of time, sufficient to cause negative irreversible effect on plant growth and development [1]. This phenomenon affects plants depending on its intensity, duration, and rate of increment of the temperature; the frequency of such event in climatic zones depends on the probability and period of high temperatures that occur during the day or during the night. These levels of temperature have a diversity of effects on crops, and in the case of wheat, they also modify grain quality, but the final effect will depend on the phenological stage of the plant and the genotype [2]. High temperatures occur in all agricultural areas of the world, but since it is a common event, frequently its effect is not taken into consideration; however, in winter cereals yield reduction caused by high temperatures during the grain-filling stage may range from 10 to 15 % [3,4]. Wheat is cultivated in tropical or subtropical areas, regions that have temperature higher than 17.5 °C during the coolest month of the crop season. More than 7 million hectares in approximately 50 countries comply with this condition, located primarily in Southeast Asia, as well as in India and Bangladesh [5], in Sub-Saharan Africa [6], Brazil, Thailand, Uganda, Mexico, Sudan, Egypt, Nigeria, and Syria [7]. To comply with the demand of food worldwide in the

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future, wheat productivity must increase in both the favorable and marginal environments; this will have to face new challenges, since it is probable that when agricultural areas expand, crops will be subjected to various types of stresses, including heat. An increase of 1-4 ºC during the day and night have been forecasted by most models, which in some crops, high temperature during the night seems to be more damaging to productivity than high temperature during the day [8]. Flowering of winter crops in temperate zones must take place with the lowest risk of a frost, therefore, the sowing date is important, since high temperature generally occurs during the grain-filling period; high temperature and low water availability are the most common abiotic stresses in winter cereals [3]. Wheat consumption and importation by developing countries in the warmer regions are factors that lead to the increase of local wheat production [9]. Since 1980´s, the support of the United Nations Development Programme (UNDP) enabled wheat breeders from the International Maize and Wheat Improvement Center (CIMMYT) to expand their research on the generation of high yielding, disease resistant, semi-dwarf wheats adapted to the warmer, subtropical area of the world. Then, CIMMYT initiated the Stress Adaptive Trait Yield Nursery (SATYN) which is formed with lines for drought-stressed areas and for heat stress conditions, for major spring wheat-growing countries such as Bangladesh, China, Egypt, India, Iran, Mexico, Nepal, and Pakistan [10]. The objective of this work was to evaluate the performance of a set of wheat lines comprising the 8th SATYN, subjected to late sowing, and therefore, exposed to a warmer and shorter crop season.

2. Material and methods

Thirty two advanced bread wheat lines from the 8th Stress Adapted Trait Yield Nurseries (SATYN), which included four groups of sister lines (lines 4-5, 6-7, 11-12, and 15-16) (Table 1) selected by the International Maize and Wheat Improvement Center´s wheat breeding for their tolerance to stress, were sown on January 16 and 30, 2019, at the Norman E. Borlaug Experimental Station which belongs to the National Institute for Forestry, Agriculture, and Livestock Research, and it located in block 910 in the Yaqui Valley, Sonora (27º22´3.01" N and 109º55´40.22" W), in a clay soil with pH of 7.8. The commercial bread wheat cultivar Borlaug 100 which has shown an average grain yield of 6.1 and 7.0 t ha^{-1} with two and four complementary irrigations, respectively, in experimental plots [12] was used as check.

Table 1 Advanced bread wheat lines from the 8th Stress Adaptive Trait Yield Nursery from CIMMYT, sown on January 16 and 30, 2019, at the Norman E. Borlaug Experimental Station in the Yaqui Valley, Sonora, Mexico

No.	Pedigree and selection history
1	SOKOLL/WBLL1/5/W15.92/4/PASTOR//HXL7573/2*BAU/3/WBLL1 PTSS11Y00209S-099B-099Y-099B-39Y-020Y-0B
2	SOKOLL/4/PASTOR//HXL7573/2*BAU/3/WBLL1 PTSS11Y00094S-0SHB-099B-099Y-099B-1Y-020Y-0B
3	SOKOLL/WBLL1/4/2*PASTOR//HXL7573/2*BAU/3/WBLL1 PTSS13Y00176T-099B-21Y-020Y-0B
4	CIT71/CPT//AE.SQUARROSA (629)/4/2*PASTOR//HXL7573/2*BAU/3/WBLL1 PTSS13Y00197T-099B-7Y-020Y-0B
5	CIT71/CPT//AE.SQUARROSA (629)/4/2*PASTOR//HXL7573/2*BAU/3/WBLL1 PTSS13Y00197T-099B-27Y-020Y-0B
6	IWA8611532/4/PASTOR//HXL7573/2*BAU/3/WBLL1/5/BABAX/LR42//BABAX/3/ER2000 PTSS12SHB00022T-099TOPB-099Y-099B-11Y-020Y-0B
7	IWA8611532/4/PASTOR//HXL7573/2*BAU/3/WBLL1/5/BABAX/LR42//BABAX/3/ER2000 PTSS12SHB00022T-099TOPB-099Y-099B-15Y-0Y
8	W15.92/4/PASTOR//HXL7573/2*BAU/3/WBLL1/5/IWA8612414/6/BABAX/LR42//BABAX/3/ER2000 PTSS12GHB00012T-0TOPB-099Y-099B-4Y-020Y-0B
9	W15.92/4/PASTOR//HXL7573/2*BAU/3/WBLL1/5/OAX92.2.5/6/BABAX/LR42//BABAX/3/ER2000 PTSS12GHB00017T-0TOPB-099Y-099B-2Y-020Y-0B
10	BAV92/SERI CMSS96Y04084S-0Y-1B-93TLA-0B-0Y-106B-0Y-0Y-0Y-0Y

11	PBL94.14.30/4/PASTOR//HXL7573/2*BAU/3/WBLL1/5/BABAX/LR42//BABAX/3/ER2000 PTSS12SHB00003T-0TOPB-099Y-099B-6Y-020Y-0B
12	PBL94.14.30/4/PASTOR//HXL7573/2*BAU/3/WBLL1/5/BABAX/LR42//BABAX/3/ER2000 PTSS12SHB00003T-0TOPB-099Y-099B-7Y-020Y-0B
13	MEX94.15.34/4/PASTOR//HXL7573/2*BAU/3/WBLL1/5/BABAX/LR42//BABAX/3/ER2000 PTSS12SHB00004T-0TOPB-099Y-099B-10Y-020Y-0B
14	SOKOLL/4/PASTOR//HXL7573/2*BAU/3/WBLL1/5/SOKOLL/3/PASTOR//HXL7573/2*BAU PTSS12SHB00016T-0TOPB-099Y-099B-2Y-020Y-0B
15	SOKOLL/5/W15.92/4/PASTOR//HXL7573/2*BAU/3/WBLL1/6/SOKOLL/3/PASTOR//HXL7573/2*BAU PTSS12SHB00020T-0TOPB-099Y-099B-6Y-020Y-0B
16	SOKOLL/5/W15.92/4/PASTOR//HXL7573/2*BAU/3/WBLL1/6/SOKOLL/3/PASTOR//HXL7573/2*BAU PTSS12SHB00020T-0TOPB-099Y-099B-25Y-020Y-0B
17	ALTAR84/AE.SQUARROSA(895)/4/PASTOR//HXL7573/2*BAU/3/WBLL1/5/BABAX/LR42//BABAX/3/ER2000 PT11SHB00008T-0TOPB-099Y-099B-1Y-020Y-0B
18	MEX94.27.1.20/3/SOKOLL//ATTILA/3*BCN/4/PUB94.15.1.12/WBLL1 PTSS09GHB00029S-0SHB-099Y-4Y-020Y-0MXI
19	SHAG_22/AE.SQUARROSA(721)//WHEAR/KRONSTADF2004/7/SHA7/VEE#5/5/VEE#8//JUP/BJY/3/F3.71/TRM/4/2*WEAVER/6/SKAUZ/PARUS//PARUS SDSS12B00981T-0Y-0B-0B-26Y-0M-0Y
20	CROC_1/AE.SQUARROSA (517)//KACHU/3/BAJ #1 SDSS12B00833T-0Y-0B-0B-54Y-0M-0Y
21	68.111/RGB-U//WARD/3/AE.SQUARROSA (452)/4/2*OASIS/SKAUZ//4*BCN/5/NAVJ07/6/KACHU SDSS12B01185T-0Y-0B-0B-133Y-0M-0Y
22	W15.92/4/PASTOR//HXL7573/2*BAU/3/WBLL1 PTSS02B00102T-0TOPY-0B-0Y-0B-11Y-0M-0SY-0B-0Y
23	SOKOLL/WBLL1 PTSS02Y00021S-099B-099Y-030ZTM-040SY-040M-31Y-0M-0SY-0B-0Y
24	SCOOP_1/AE.SQUARROSA (634)//KACHU/3/BAJ #1 SDSS12B00821T-0Y-0B-0B-32Y-0M-0Y
25	SOKOLL/3/PASTOR//HXL7573/2*BAU/4/PARUS/PASTOR PTSA08M00046S-050ZTM-050Y-50ZTM-010Y-0B-020Y-0MXI
26	PUB94.15.1.12/WBLL1 PTSS02Y00027S-011Y-0B-0Y-0B-7Y-0M-0SY-0Y-0Y
27	BAJ #1 CGSS01Y00134S-099Y-099M-099M-13Y-0B
28	BORLAUG100 F2014 CMSS06Y00605T-099TOPM-099Y-099ZTM-099Y-099M-11WGY-0B-0MEX
29	SOKOLL CMSS97M00316S-0P20M-0P20Y-43M-010Y
30	FRANCOLIN #1 CGSS01B00056T-099Y-099M-099M-099Y-099M-14Y-0B

31	SOKOLL/WBLL1 PTSS02Y00021S-099B-099Y-099B-099Y-213B-0Y
32	JNRB.5/PIFED/5/BJY/COC//PRL/BOW/3/SARA/THB//VEE/4/PIFED PTSS08GHB00011S-0SH-099SHB-099SHB-099SHB-52Y-0Y

Plots consisted of 1 bed 2 m long with two rows and 0.80 m apart without replications, and a seed density of 100 kg ha^{-1}. Weed control was done manually and three complementary irrigations were applied every 30 days after the irrigation for seed germination. The agronomic management was based on the technical recommendations by Figueroa-López *et al*. [12]. The daily average temperature (°C), the maximum and minimum, relative humidity, the number of cold and heat units, and precipitation were recorded from January 16 to May 15, 2019 by the weather station CIANO-910, located in block 910 in the Yaqui Valley [13]; this station belongs to the automated weather station network of Sonora [14]. 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. The variables evaluated were: days to heading, plant height (cm), and grain weight in 20 spikes (g) since grain weight per plot could not be evaluated due to bird damage. Threshing was carried out with a single spike stationary thresher.

3. Results and discussion

The range of the average temperature during the period of evaluation was 11.5-24.0 °C (Figure 1), while for the maximum temperature it was 17.5-35.2 °C and 3.6-16.8 °C for the minimum temperature. Maximum temperatures above 30 °C occurred from one to several hours during the following days: March 3 (1 h), 20 (2), 21 (1), 24 (3), 25 (3), 26 (2), 28 (2), 29 (1), 31 (2); April 4 (1), 7 (3), 8 (5), 9 (7), 10 (1), 14 (2), 18 (5), 19 (8), 20 (4), 24 (1), 25 (7), 26 (8), 27 (6), 28 (6), 29 (6), 30 (3); May 1 (7), 2 (4), 3 (8), 4 (7), 5 (7), 8 (2), 9 (2), 13 (3), 14 (8), and 15 (8), 2019.

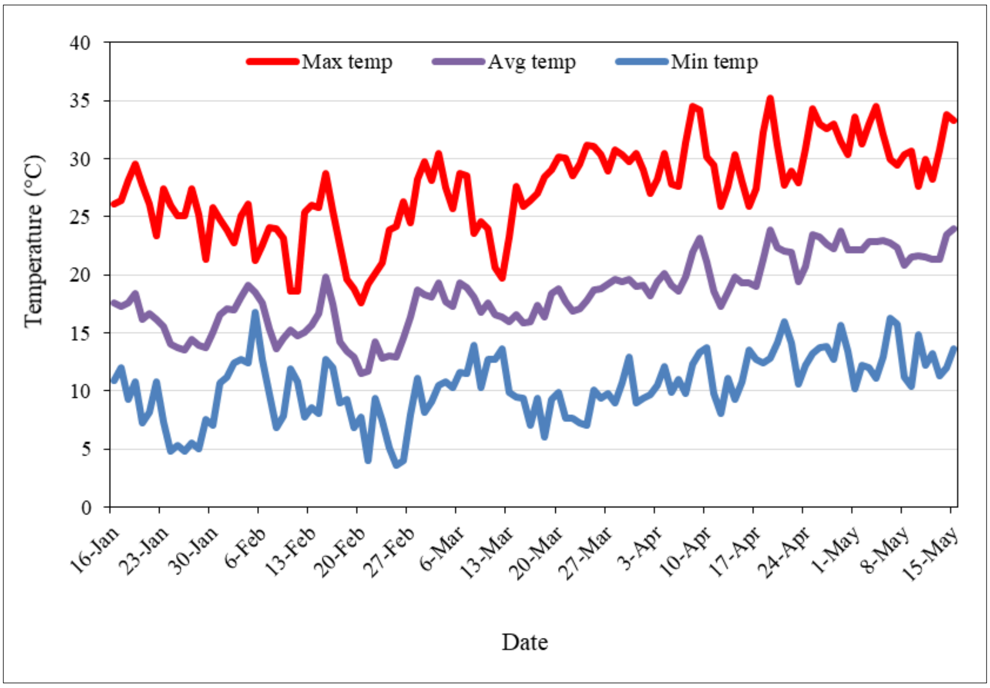

Figure 1 Average temperature from January 16 to May 15, 2019, recorded from the weather station CIANO-910, at the Norman E. Borlaug Experimental Station in the Yaqui Valley, Sonora, Mexico, during the crop season 2018-2019

Heading dates for the first sowing date occurred from March 27 to April 8 and from April 11 to 18 for the second date, therefore, the first date was exposed to periods of high temperature longer than the second date, although both sowing dates might not have been affected seriously during flowering [stage 65, 15] since the higher number of hours with temperature greater than 30 °C occurred after April 25. Continuous hours from two to three on 18 different days with temperature above 30 °C occurred between 12 and 15 pm, while from four to eight on 17 different days between 10 am and 17 pm. 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 [16]). Weeks where the maximum temperature reached more than 30°C in some days and in some hours were March 3-9 with 1 heat unit (HU), 17-23 (3), 24-30 (11), March 31, April 6 (3), April 7-13 (16), 14-20 (19), 21-27 (22), April 28-May 4 (41), 5-11 (11), and the days 12-15 (19); the total heat units accumulated during the period of time that covered this work was 146 which indicates a cooler season than in 2017-2018 where 254 heat units were recorded in a similar period of time [17]. In relation to cold units, with the exception of weeks March 3-9, and April 21 to May 15, the rest of the weeks starting from January 16 to April 14-20 accumulated cold units, ranging from 2 to a maximum of 50 during the week of January 20 to 26, followed by the weeks of February 17-23 and February 24 to March 2 with 49 and 43, respectively (Figure 2). A total of 293 cold units were recorded during the period of the study. 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 [18].

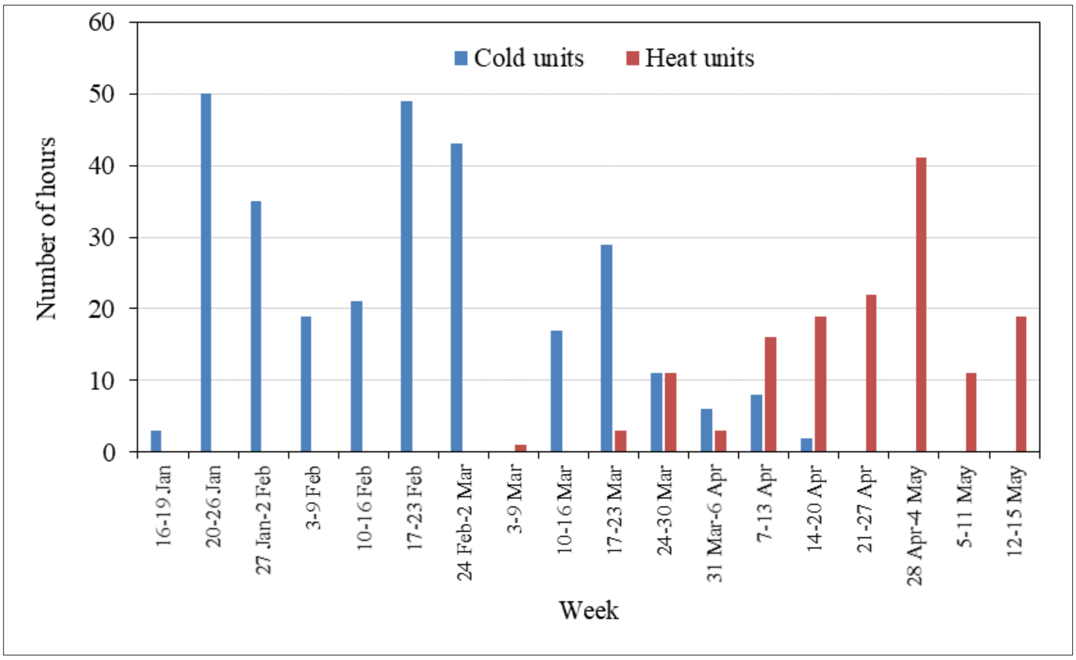

Figure 2 Number of cold and heat units accumulated from January 16 to May 15, 2019, recorded from the weather station CIANO-910, at the Norman E. Borlaug Experimental Station in the Yaqui Valley, Sonora, Mexico, during the crop season 2018-2019

The wheat plant also requires the accumulation of cold units, to prolong its biological cycle, which generally leads to a higher grain yield [19]. During January the low temperature range was 4.80-10.67 °C, in February 3.63-12.72 °C, in March 6.0-13.94 °C, in April 8.10-15.93 °C, and in May 10.15-16.27 °C. 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 [12]. Late sowing with reduce irrigation of the experimental germplasm in this work was focused on exposure to heat stress. The average days to heading of the group of lines and commercial bread wheat cultivar Borlaug 100 was 76 for the first sowing date and 73 for the second; there were six early lines with 70 days in the first date, while in the second date only SOKOLL/WBLL1/4/2*PASTOR// HXL7573/2*BAU/3/WBLL1 headed in 70 days. Some lines were not affected greatly in the second sowing date by the temperature increase detected during the middle of April (Figure 3); lines that had a two day difference or less for heading during the first and second dates were No. 1, 4, 5, 7, 8, 9, 10, 11, 12, 13, 15, 16, 17, 19, 20, 21, 22, 23, 30, and 32, while those with the a larger difference were No. 27 and 31 with 3 days, No. 2, 18, 24, 25, and 28 with 4, No. 6 with 5, No. 3 with 6, No. 14 and 29 with 7, and No. 26 (PUB94.15.1.12/WBLL1) with 10.

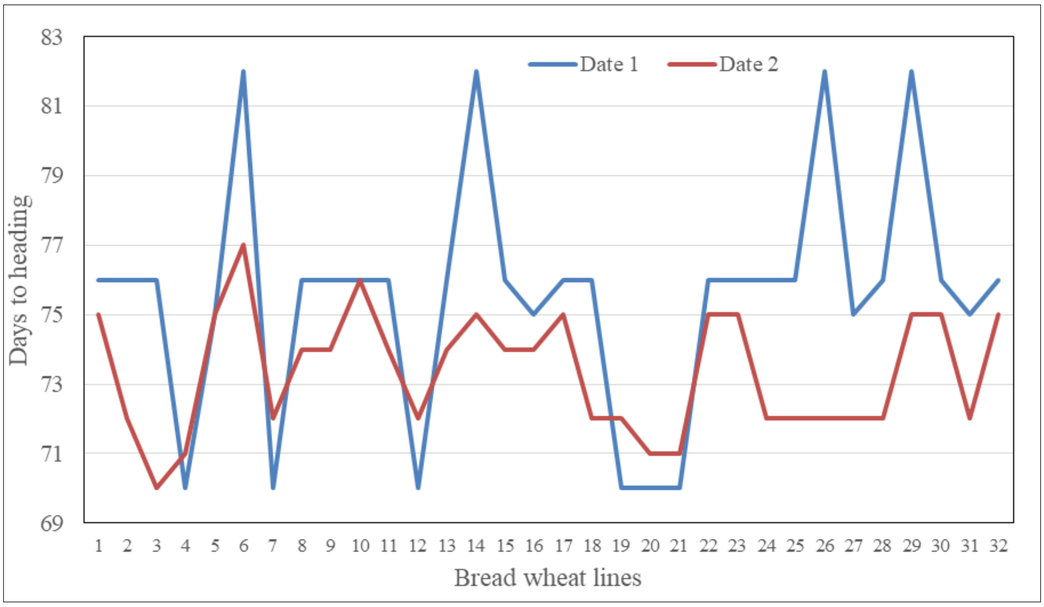

Figure 3 Days to heading of bread wheat cultivar Borlaug 100 (28), and 31 advanced bread wheat lines adapted to stress, sown late on January 16 and 30, 2019, at the Norman E. Borlaug Experimental Station in the Yaqui Valley, Sonora, Mexico

The average plant height of the group was 95 cm for the first sowing date and 88 cm for the second (Figure 4); W15.92/4/PASTOR//HXL7573/2*BAU/3/WBLL1/5/OAX92.2.5/6/BABAX/LR42//BABAX/3/ER2000 (line No. 9) was the tallest in the first date with 120 cm and lines SOKOLL/WBLL1/4/2*PASTOR//HXL7573/2*BAU/3/ WBLL1 (3), CROC_1/AE.SQUARROSA(517)//KACHU/3/BAJ#1 (20), and 68.111/RGB-U//WARD/3/AE.SQUARROSA(452)/4/ 2*OASIS/SKAUZ//4*BCN/5/NAVJ07/6/KACHU (21) were the shortest with 80 cm.

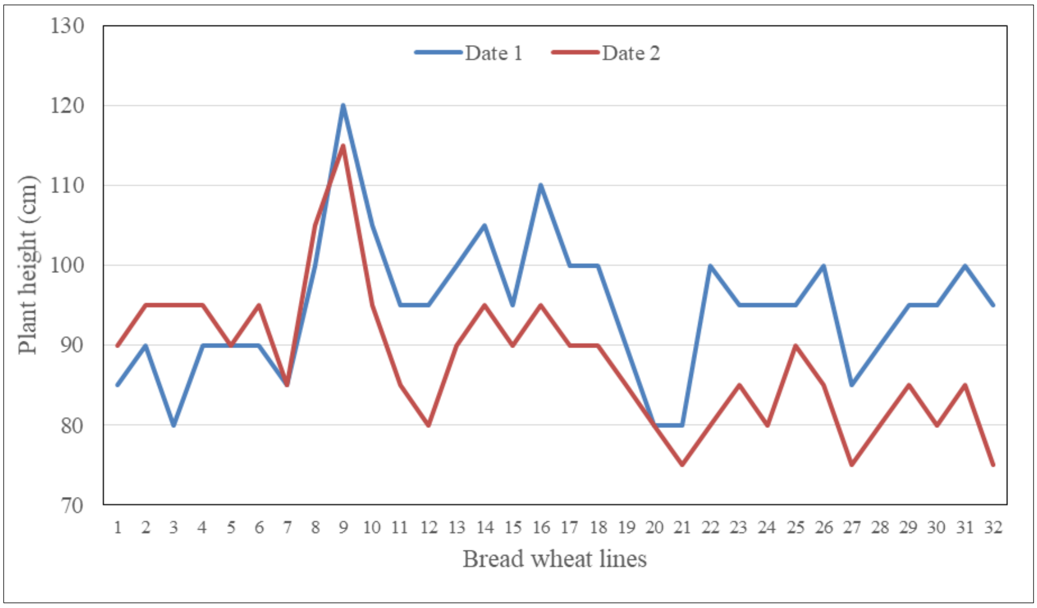

Figure 4 Plant height of bread wheat cultivar Borlaug 100 (No. 28), and 31 advanced bread wheat lines adapted to stress, sown late on January 16 and 30, 2019, at the Norman E. Borlaug Experimental Station in the Yaqui Valley, Sonora, Mexico

In the second date line W15.92/4/PASTOR//HXL7573/2*BAU/3/WBLL1/5/OAX92.2.5/6/BABAX/LR42// BABAX/3/ER2000 (9) was also the tallest with 115 cm while lines 68.111/RGB-U//WARD/3/AE.SQUARROSA (452)/4/2*OASIS/SKAUZ//4*BCN/5/NAVJ07/6/KACHU (21), BAJ#1 (27), and JNRB.5/PIFED/5/BJY/COC// PRL/BOW/3/SARA/THB//VEE/4/PIFED (32) were the shortest with 75 cm. There were several lines which did not show any difference in height in both dates, like sister line CIT71/CPT//AE.SQUARROSA(629)/4/2*PASTOR//HXL7573/2*BAU/3/WBLL1 (line No. 5, PTSS13Y00197T-099B-27Y-020Y-0B) with 90 cm, another sister line IWA8611532/4/PASTOR//HXL7573/2*BAU/3/WBLL1/5/BABAX/LR42//BABAX/3/ER2000 (No. 7, PTSS12SHB00022T-099TOPB-099Y-099B-15Y-0Y) with 85 cm, and CROC_1/AE.SQUARROSA (517)//KACHU/3/BAJ #1 (No. 20) with 80 cm. Fuentes-Dávila *et al*. [20] reported that a group of lines adapted to stress as well as the two cultivars used in this work, during 2017 showed an average days to heading of 68 and 60 cm for plant height, while in 2018 with another group of lines, the average was 69 days and 84 cm, respectively [17]. Cultivar Borlaug 100 had 68 days for heading and 60 cm height in 2017, and 69 days for heading and 75 cm height in 2018, while in 2019, it had 74 days for heading and an average height of 85 cm. In the span of those three years, results indicate that climatic condition were more stressful in 2017 as reported by Fuentes-Dávila *et al*. [17], since the highest average temperature from January to the middle of May was higher than in 2018 and 2019, which was partly reflected in days to heading and plant height (Table 2). The total average temperature during the 2017 period was 33.24 °C, 29.03 in 2018, and 18.26 °C in 2019. The average physiological maturity of the group of lines and cultivar Borlaug 100 in this study occurred after 109 days for the first sowing date and 104 for the second with a range of 106 to 113 and 98 to 107, respectively (Figure 5).

Table 2 Average monthly temperatures during January to the middle of May in three years in the Yaqui Valley, Sonora, Mexico, and days to heading and plant height of selected germplasm with tolerance to drought and heat

Year	Average temperature (°C)					Days to heading (avg)	Plant height (cm)
	January	February	March	April	May		
2017	28.22	31.26	32.97	37.76	36.0	68	60
2018	26.39	25.02	28.40	31.71	33.64	69	84
2019	15.65	15.42	17.84	20.72	22.25	74	92

The average grain weight of the group in 20 spikes in the first sowing date was 55.0 g and 40.9 in the second (Figure 6); the line MEX94.15.34/4/PASTOR//HXL7573/2*BAU/3/WBLL1/5/BABAX/LR42//BABAX/3/ER2000 (13) showed the highest weight in the first date with 71.1 g, followed by SOKOLL (29) with 67.7 g, and MEX94.27.1.20/3/SOKOLL//ATTILA/3*BCN/4/PUB94.15.1.12/WBLL1 (18) with 65.9 g, while lines W15.92/4/PASTOR//HXL7573/2*BAU/3/WBLL1/5/IWA8612414/6/BABAX/LR42//BABAX/3/ER2000 (8), SOKOLL/WBLL1/5/W15.92/4/PASTOR//HXL7573/2*BAU/3/WBLL1 (1), and SHAG_22/AE.SQUARROSA(721)//WHEAR/KRONSTADF2004/7/SHA7/VEE#5/5/VEE#8//JUP/BJY/3/F3.71/TRM/4/2*WEAVER/6/SKAUZ/ PARUS//PARUS (19) showed the lowest grain weight in 20 spikes with 41.0, 43.4, and 44.4 g, respectively.

Figure 5 Days to physiological maturity of bread wheat cultivar Borlaug 100 (No. 28), and 31 advanced bread wheat lines adapted to stress, sown late on January 16 and 30, 2019, at the Norman E. Borlaug Experimental Station in the Yaqui Valley, Sonora, Mexico

In the second date, the same line MEX94.15.34/4/PASTOR//HXL7573/2*BAU/3/WBLL1/5/BABAX/LR42//BABAX/3/ER2000 (13) showed the highest grain weight in 20 spikes with 49.5 g, followed by the sister line SOKOLL/5/W15.92/4/PASTOR//HXL7573/2*BAU/3/WBLL1/6/SOKOLL/3/PASTOR//HXL7573/2*BAU (16, PTSS12SHB00020T-0TOPB-099Y-099B-25Y-020Y-0B) with 49.1 g, and SOKOLL/4/PASTOR//HXL7573/2*BAU/3/WBLL1 (2) with 48.1 g, while lines (sister line) PBL94.14.30/4/PASTOR//HXL7573/2*BAU/3/WBLL1/5/BABAX/LR42//BABAX/3/ER2000 (12, PTSS12SHB00003T-0TOPB-099Y-099B-7Y-020Y-0B), SCOOP_1/AE.SQUARROSA (634)//KACHU/3/BAJ #1 (24), and FRANCOLIN #1 (30) showed the lowest grain weight in 20 spikes with 25.6, 28.0, and 28.9 g, respectively.

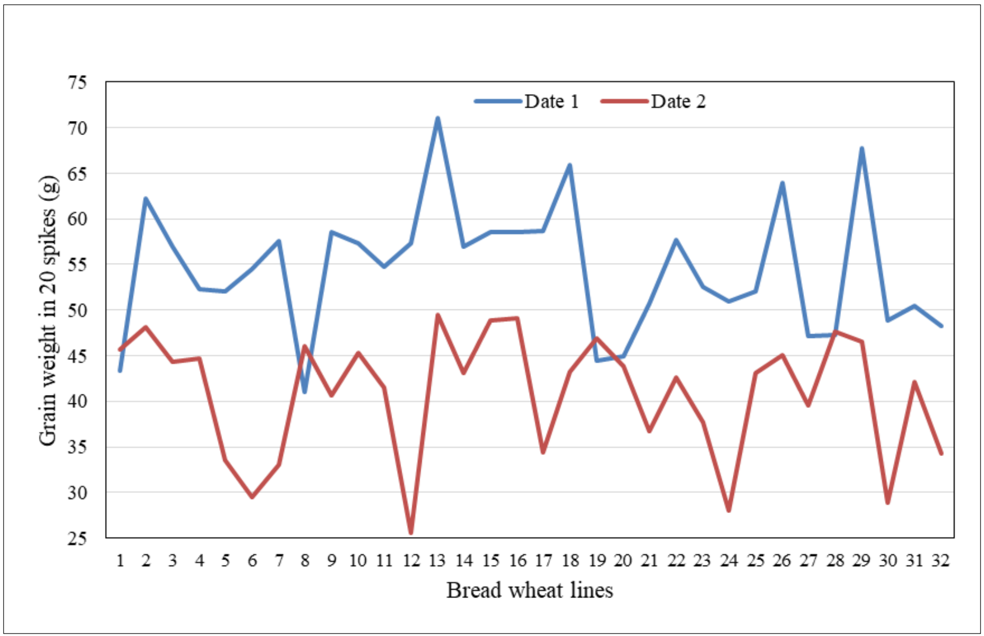

Figure 6 Grain weight in 20 spikes of bread wheat cultivar Borlaug 100 (No. 28), and 31 advanced bread wheat lines adapted to stress, sown late on January 16 and 30, 2019, at the Norman E. Borlaug Experimental Station in the Yaqui Valley, Sonora, Mexico

Although grain yield per hectare was not calculated, cultivar Borlaug 100 showed stability as it produced 47.3 g grain weight in 20 spikes in the first sowing date and 47.7 in the second date; this corroborates the results obtained in 2018 when it produced 5.02 t ha^{-1} and 4.45 in 2017 under stress conditions [17,20]. Also, Borlaug 100 has shown good adaptability by the grain yield obtained in five out of six regions throughout Mexico, overcoming three other commercial bread wheat cultivars by as much as 41 % [21]. Other lines that showed stability in grain weight in 20 spikes were: SOKOLL/WBLL1/5/W15.92/4/PASTOR//HXL7573/2*BAU/3/WBLL1 (1), W15.92/4/PASTOR//HXL7573/2*BAU/3/WBLL1/5/IWA8612414/6/BABAX/LR42//BABAX/3/ER2000 (8), SHAG_22/AE.SQUARROSA(721)//WHEAR/KRONSTADF2004/7/SHA7/VEE#5/5/VEE#8//JUP/BJY/3/F3.71/TRM/4/2*WEAVER/6/SKAUZ/PARUS//PARUS (19), and CROC_1/AE.SQUARROSA (517)//KACHU/3/BAJ #1 (20), while those with large difference in weight greater than 20 g were: 6, 7, 12, 13, 17, 18, 24, 29, and 30, being the sister line PBL94.14.30/4/PASTOR//HXL7573/2*BAU/3/WBLL1/5/BABAX/LR42//BABAX/3/ER2000 (12, PTSS12SHB00003T-0TOPB-099Y-099B-7Y-020Y-0B) with the largest difference of 31.7 g. The best agronomic type consistent in both dates, was shown by the line PUB94.15.1.12/WBLL1 (26). The average temperature during the period of the study was 18.26 °C with a maximum of 35.2 °C and a minimum of 3.6 °C; the average relative humidity was 67.0 %; there were 13.1 mm of precipitation, and the number of heat and cold units was 146 and 293, respectively. The weight of 20 grains showed a rather similar pattern in both sowing dates being lower in the second date, with the exception of lines 2, 6, and 8 which were rather similar, and lines 3, and 7 with opposite trend (Figure 7).

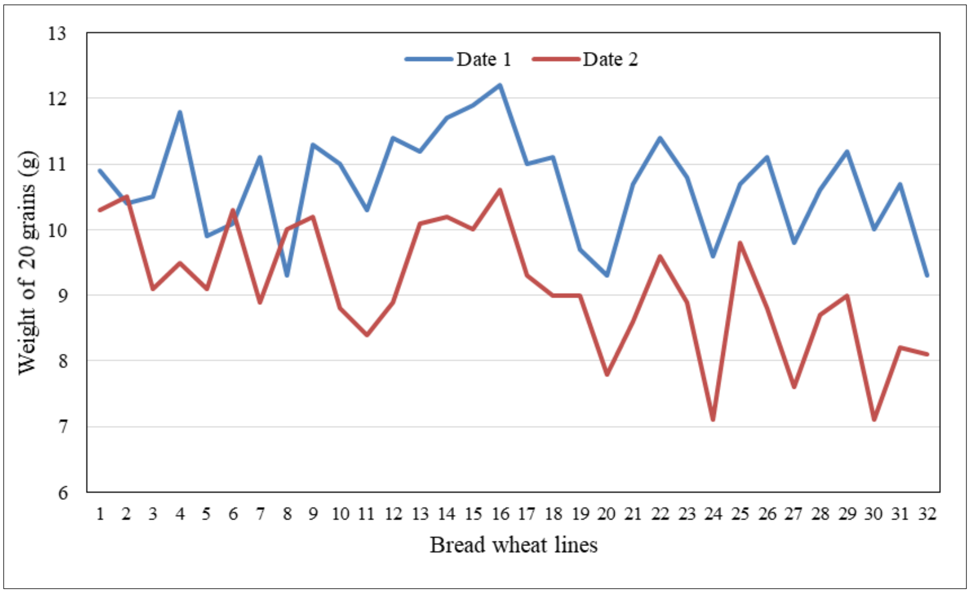

Figure 7 Weight of 20 grains of bread wheat cultivar Borlaug 100 (28), and 31 advanced bread wheat lines adapted to stress, sown late on January 16 and 30, 2019, at the Norman E. Borlaug Experimental Station in the Yaqui Valley, Sonora, Mexico

The average weight of 20 grains in the first sowing date was 10.7 g and 9.1 in the second date, with a range of 9.3 to 12.2 and 7.1 to 10.6 g, respectively. The temperature that prevailed during the period of the study which had an average monthly range of 15.4 to 22.2 °C and an overall average of 18.4 °C, did not cause an important heat stress [22] on the bread wheat lines which would lead to grain yield reduction, although the evaluation was limited by bird damage to the wheat plots. Plant height also reflected the low level of heat stress, since cultivar Borlaug 100 was taller than the report by Camacho-Casas *et al*. [21] where they indicate a height of 89 and 95 cm when subjected to two and four complementary irrigations, while in this study, Borlaug 100 had an average height of 85 cm. If the temperature trend detected during the January-May period during years 2017, 2018, and 2019, in the Yaqui Valley, would continue, it will be necessary to evaluate wheat germplasm for heat stress tolerance under sowings at the end of January and in the middle of February.

4. Conclusion

The average days for heading of 31 bread wheat lines and cultivar Borlaug 100 was 74.5 days and the avg plant height was 91.5 cm; the line W15.92/4/PASTOR//HXL7573/2*BAU/3/WBLL1/5/OAX92.2.5/6/BABAX/LR42//BABAX/3/ER2000 was the tallest in the first sowing date with 120 cm and with 115 in the second date.

The average grain weight of the group in 20 spikes in the first sowing date was 55 g and 40.9 in the second; the line MEX94.15.34/4/PASTOR//HXL7573/2*BAU/3/WBLL1/5/BABAX/LR42//BABAX/3/ER2000 showed the highest weight in the first and second dates with 71.1 and 49.5, respectively.

The average temperature during the period of the study was 18.26 °C with a maximum of 35.2 °C and a minimum of 3.6 °C; the average relative humidity was 67.0 %; there were 13.1 mm of precipitation, and the number of heat and cold units was 146 and 293, respectively.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare that No conflict of interest.

References

[1] Wahid A, Gelani S, Ashraf M, and Foolad MR. 2007. Heat tolerance in plants: An overview. Environmental and Experimental Botany 61:199-223. http://doi.org/10.1016/j.envexpbot. 2007.05.011.

[2] Savin R. 2010. Abiotic stress and quality in winter cereals. In: Advances in ecophysiology of grain crops. pp. 201-210. Editores: Miralles, D.J., Aguirrezábal L.N., Otegui, M.E., Kruk, B.C. and Izquierdo N. Constraints for the productivity of wheat and barley. Editorial Facultad de Agronomía. UBA, Buenos Aires, Argentina. 306 p. ISBN: 978-950-29-1215-8.

[3] Wardlaw IF, and Wrigley CW. 1994. Heat tolerance in temperate cereals: an overview. Australian Journal of Plant Physiology 21(6):695-703. https://doi.org/10.1071/PP9940695.

[4] Tewolde H, Fernandez CJ, Erickson CA. 2006. Wheat cultivars adapted to post-heading high temperature stress. J. Agronomy and Crop Science 192:111-120.

[5] Hede A, Skovmand B, Reynolds MP, Crossa J, Vilhelmsen AL, and Stølen O. 1999. Evaluating genetic diversity for heat tolerance traits in Mexican wheat landraces. Genetic Resources and Crop Evolution 46:37-45. https://doi.org/10.1023/A:1008684615643.

[6] Fischer RA, and Byerlee DR. 1991. Trends of wheat production in the warmer areas: Major issues and economic considerations. pp. 3-27. In: Saunders DA. (Ed.). Wheat for the Non-traditional Warm Areas. Mexico, D.F., CIMMYT. 549 p.

[7] Reynolds MP, Singh RP, Ibrahim A, Ageeb OAA, LarqueSaavedra A, and Quick JS. 1998. Evaluating the physiological traits to complement empirical selection for wheat in warm environments. Euphytica 100:85-94. https://doi.org/10.1023/A:1018355906553.

[8] Hall AE. 1992. Breeding for heat tolerance. Plant Breeding Reviews 10:129-168. doi:10.1002/9780470650011.ch5.

[9] Kohli MM, Mann CE, and Rajaram S. 1990. Global status and recent progress in breeding wheat for the warmer areas. pp. 96-112. In: Saunders DA. (Ed.). Wheat for the Non-traditional Warm Areas. Mexico, D.F., CIMMYT. 549 p.

[10] Reynolds M, and Payne T. 2020, Global Wheat Program; IWIN Collaborators. 6th Stress Adapted Trait Yield Nurseries, https://hdl.handle.net/11529/10548426, CIMMYT Research Data and Software Repository Network, V1. Available at https://data.cimmyt.org/dataset. xhtml?persistentId=hdl:11529/10548426.

[11] Chavez-Villalba G, Camacho-Casas MA, Alvarado-Padilla JI, Huerta-Espino J, Villaseñor-Mir HE, Ortiz-Monasterio JI, and Figueroa-López P. 2021. Borlaug 100, variety of bread wheat for irrigated conditions in northwestern Mexico. Revista Fitotecnia Mexicana 44(1):123-125. Available at chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://revistafitotecniamexicana.org/documentos/44-1/ 16a.pdf.

[12] 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.

[13] 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.

[14] REMAS (Network of Automatic Meteorological Stations of Sonora). 2022. Descargar datos. http://www.siafeson.com/remas/. Accessed on July 24, 2022.

[15] 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

[16] Briggle LW, and Curtis BC. 1987. Wheat worldwide. pp: 1-32. In: Wheat and Wheat Improvement. 2nd Ed. Heyne EG. (Ed.). American Society of Agronomy, Inc. Madison, Wisconsin, USA. 765 p.

[17] Fuentes-Dávila, G., Rosas-Jáuregui, I.A., Ayón-Ibarra, C.A., Félix-Fuentes, J.L., Félix-Valencia, P., and Torres-Cruz, M.M. 2023. Grain yield of wheat advanced lines adapted to stress, during the crop season 2017-2018. World Journal of Advanced Research and Reviews 19(03):420-427. http://doi.org/10.30574/wjarr.2023.19.3.1813.

[18] Moreno Dena JM, Salazar Solano V, and Rojas Rodríguez IS. 2018. Economic impacts of cold hours on wheat production in Sonora, Mexico. Entreciencias: dialogues in the knowledge society: 6(16):15-29. https://doi.org/10.22201/enesl.20078064e.2018. 16.63206.

[19] Félix-Valencia P, Ortíz-Enríquez JE, Fuentes-Dávila G, Quintana-Quiróz JG. and Grageda-Grageda J. 2009. Cold hours in relation to wheat yield: production areas of the state of Sonora. INIFAP, Northwest Regional Research Center, Valle del Yaqui Experimental Field. Technical Brochure No. 63. Cd. Obregón, Sonora, México. 40 p. ISBN 978-607-425-159-3.

[20] Fuentes-Dávila G, Rosas-Jáuregui IA, Ayón-Ibarra CA, Félix-Fuentes JL, Félix-Valencia P, and Torres-Cruz MM. 2022. Grain yield and other parameters of wheat lines adapted to heat stress, sown late during the crop season 2016-2017. International Journal of Agriculture, Environment, and Bioresearch 7(6):1-10. https://doi.org/10.35410/IJAEB.2022.5777.

[21] Camacho-Casas MA, Chávez-Villalba G, Fuentes-Dávila G, Figueroa-López P, Huerta-Espino J, Villaseñor-Mir HE, and 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.

[22] Meena S, Arora A, Taria S, Yadav S, Kumar S, Pushkar S, Chinnusamy V, Kumar RR, and Padaria JC. 2023. Unraveling the physiological and molecular mechanisms regulating grain yield under combined drought and heat stress in wheat (*Triticum aestivum*). Indian Journal of Agricultural Sciences 93(8):821-826. https://doi.org/10.56093/ijas.v93i8.138471.