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(RESEARCH ARTICLE)

Performance of bread wheat advanced lines under late sowing and reduced irrigation

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Abstract

Twenty eight advanced wheat lines and cultivar Borlaug 100 were sown on January 15 and 30, 2020, at the Norman E. Borlaug Experimental Station, in the Yaqui Valley, Sonora, México. Plots consisted of 1 bed 2 m long with two rows and 0.80 m apart with two replications, a seed density of 100 kg ha^{-1} with two complementary irrigations. Average daily temperature (°C), maximum, minimum, relative humidity, rainfall, heat and cold units were recorded from January 1 to May 15, 2020. The average days for heading of the group was 67 for the first sowing date and 64 for the second, while days for physiological maturity were 103 and 95, respectively. The average plant height of the group for the first and second sowing dates was 83 cm; line SOKOLL/3/PASTOR//HXL7573/2*BAU/4/PARUS/ PASTOR/5/PIHA// WORRAKATTA/2*PASTOR/3/PRL/2*PASTOR consistently reached the maximum height with 92.5 and 95 cm in the first and second dates, respectively. The average a thousand grain weight of the group was 53.8 g for the first sowing date and 43.8 for the second; sister line SOKOLL/3/PASTOR//HXL7573/2*BAU/4/ SOKOLL/WBLL1/5/PIHA// WORRAKATTA/2*PASTOR/3/PRL/2*PASTOR (PTSS14Y00057S-0B-099Y-099B-43Y-020Y) showed the highest average weight with 57.07 g. The average grain yield per plot was 340 g; sister line WBLL4//OAX93.24.35/WBLL1 /5/CROC_1/AE.SQUARROSA(205)//BORL95/3/PRL/SARA//TSI/VEE#5/4/FRET2/6/D67.2/PARANA66.270//AE.SQ UARROSA(320)/3/CUNNINGHAM/4/VORB (PTSS15Y00024S-099B-099Y-099M-10Y-020Y) showed the highest yield with 420 g which was above 5 t ha^{-1}. The average temperature was 19.09 °C with a maximum of 36.3 °C and a minimum of 1.04 °C, and the number of heat and cold units was 229 and 227, respectively.

Keywords: Wheat; *Triticum* spp; Grain yield; Drought stress; Heat stress

1. Introduction

The increment of temperature over a threshold level during a period of time, which causes a negative irreversible effect on plant growth and development is defined as heat stress [1]). There is a diversity of effects on crops depending upon duration and rate of increment of the temperature, whether it occurs during the day or during the night. Wheat experiences heat stress to varying degrees at different phenological stages, but this type of stress is more harmful during the reproductive phase than during the vegetative phase, due to direct effect on grain number, dry weight as well as grain quality, although the final effect will also depend on the genotype [2,3]. Yield reduction in winter cereals caused by high temperatures during the grain-filling stage may range from 10 to 15% [4,5]. Wheat is cultivated in tropical or subtropical areas, which have a 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 [6], in Sub-Saharan Africa [7], Brazil, Thailand, Uganda, Mexico, Sudan, Egypt, Nigeria, and Syria [8]. To comply with the demand of food worldwide in the future, wheat productivity must increase in favorable and marginal environments, and as the agricultural area expand, the crop will be subjected to various types of stresses,

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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 [9]. 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 [4]. Wheat consumption and importation by developing countries in the warmer regions are factors that lead to the increase of local wheat production [10]. Drought is the single most devastating environmental stress which affects crop productivity. Agricultural drought is the lack of ample moisture required for normal plant growth and development to complete the life cycle. It severely affects plant growth and development, and biomass accumulation. The main effects in plants are reduced rate of cell division and expansion, leaf size, stem elongation, root proliferation, disturbed stomatal oscillations, plant water and nutrient relations with diminished crop productivity, and water use efficiency [11]. 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. Therefore, the Stress Adaptive Trait Yield Nursery (SATYN) was implemented; this nursery 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 [12]. The objective of this work was to evaluate the performance of a set of wheat lines comprising the 9th SATYN, subjected to late sowing, and therefore, exposed to a warmer and shorter crop season with reduced irrigation.

2. Materials and methods

Twenty eight advanced wheat lines from the 9th Stress Adapted Trait Yield Nurseries (SATYN), which included six groups of sister lines (lines 1, 2 and 16; 3 and 4; 5 and 18; 7 and 8, 12-14, and 19-23) (Table 1) selected by the International Maize and Wheat Improvement Center´s wheat breeding for their tolerance to stress, were sown on January 15 and 30, 2020, at the Norman E. Borlaug Experimental Station which belongs to the National Institute for Forestry, Agriculture, and Livestock Research, located in block 910 in the Yaqui Valley, Sonora, Mexico (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 [13] was used as check.

Table 1 Advanced bread wheat lines from the 9th Stress Adaptive Trait Yield Nursery from CIMMYT, sown on January 15 and 30, 2020, at the Norman E. Borlaug Experimental Station in the Yaqui Valley, Sonora, Mexico

No	Pedigree and selection history
1	SOKOLL/3/PASTOR//HXL7573/2*BAU/4/SOKOLL/WBLL1/5/PIHA//WORRAKATTA/2* PASTOR/3/PRL/2*PASTOR PTSS14Y00057S-0B-099Y-099B-10Y-020Y-0B
2	SOKOLL/3/PASTOR//HXL7573/2*BAU/4/SOKOLL/WBLL1/5/PIHA//WORRAKATTA/2* PASTOR/3/PRL/2*PASTOR PTSS14Y00057S-0B-099Y-099B-26Y-020Y-0B
3	SOKOLL/3/PASTOR//HXL7573/2*BAU/4/WBLL4//OAX93.24.35/WBLL1/5/D67.2/ PARANA66.270//AE.SQUARROSA (320)/3/CUNNINGHAM/4/VORB PTSS14Y00013S-0B-099Y-099B-17Y-020Y-0B
4	SOKOLL/3/PASTOR//HXL7573/2*BAU/4/WBLL4//OAX93.24.35/WBLL1/5/D67.2/PARANA 66.270//AE.SQUARROSA (320)/3/CUNNINGHAM/4/VORB PTSS14Y00013S-0B-099Y-099B-22Y-020Y-0B
5	SOKOLL/WBLL1/4/PIHA//WORRAKATTA/2*PASTOR/3/PRL/2*PASTOR PTSS14Y00079S-0B-099Y-099B-1Y-020Y-0B
6	FRTL//ATTILA/3*BCN/5/D67.2/PARANA66.270//AE.SQUARROSA(320)/3/CUNNINGHAM/4/VORB PTSS15Y00010S-099B-099Y-099M-2Y-020Y
7	SOKOLL/3/PASTOR//HXL7573/2*BAU/5/CROC_1/AE.SQUARROSA(205)//BORL95/3/PRL/SARA//TSI/VE E#5/4/FRET2/6/D67.2/PARANA66.270//AE.SQUARROSA(320)/3/ CUNNINGHAM/4/VORB

	PTSS15Y00023S-099B-099Y-099M-2Y-020Y
8	SOKOLL/3/PASTOR//HXL7573/2*BAU/5/CROC_1/AE.SQUARROSA(205)//BORL95/3/PRL/SARA//TSI/VEE#5/4/FRET2/6/D67.2/PARANA66.270//AE.SQUARROSA(320)/3/ CUNNINGHAM/4/VORB PTSS15Y00023S-099B-099Y-099M-6Y-020Y
9	BORLAUG100 F2014 CMSS06Y00605T-099TOPM-099Y-099ZTM-099Y-099M-11WGY-0B-0MEX
10	SOKOLL/3/PASTOR//HXL7573/2*BAU/5/CROC_1/AE.SQUARROSA(205)//BORL95/3/PRL/SARA//TSI/VEE#5/4/FRET2/6/D67.2/PARANA66.270//AE.SQUARROSA(320)/3/ CUNNINGHAM/4/VORB PTSS15Y00023S-099B-099Y-099M-23Y-020Y
11	SOKOLL CMSS97M00316S-0P20M-0P20Y-43M-010Y
12	WBLL4//OAX93.24.35/WBLL1/5/CROC_1/AE.SQUARROSA(205)//BORL95/3/PRL/SARA//TSI/VEE#5/4/FRET2/6/D67.2/PARANA66.270//AE.SQUARROSA(320)/3/CUNNINGHAM/ 4/VORB PTSS15Y00024S-099B-099Y-099M-2Y-020Y
13	WBLL4//OAX93.24.35/WBLL1/5/CROC_1/AE.SQUARROSA(205)//BORL95/3/PRL/SARA//TSI/VEE#5/4/FRET2/6/D67.2/PARANA66.270//AE.SQUARROSA(320)/3/CUNNINGHAM/ 4/VORB PTSS15Y00024S-099B-099Y-099M-10Y-020Y
14	WBLL4//OAX93.24.35/WBLL1/5/CROC_1/AE.SQUARROSA(205)//BORL95/3/PRL/SARA//TSI/VEE#5/4/FRET2/6/D67.2/PARANA66.270//AE.SQUARROSA(320)/3/CUNNINGHAM/ 4/VORB PTSS15Y00024S-099B-099Y-099M-17Y-020Y
15	CROC_1/AE.SQUARROSA(205)//BORL95/3/PRL/SARA//TSI/VEE#5/4/FRET2/5/PIHA// WORRAKATTA/2*PASTOR/3/PRL/2*PASTOR PTSS15Y00046S-099B-099Y-099M-7Y-020Y
16	SOKOLL/3/PASTOR//HXL7573/2*BAU/4/SOKOLL/WBLL1/5/PIHA//WORRAKATTA/2* PASTOR/3/PRL/2*PASTOR PTSS14Y00057S-0B-099Y-099B-43Y-020Y
17	SOKOLL/3/PASTOR//HXL7573/2*BAU/4/PARUS/PASTOR/5/PIHA//WORRAKATTA/2* PASTOR/3/PRL/2*PASTOR PTSS14Y00062S-0B-099Y-099B-39Y-020Y
18	SOKOLL/WBLL1/4/PIHA//WORRAKATTA/2*PASTOR/3/PRL/2*PASTOR PTSS14Y00071S-0B-099Y-099B-33Y-020Y
19	MEX94.27.1.20/3/SOKOLL//ATTILA/3*BCN/4/PUB94.15.1.12/WBLL1/5/MUCUY PTSS14Y00328S-0B-099Y-099B-9Y-020Y
20	MEX94.27.1.20/3/SOKOLL//ATTILA/3*BCN/4/PUB94.15.1.12/WBLL1/5/MUCUY PTSS14Y00328S-0B-099Y-099B-32Y-020Y
21	MEX94.27.1.20/3/SOKOLL//ATTILA/3*BCN/4/PUB94.15.1.12/WBLL1/5/MUCUY PTSS14Y00328S-0B-099Y-099B-33Y-020Y
22	MEX94.27.1.20/3/SOKOLL//ATTILA/3*BCN/4/PUB94.15.1.12/WBLL1/5/MUCUY PTSS14Y00329S-0B-099Y-099B-17Y-020Y
23	MEX94.27.1.20/3/SOKOLL//ATTILA/3*BCN/4/PUB94.15.1.12/WBLL1/5/MUCUY PTSS14Y00329S-0B-099Y-099B-33Y-020Y
24	CHEN/AE.SQ//2*OPATA/5/SERI.1B//KAUZ/HEVO/3/AMAD*2/4/KIRITATI/6/FRET2*2/ SHAMA//KACHU SDSS12B00920T-0Y-0B-0B-72Y-0M-0Y
25	68.111/RGB-U//WARD/3/FGO/4/RABI/5/AE.SQUARROSA (784)/6/BECARD

	PTSS11Y00179S-0SHB-099Y-099B-099Y-23Y-020Y-0B
26	68.111/RGB-U//WARD/3/FGO/4/RABI/5/AE.SQUARROSA(778)/7/2*CHWL86/6/FILIN/ IRENA/5/CNDO/R143//ENTE/MEXI_2/3/AEGILOPSSQUARROSA(TAUS)/4/ WEAVER PT12SHB00005T-099Y-099B-099Y-22B-020Y-0B-0B
27	SOKOLL/WBLL1/4/PASTOR//HXL7573/2*BAU/3/WBLL1 PTSS11Y00144S-0SHB-099SHB-099Y-099B-099Y-19Y-020Y-0B
28	CHEN/AE.SQ//2*OPATA/3/FINSI/5/W15.92/4/PASTOR//HXL7573/2*BAU/3/WBLL1 PTSS11Y00152S-0SHB-099B-099Y-099B-099Y-17Y-020Y-0B
29	CETA/AE.SQUARROSA(435)/5/2*UP2338*2/SHAMA/3/MILAN/KAUZ//CHIL/CHUM18/4/ UP2338*2/SHAMA PTSS12SHB00048T-0TOPB-099Y-099B-11Y-020Y-0B-0B

Plots consisted of 1 bed 2 m long with two rows and 0.80 m apart with two replications, and a seed density of 100 kg ha^{-1}. Weed control was done manually and two complementary irrigations were applied 45 days after the irrigation for seed germination and the second one 30 days later (75 days after the irrigation for seed germination). The agronomic management was based on the technical recommendations by Figueroa-López *et al*. [14]. 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 [15]; this station belongs to the automated weather station network of Sonora [16]. 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 [17]. The variables evaluated were: days to heading, days to physiological maturity, plant height (cm), a thousand grain weight (g), and grain weight (g) from a 0.8 m^2 plot, after harvesting with a sickle; 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 10.3-27.0 °C (Figure 1), while for the maximum temperature it was 16.9-36.4 °C and 1.0-18.1 °C for the minimum temperature.

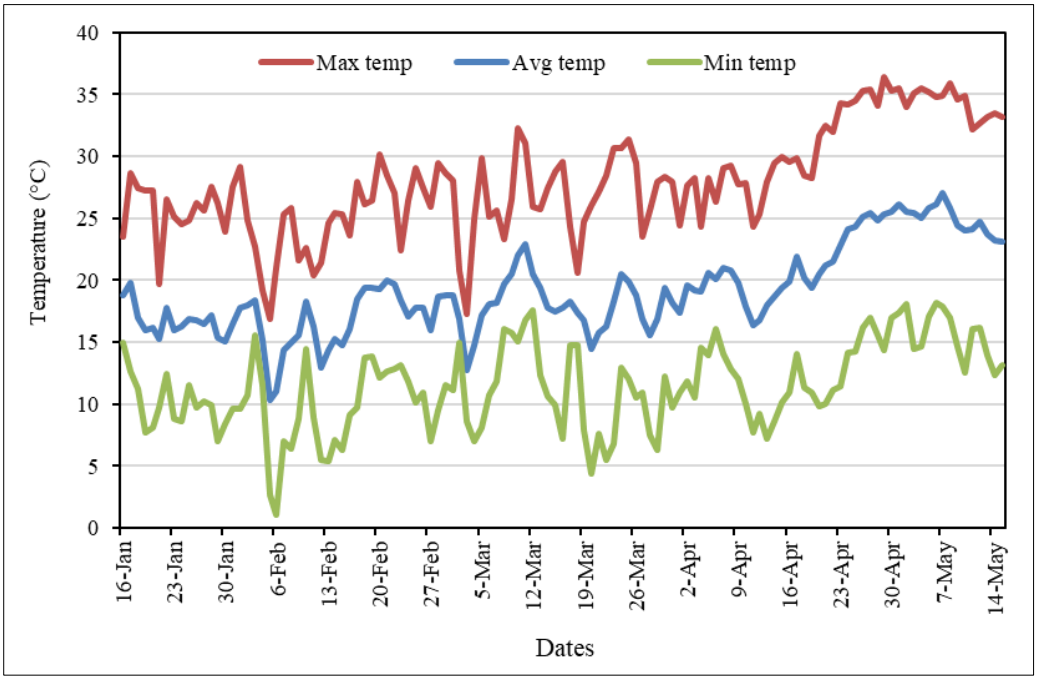

Figure 1 Average temperature from January 16 to May 15, 2020, recorded from the weather station CIANO-910, at the Norman E. Borlaug Experimental Station in the Yaqui Valley, Sonora, Mexico, during the crop season 2019-2020

Maximum temperatures above 30 °C occurred from one to several hours during the following days: February 20 (1 h), March 10 (3), 11 (4), 23 (1), 24 (2), 25 (2), April 15 (1), 20 (4), 21 (6), 22 (6), 23 (7), 24 (8), 25 (8), 26 (8), 27 (9), 28 (9), 29 (10), 30 (9), May 1 (9), 2 (9), 3 (10), 4 (10), 5 (9), 6 (10), 7 (10), 8 (9), 9 (8), 10 (8), 11 (8), 12 (9), 13 (7), 14 (8), and 15 (7) (Figure 2). The highest prevalence of heat units during 2019 [18] occurred during April 7 to May 5 with minor gaps between April 10-14, 14-18, and 20-24, while for the 2020, there was more persistence on the occurrence of heat units from April 20 to May 15.

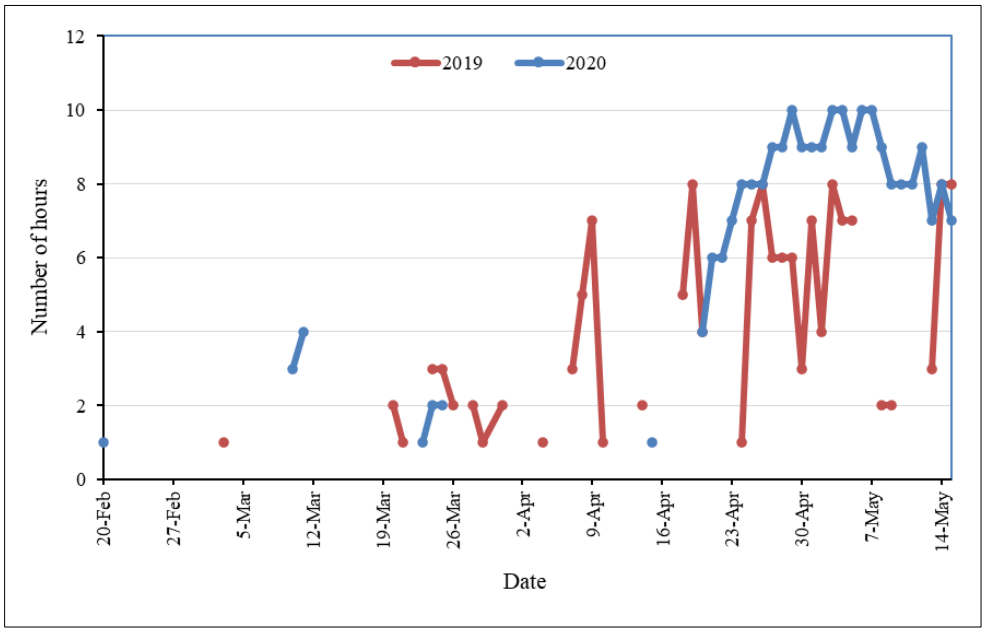

Figure 2 Daily occurrence of heat units from January 16 to May 15, 2020, recorded from the weather station CIANO-910, at the Norman E. Borlaug Experimental Station in the Yaqui Valley, Sonora, Mexico, during the crop seasons 2018-2019 and 2019-2020

Heading dates for the first sowing date occurred from March 19 to 25 and from April 3 to 7 for the second date, therefore, plants in the first date were only exposed to five HU during March 23-25, while plants in the second date did not have any exposure to any HU; consequently, since heat stress did not affect flowering [stage 65, 19], it might not had influence on the grain final outcome. Continuous hours from two to three on 3 different days with temperature above 30 °C occurred between 13 and 15 pm, while from four to ten on 27 different days between 9 am and 18 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 [20]). Weeks where the maximum temperature reached more than 30 °C in some days and in some hours were February 16-22 with 1 heat unit (HU), March 8-14 (7), 22-28 (5), April 12-18 (1), 19-25 (39), April 26-May 2 (63), May 3-9 (66), and 10-15 (47); the total heat units accumulated during the period of time that covered this work was 229, being a season between the 254 HU of 2018 [21] and 146 of 2019 [18]. In relation to cold units, with the exception of weeks January 12-18, March 8-14, and April 26 to May 15, the rest of the weeks starting from January 19-25 to April 19-25 accumulated cold units, ranging from 1 to a maximum of 39 during the week of February 2-8, followed by the weeks of February 9-15 and March 15-21 with 38 and 28, respectively (Figure 3). A total of 227 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 [22].

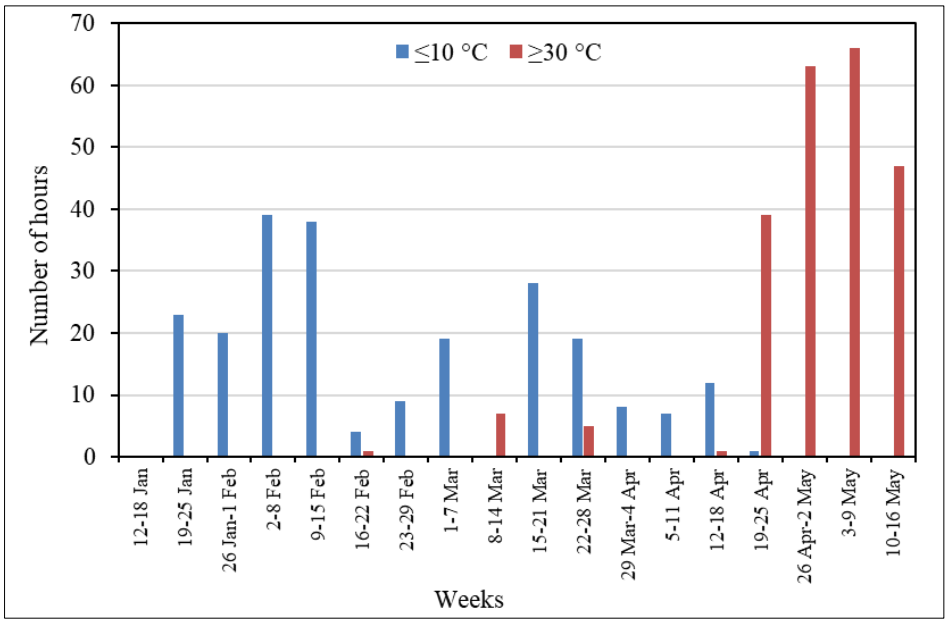

Figure 3 Number of cold and heat units accumulated from January 16 to May 15, 2020, recorded from the weather station CIANO-910, at the Norman E. Borlaug Experimental Station in the Yaqui Valley, Sonora, Mexico, during the crop season 2019-2020

The wheat plant also requires the accumulation of cold units, to prolong its biological cycle, which generally leads to a higher grain yield [17]. During January the low temperature range was 6.9-15.0 °C, in February 1.04-15.53 °C, in March 4.3-17.5 °C, in April 7.2-17.0 °C, and in May 12.3-18.1 °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 exposed to heat stress [14]. Late sowing with reduced 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 67 for the first sowing date and 64 for the second; Borlaug 100 and three other lines headed 64.5 days after the first sowing date, while sister line SOKOLL/3/PASTOR//HXL7573/2*BAU/5/CROC_1/AE.SQUARROSA(205)//BORL95/3/PRL/SARA//TSI/VEE#5/4/FRET2/6/D67.2/PARANA66.270//AE.SQUARROSA(320)/3/CUNNINGHAM/4/VORB (line No. 7, PTSS15Y00023S-099B-099Y-099M-2Y-020Y) headed 63.5 das (Figure 4).

Figure 4 Days to heading bread wheat cultivar Borlaug 100 (No. 9), and 28 advanced bread wheat lines adapted to stress, sown late on January 16 and 30, 2020, at the Norman E. Borlaug Experimental Station in the Yaqui Valley, Sonora, Mexico.

Lines MEX94.27.1.20/3/SOKOLL//ATTILA/3*BCN/4/PUB94.15.1.12/WBLL1/5/MUCUY (No. 23) and 68.111/ RGB-U//WARD/3/FGO/4/RABI/5/AE.SQUARROSA(778)/7/2*CHWL86/6/FILIN/IRENA/5/CNDO/R143//ENTE/MEXI_2 /3/AEGILOPS SQUARROSA (TAUS)/4/WEAVER (No. 26) headed 69 das. In the second date, there were three lines (No. 7, 8, and 15) that headed 62 das, and seven (No. 2, 6, 12, 19, 20, 22, and 23) that headed 66 das. Some lines were not affected greatly in the second sowing date by the fluctuating highest temperature detected during March 31 and April 10 (Figure 1); lines that had a two day difference or less for heading during the first and second dates were No. 2, 3, 4, 6, 7, 9, 10, 11, 12, 16, 19, 20, 22, and 27, while those with the a larger difference of 2.5-3 days were No. 1, 5, 13, 14, 15, 21, 23, 24, 25, and 29, and with 3.5-4 days were No. 8, 17, 18, 26, and 28; the highest difference of four days was shown by sister line No. 18 SOKOLL/WBLL1/4/PIHA//WORRAKATTA/2* PASTOR/3/PRL/2*PASTOR (PTSS14Y00071S-0B-099Y-099B-33Y-020Y). The average plant height of the group was 82.7 cm for the first sowing date and 83 cm for the second (Figure 5).

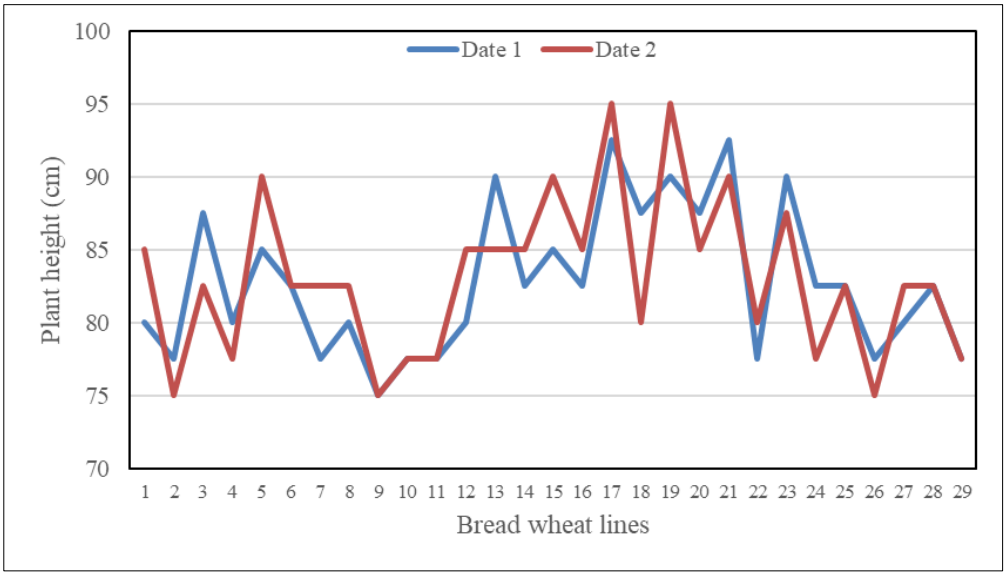

Figure 5 Plant height of bread wheat cultivar Borlaug 100 (No. 9), and 28 advanced bread wheat lines adapted to stress, sown late on January 16 and 30, 2020, at the Norman E. Borlaug Experimental Station in the Yaqui Valley, Sonora, Mexico

SOKOLL/3/PASTOR//HXL7573/2*BAU/4/PARUS/PASTOR/5/PIHA//WORRAKATTA/2*PASTOR/3/PRL/2*PASTOR (line No. 17) and sister line MEX94.27.1.20/3/SOKOLL//ATTILA/3*BCN/4/PUB94.15.1.12/WBLL1/5/MUCUY (PTSS14Y00328S-0B-099Y-099B-33Y-020Y, No. 21) were the tallest in the first date with 92.5 cm, while cultivar Borlaug 100 (No. 9) was the shortest with 75 cm. In the second date, the same line No. 17 and another sister line MEX94.27.1.20/3/SOKOLL//ATTILA/3*BCN/4/PUB94.15.1.12/WBLL1/5/MUCUY (PTSS 14Y00328S-0B-099Y-099B-9Y-020Y, No. 19) were the tallest ones with 95 cm, while sister line SOKOLL/3/PASTOR//HXL7573/2*BAU /4/SOKOLL/WBLL1/5/PIHA//WORRAKATTA/2*PASTOR/3/PRL/2*PASTOR(PTSS14Y00057S-0B-099Y-099B-26Y-020Y-0B, No. 2), cultivar Borlaug 100 (No. 9), and 68.111/RGB-U//WARD/3/FGO/4/RABI/5/AE.SQUARROSA(778)/7/ 2*CHWL86/6/FILIN/IRENA/5/CNDO/R143//ENTE/MEXI_2/3/AEGILOPS SQUARROSA (TAUS)/4/WEAVER (No. 26) were the shortest with 75 cm. There were several lines which did not show any difference in height in both dates, like lines No. 6, 9, 10, 11, 25, 28, and 29 (Figure 5); lines No. 2, 3, 4, 13, 18, 20, 21, 23, 24, and 26 were taller in the first date than in the second date, being the highest difference 7.5 cm in sister line SOKOLL/WBLL1/4/PIHA//WORRAKATTA /2*PASTOR/3/PRL/2* PASTOR (PTSS14Y00071S-0B-099Y-099B-33Y-020Y, No. 18). Lines taller in the second date than in the first date were No. 1, 5, 7, 8, 12, 14, 15, 16, 17, 19, 22, and 27. Fuentes-Dávila *et al*. [23] reported that during the 2016-2017 wheat season, a group of lines adapted to stress as well as the two cultivars used in that work, showed an average of 68 days to heading and 60 cm for plant height; during the wheat season 2017-2018, another group of lines showed an average of 69 days for heading and 84 cm for plant height [21], while in 2018-2019, another group of lines showed an average of 75 days for heading and 92 cm for plant height [18]. Cultivar Borlaug 100 had 68 days for heading and 60 cm height in 2017, 69 days for heading and 75 cm height in 2018, in 2019, it had 74 days for heading and an average height of 85 cm, and in 2020 it had 64 days for heading and 75 cm for plant height. In the span of those four years, results indicate that climatic condition were more stressful in 2017 as reported by Fuentes-Dávila *et al*. [21], since the highest average temperature from January to the middle of May was higher than in 2018, 2019, and 2020 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, 18.26 °C in 2019, and 19.09 °C in 2020. The average physiological maturity of the group of

lines and cultivar Borlaug 100 in this study occurred after 103 days for the first sowing date and 95 for the second with a range of 101 to 105 and 93.5 to 97.5, respectively (Figure 6).

Table 2 Average monthly temperatures during January to the middle of May in four 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
2020	16.70	16.70	18.00	20.88	24.94	66	83

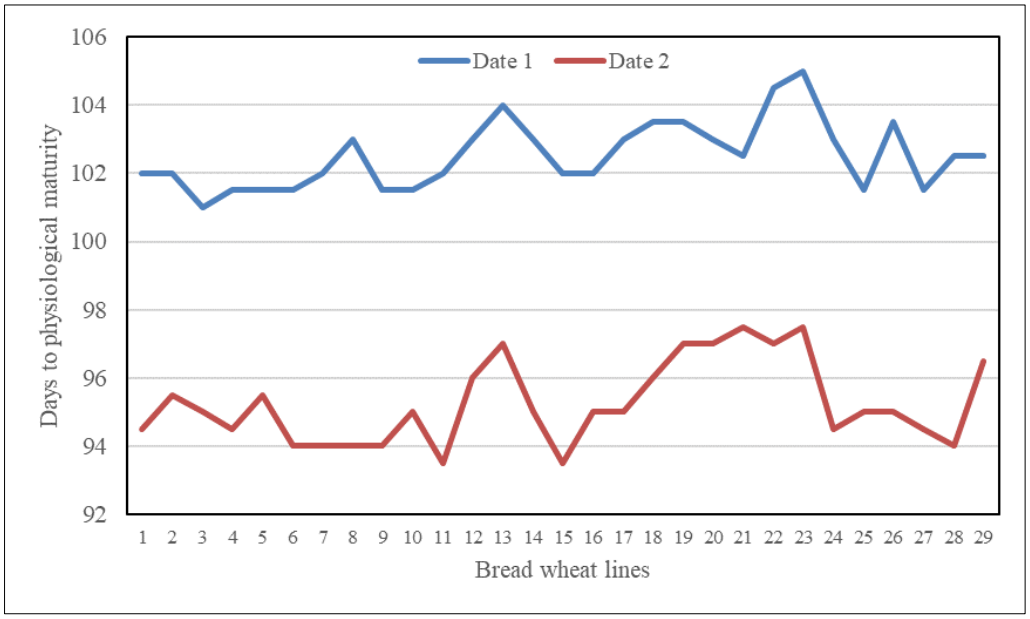

Figure 6 Days to physiological maturity of bread wheat cultivar Borlaug 100 (No. 9), and 28 advanced bread wheat lines adapted to stress, sown late on January 16 and 30, 2020, at the Norman E. Borlaug Experimental Station in the Yaqui Valley, Sonora, Mexico

The average a thousand grain weight of the group for the first date was 48.8 g (Figure 7); the sister line SOKOLL/3/PASTOR//HXL7573/2*BAU/4/SOKOLL/WBLL1/5/PIHA//WORRAKATTA/2*PASTOR/3/PRL/2*PASTOR (PTSS14Y00057S-0B-099Y-099B-43Y-020Y, No. 16) showed the highest weight with 63.6 g, followed by CROC_1/AE.SQUARROSA(205)//BORL95/3/PRL/SARA//TSI/VEE#5/4/FRET2/5/PIHA//WORRAKATTA/2*PASTOR /3/PRL/2*PASTOR (No. 15) with 60.4 g, while the line SOKOLL (No. 11) showed the lowest a thousand grain weight with 47.5.

Figure 7 A thousand grain weight of bread wheat cultivar Borlaug 100 (No. 9), and 28 advanced bread wheat lines adapted to stress, sown late on January 16 and 30, 2020, at the Norman E. Borlaug Experimental Station in the Yaqui Valley, Sonora, Mexico

The average a thousand grain weight of the group in the second date was 43.8 g; the sister line SOKOLL/3/PASTOR //HXL7573/2*BAU/5/CROC_1/AE.SQUARROSA(205)//BORL95/3/PRL/SARA//TSI/VEE#5/4/FRET2/6/D67.2/ PARANA66.270//AE.SQUARROSA (320)/3/CUNNINGHAM/4/VORB (PTSS15Y00023S-099B-099Y-099M-6Y-020Y, No. 8) showed the highest weight with 51.7 g, followed by the sister line SOKOLL/3/PASTOR//HXL7573/2*BAU /4/SOKOLL/WBLL1/5/PIHA//WORRAKATTA/2*PASTOR/3/PRL/2*PASTOR (PTSS14 Y00057S-0B-099Y-099B-43Y-020Y, No. 16) with 50.6 g, while the line FRTL//ATTILA/3*BCN/5/D67.2/PARANA66.270//AE.SQUARROSA (320)/3/ CUNNINGHAM/4/VORB (No. 6) showed the lowest a thousand grain weight with 38.4. The average grain weight per plot of the group in the first sowing date was 360 g and 310 in the second (Figure 8); the sister line WBLL4// OAX93.24.35/WBLL1/5/CROC_1/AE.SQUARROSA(205)//BORL95/3/PRL/SARA//TSI/VEE#5/4/FRET2/6/D67.2/PA RANA66.270//AE.SQUARROSA(320)/3/CUNNINGHAM/4/VORB (PTSS15Y00024S-099B-099Y-099M-17Y-020Y, No. 14) showed the highest weight with 460 g, followed by the sister line MEX94.27.1.20/3/SOKOLL //ATTILA/3*BCN/4/PUB94.15.1.12/WBLL1/5/ MUCUY (PTSS14Y00328S-0B-099Y-099B-32Y-020Y, No. 20) with 430 g, while lines CROC_1/AE.SQUARROSA(205)//BORL95/3/PRL/SARA//TSI/VEE#5/4/FRET2/5/PIHA// WORRAKATTA/2*PASTOR/3/PRL/2*PASTOR (No. 15) and 68.111/RGB-U//WARD/3/FGO/4/RABI/5/AE. SQUARROSA(778)/7/2*CHWL86/6/FILIN/IRENA/5/CNDO/R143//ENTE/MEXI_2/3/AEGILOPSSQUARROSA(TAUS) /4/WEAVER (No. 26), showed the lowest grain weight with 290 g.

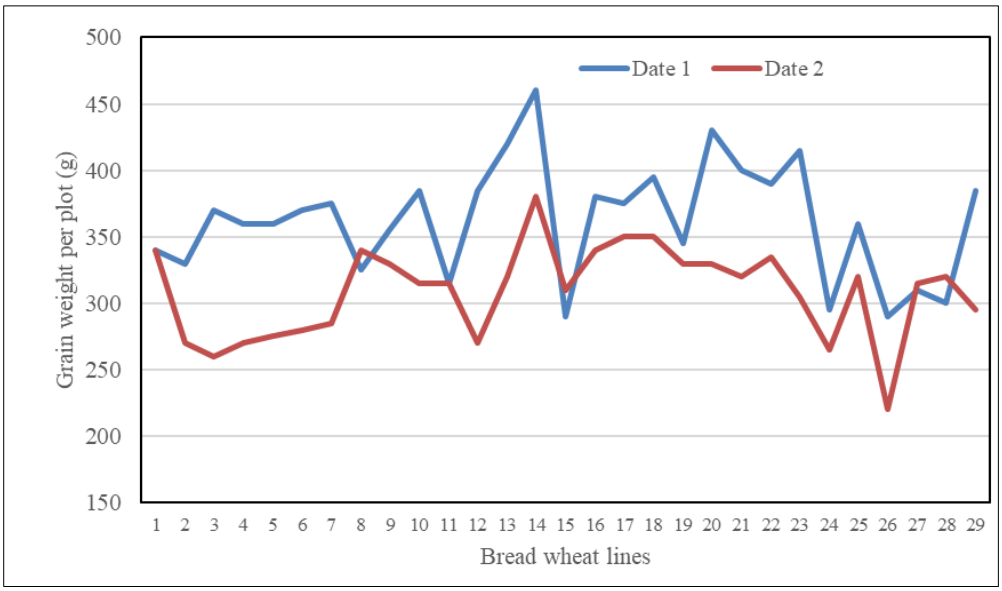

Figure 8 Grain weight per plot of bread wheat cultivar Borlaug 100 (No. 9), and 28 advanced bread wheat lines adapted to stress, sown late on January 16 and 30, 2020, at the Norman E. Borlaug Experimental Station in the Yaqui Valley, Sonora, Mexico

In the second date, the same line sister line WBLL4//OAX93.24.35/WBLL1/5/CROC_1/AE.SQUARROSA (205)//BORL95/3/PRL/SARA//TSI/VEE#5/4/FRET2/6/D67.2/PARANA66.270//AE.SQUARROSA(320)/3/ CUNNINGHAM/4/VORB (PTSS15Y00024S-099B-099Y-099M-17Y-020Y, No. 14) showed the highest grain weight per plot with 380 g, followed by SOKOLL/3/PASTOR//HXL7573/2*BAU/4/PARUS/PASTOR/5/PIHA// WORRAKATTA/2*PASTOR/3/PRL/2*PASTOR (No. 17) and sister line SOKOLL/WBLL1/4/PIHA// WORRAKATTA/2*PASTOR/3/PRL/2*PASTOR (PTSS14Y00071S-0B-099Y-099B-33Y-020Y, No. 18) with 350 g, while 68.111/RGBU//WARD/3/FGO/4/RABI/5/AE.SQUARROSA(778)/7/2*CHWL86/6/FILIN/IRENA/5/CNDO/R143//EN TE/MEXI_2/3/AEGILOPS SQUARROSA (TAUS)/4/WEAVER (No. 26) showed the lowest grain weight with 220 g. The stability shown by cultivar Borlaug 100 in 2019 when the grain weight from 20 spikes in similar sowing dates (January 16 and 30, 2019) was 47.3 g in the first sowing date and 47.7 in the second date [18], in 2018, when it produced 5.02 t ha^{-1} and 4.45 in 2017 under stress conditions [21,23], was corroborated in this work, as it showed 355 and 330 g per plot in the first and second sowing dates, with an average of 342 which corresponds to 4.28 t ha^{-1}. 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 % [24]. Other lines that showed stability in grain weight per plot were: sister line SOKOLL/3/PASTOR//HXL7573/2*BAU/4/SOKOLL/WBLL1/5/PIHA//WORRAKATTA/2* PASTOR/3/PRL/2*PASTOR (PTSS14Y00057S-0B-099Y-099B-10Y-020Y-0B, No. 1), and SOKOLL (No. 11), while those lines with a difference equal or greater than 100 g of grain weight per plot between the first and second sowing dates were: sister line SOKOLL/3/PASTOR//HXL7573/2*BAU/4/WBLL4//OAX93.24.35/WBLL1/5/D67.2/PARANA66.270 //AE.SQUARROSA (320)/3/CUNNINGHAM/4/VORB (PTSS14Y00013S-0B-099Y-099B-17Y-020Y-0B, No. 3), sister line WBLL4//OAX93.24.35/WBLL1/5/CROC_1/AE.SQUARROSA(205)//BORL95/3/PRL/SARA//TSI/VEE#5/4/FRET2/6/ D67.2/PARANA66.270//AE.SQUARROSA(320)/3/CUNNINGHAM/4/VORB (PTSS15Y000 24S-099B-099Y-099M-2Y-020Y, No. 12), sister line WBLL4//OAX93.24.35/WBLL1/5/CROC_1/AE.SQUARROSA (205)//BORL95/3/PRL/SARA// TSI/VEE#5/4/FRET2/6/D67.2/PARANA66.270//AE.SQUARROSA(320)/3/CUNNINGHAM/4/VORB (PTSS15Y00024S -099B-099Y-099M-10Y-020Y, No. 13), sister line MEX94.27.1.20/3/SOKOLL//ATTILA/3*BCN/4/PUB94.15.1.12/ WBLL1/5/MUCUY (PTSS14Y00328S-0B-099Y-099B-32Y-020Y, No. 20), and sister line MEX94.27.1.20/3/SOKOLL// ATTILA/3*BCN/4/PUB94.15.1.12/WBLL1/5/MUCUY (PTSS14Y00329S-0B-099Y-099B-33Y-020Y, No. 23). On the other hand, those lines which showed a little greater grain weight per plot in the second date were: sister line SOKOLL/3/PASTOR//HXL7573/2*BAU/5/CROC_1/AE. SQUARROSA(205)//BORL95/3/PRL/SARA//TSI/VEE#5/4/ FRET2/6/D67.2/PARANA66.270//AE.SQUARROSA(320)/3/CUNNINGHAM/4/VORB (PTSS15Y00023S-099B-099Y-099M-6Y-020Y, No. 8), CROC_1/AE.SQUARROSA(205)//BORL95/3/PRL/SARA//TSI/VEE#5/4/FRET2/5/PIHA// WORRAKATTA/2*PASTOR/3/PRL/2*PASTOR (No. 15), SOKOLL/WBLL1/4/PASTOR//HXL7573/2*BAU/3/ WBLL1 (No. 27), and CHEN/AE.SQ//2*OPATA/3/FINSI/5/W15.92/4/PASTOR//HXL7573/2*BAU/3/WBLL1 (No. 28). Lines with the best agronomic type consistent in both dates were: sister line WBLL4//OAX93.24.35/WBLL1/5/CROC_1 /AE.SQUARROSA(205)//BORL95/3/PRL/SARA//TSI/VEE#5/4/FRET2/6/D67.2/PARANA66.270//AE.SQUARROSA (320)/3/CUNNINGHAM/4/VORB (PTSS15Y00024S-099B-099Y-099M-17Y-020Y, No. 14) and sister line

MEX94.27.1.20/3/SOKOLL//ATTILA/3*BCN/4/PUB94.15.1.12/WBLL1/5/MUCUY (PTSS14Y00 329S-0B-099Y-099B-33Y-020Y, No. 23). The temperature that prevailed during the period of the study which had an average monthly range of 16.7 to 24.9 °C and an overall average of 19.09 °C, condition rather similar as that reported for the year 2019 [18], it did not cause an important heat stress [25] on the bread wheat lines which would lead to greater grain yield reduction. However, the limited application of water with two complementary irrigations caused a drought stress. Drought affects all plant development stages from germination, vegetative and reproductive growth to grain filling and maturation of the crop [26]. It reduces nitrogen uptake efficiency and utilization by plants. The deprived nutrient uptake is due to impaired membrane permeability and active transport and reduces transpiration rate resulting in repressed root absorbing power. The intake of CO2 is reduced due to stomatal closure, and inside the stomata, a high level of oxygen produces reactive oxygen species, caused by the partial reduction of oxygen, and causes rupturing of membranes which become leaky, thereby affecting respiration, photosynthesis, and the overall development of the plant. Double ridge to anthesis stage is the most sensitive growth period regarding wheat yield to water déficit, because of the negative influence on the number of spikelets and ultimately kernels per spike. Water deficit might decrease wheat grain yield from 17 to 70% [26]. This was reflected on cultivar Borlaug 100 which under full irrigation (four complementary irrigations) the grain yield was 8.797 t ha^{-1} [27], while under the conditions of this work, it yielded 4.280 t ha^{-1}.

4. Conclusion

The average days for heading of twenty eight advanced wheat lines and bread wheat cultivar Borlaug 100 was 67 days for the first sowing date and 64 for the second, while days for physiological maturity were 103 and 95, respectively.

The average plant height of the group for the first and second sowing dates was 83 cm; line SOKOLL/3/PASTOR//HXL7573/2*BAU/4/PARUS/PASTOR/5/PIHA//WORRAKATTA/2*PASTOR/3/PRL/2* PASTOR consistently reached the maximum height with 92.5 and 95 cm in the first and second dates, respectively.

The average a thousand grain weight of the group was 53.8 g for the first sowing date and 43.8 for the second; sister line SOKOLL/3/PASTOR//HXL7573/2*BAU/4/SOKOLL/WBLL1/5/PIHA//WORRAKATTA/2*PASTOR/3/PRL/2*PASTOR (PTSS14Y00057S-0B-099Y-099B-43Y-020Y) showed the highest average weight with 57.07 g, while SOKOLL showed the lowest TGW with 43.6 g.

The overall average grain yield per plot was 340 g. Outstanding were sister lines WBLL4//OAX93.24.35/WBLL1/5/CROC_1/AE.SQUARROSA(205)//BORL95/3/PRL/SARA//TSI/VEE#5/4/FRET2/6/D67.2/PARANA66.270//AE.SQUARROSA(320)/3/CUNNINGHAM/4/VORB (PTSS15Y00024S-099B-099Y-099M-10Y-020Y) with an average of 420 g which was above 5 t ha^{-1}, MEX94.27.1.20/3/SOKOLL//ATTILA/3*BCN/4/PUB94.15.1.12/WBLL1/5/MUCUY (PTSS14Y00328S-0B-099Y-099B-32Y-020Y) with 380 g, and SOKOLL/WBLL1/4/PIHA//WORRAKATTA/2*PASTOR/3/PRL/2*PASTOR with 372 g which were above 4.6 t ha^{-1}.

The average temperature was 19.09 °C with a maximum of 36.3 °C and a minimum of 1.04 °C; the average relative humidity was 68.4 %; there were 15.3 mm of precipitation, and the number of heat and cold units was 229 and 227, 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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