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Grain yield of wheat advanced lines adapted to stress, during the crop season 2017-2018

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Abstract

Twenty five advanced wheat lines which included six groups of sister lines and the commercial durum wheat cultivar Movas C2009 as well as bread wheat cultivar Borlaug 100 were sown on January 16 and 30, 2018, 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, and cold units were recorded from January 16 to May 15, 2018. The variables evaluated were: days to heading, a thousand grain weight (g), and grain yield per plot (g). The average days for heading of lines was 69 days. The average plant height of the group was 84 cm; lines IWA8612949/3/2*ATILLA*2/PBW65//MURGA and BAV92/SERI showed a height of 100 and 95 cm, respectively. The average a thousand grain weight of the group was 41.3 g; line SOKOLL/3/PASTOR//HXL7573 /2*BAU/4/SOKOLL/WBLL1 showed the highest weight with 46.3 g, followed by IWA8612949/3/2*ATILLA*2 /PBW65//MURGA and CROC_1/AE.SQUARROSA(256)/4/PASTOR//HXL7573/2*BAU/3/WBLL1/5/BABAX/ LR42//BABAX/3/ER2000 with 46.2 and 45.3 g, respectively; while the line FRANCOLIN#1 showed the lowest TGW with 36.2 g. The average grain yield per plot was 339.5 g. Outstanding lines were W15.92/4/PASTOR// HXL7573/2*BAU/3/WBLL1 (442 g), SOKOLL (426 g), and FRANCOLIN#1 (422 g) which were above 5.27 t ha^{-1}. The average temperature was 19.26°C with a maximum of 38.7°C and a minimum of 2.1°C; the average relative humidity was 64.0%; there were 9.1 mm of precipitation, and the number of cold units was 254.

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

1. Introduction

According to Wahid *et al.* [1] 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. Heat stress impacts crops based on intensity, duration, and rate of increment of the temperature, and the periodicity of its occurrence in climatic zones, depends on the probability and period of high temperatures that occur during the day and/or the night. High temperatures have a complex effect on crops, modify the quality of wheat grains, and its end effect will depend on the phenological stage of the plant and the genotype [2]. High temperatures occur in all agricultural areas worldwide, and since it is a common event, frequently its effect is not taken into consideration; but yield reduction in winter cereals caused by high temperatures during the grain-filling phenological stage might reach from 10 to 15% [3,4]. Wheat is cultivated in tropical or subtropical areas which are defined as regions with temperature higher than 17.5°C during the coolest month of the crop season. There are more than 7 million hectares in around 50 countries that comply with this condition, primarily in Southeast Asia, as well as in India and Bangladesh [5], in Sub-Saharan Africa

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[6], Brazil, Thailand, Uganda, Mexico, Sudan, Egypt, Nigeria, and Syria [7]. The probability that high temperatures occur in a given agricultural region, depends on the sowing date, the altitude, and the presence of events of high temperature. To comply with the demand of wheat worldwide in the future, productivity must increase in both the favorable and marginal environments. It is probable that when agricultural areas expand, crops will be subjected to certain levels of stress, including heat stress. Most models forecast an increase of 1-4ºC during the day and night, which in some crops, high temperature during the night seems to be more damaging to productivity than high temperature during the day [8]. Flowering must take place with the lowest or without risk of a frost in winter crops of temperate zones, therefore, the sowing date is of great importance, 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 important reasons for the increase of local wheat production [9]. Since 1982, the support of the United Nations Development Programme 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. CIMMYT generated 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 7th SATYN, subjected to late sowing, and therefore, exposed to a warmer and shorter crop season.

2. Material and methods

Twenty five advanced bread wheat lines from the 7th Stress Adapted Trait Yield Nurseries (SATYN), including six groups of sister lines (lines 7-9, 10-12, 13-14, 15-16, 17-18, 24 and 27) (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, 2018, 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 durum wheat cultivar Movas C2009 and bread wheat cultivar Borlaug 100 were used as checks. The former has shown grain yields between 5.9 and 7.6 t ha^{-1} with two, three, and four complementary irrigations, respectively, in experimental plots [11], while the latter 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]. 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.* [13]. The daily average temperature (°C), the maximum and minimum, relative humidity, and the number of cold and heat units, were recorded from January 16 to May 15, 2018 by the weather station CIANO-910, located in block 910 in the Yaqui Valley [14]; this station belongs to the automated weather station network of Sonora [15]. 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), 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

Maximum temperatures above 30°C occurred for several hours on January 29 and 30, 2018, and later during the season on March 8, while during that period of time, the maximum temperature range was 17.37 to 29.65°C (Figure 1) which probably did not cause heat stress on wheat during seed germination, tillering, stem elongation and booting (stages 07 to 45) [16].

Briggle and Curtis [17] indicated that although wheat is a cool-season crop, it can develop in different climatic zones; its production is concentrated between latitudes 30-60°N and 27-40°S, but it can be grown beyond these limits, with an optimum growth temperature of about 25°C. The average high temperature between January 31 and March 7 was 25.58°C. After March 8, temperatures above 30°C were more frequent. Weeks where the maximum temperature reached more than 30°C in some days and in some hours were January 28-February 3; March 4-10, 11-17, 18-24, and 25-31; April 1-7, 8-14, 15-21, and 22-28; April 29 to May 5, 6-12, and the days 13-15; the total heat units accumulated during the period of time that covered this work was 259. The time of the day with the highest temperature recordings was 15:00 with 71, followed by 14:00 with 63, 13:00 with 54, 12:00 with 38, 16:00 with 29, and 11:00 with 25. Occurrence of continuous hours with a temperature above 30°C, particularly after March 8 was as follows: for 3 continuous hours there were 10 occurrences, for 2 and 8 h there were 7, for 9 h there were 6, for 7 h there were 5, for 5 and 6 h there were 4, for 1, 4 and 10 h there were 2, and for 11 and 12 h there was 1 occurrence. With the exception of weeks February 4-10 and April 8-14, the rest of weeks from January 14-20 to April 15-21 accumulated cold units, ranging from 1 to a maximum of 65 during the week of January 21 to 27, followed by the weeks of February 25 to March 3 and February 18-24 with 42 and 38, respectively (Figure 2). The stations from the automated weather stations network in the Yaqui Valley in the state of Sonora, that accumulated the highest number of cold units were B-2020 with 437, B-609 with 391, Estación Corral with 349, and B-111 with 347, while in CIANO-910 there were 254 CU. All phenological stages of the wheat plant are sensitive to the changes of air temperature; high temperatures favor a greater metabolic activity of the plant, as well as an acceleration of the physiologic processes that determine its growth and development [18]. On the other hand, wheat requires the accumulation of cold units, to prolong its biological cycle, and generally, this leads to greater grain yield [19]. During January the low temperature range was 3.13-10.92°C, in February 2.16-16.37°C, in March 6.04-15.41°C, in April 8.93-16.88°C, and in May 11.53-19.27°C.

Table 1 Advanced bread wheat lines from the 7th Stress Adaptive Trait Yield Nursery from CIMMYT, sown on January 16 and 30, 2018, at the Norman E. Borlaug Experimental Station in the Yaqui Valley, Sonora, Mexico

No.	Pedigree and selection history
1	MOVAS C2009
2	CHEN/AE.SQ//2*WEAVER/3/BAV92/4/JARU/5/OLI2/SALMEJA/6/CROC_1/ AE.SQUARROSA(205)//BORL95/3/ PRL/SARA//TSI/VEE#5/4/FRET2 PTSAS08M00026T-050Y-050ZTM-050Y-8ZTM-010Y-0B
3	SOKOLL/3/PASTOR//HXL7573/2*BAU/4/ASTREB PTSA08M00047S-050ZTM-050Y-36ZTM-010Y-0B
4	SOKOLL/3/PASTOR//HXL7573/2*BAU/5/CROC_1/AE.SQUARROSA(205)//BORL95/3/PRL/SARA//TSI/ VEE#5/4/FRET2 PTSA08M00052S-050ZTM-050Y-31ZTM-010Y-0B
5	SOKOLL/3/PASTOR//HXL7573/2*BAU/4/SOKOLL/WBLL1 PTSA08M00053S-050ZTM-050Y-50ZTM-010Y-0B
6	SOKOLL/3/PASTOR//HXL7573/2*BAU/4/SOKOLL/WBLL1 PTSA08M00053S-050ZTM-050Y-50ZTM-010Y-0B
7	CROC_1/AE.SQUARROSA(256)/4/ PASTOR//HXL7573/2*BAU/3/WBLL1/5/BABAX/LR42//BABAX/3/ER2000 PTSS12SHB00050T-0TOPB-099Y-099B-3Y-020Y-0B
8	IWA8612949/3/2*ATILLA*2/PBW65//MURGA PTSS13Y00137T-099B-099Y-3B-020Y-0B
9	IWA8612949/3/2*ATILLA*2/PBW65//MURGA PTSS13Y00137T-099B-099Y-59B-020Y-0B
10	IRAN-880/3/2*ATTILA*2/PBW65/MURGA PTSS13Y00139T-099B-099Y-5B-020Y-0B
11	IRAN-880/3/2*ATTILA*2/PBW65/MURGA PTSS13Y00139T-099B-099Y-9B-020Y-0B
12	IRAN-880/3/2*ATTILA*2/PBW65/MURGA PTSS13Y00139T-099B-099Y-19B-020Y-0B
13	SOKOLL/WBLL1/4/PASTOR//HXL7573/2*BAU/3/WBLL1 PTSS11Y00144S-0SHB-099SHB-099Y-099B-099Y-16Y-020Y-0B
14	SOKOLL/WBLL1/4/PASTOR//HXL7573/2*BAU/3/WBLL1 PTSS11Y00144S-0SHB-099SHB-099Y-099B-099Y-19Y-020Y-0B
15	VORB/4//PASTOR//HXL7573/2*BAU/3/WBLL1 PTSS11Y00143S-0SHB-099B-099Y-099B-099Y-22Y-020Y-0B

16	VORB/4//PASTOR//HXL7573/2*BAU/3/WBLL1 PTSS11Y00143S-0SHB-099B-099Y-099B-099Y-26Y-020Y-0B
17	CHEN/AE.SQUARROSA//2*OPATA/3/FINSI/5/W15.92/4/PASTOR//HXL7573/2*BAU/3/WBLL1 PTSS11Y00152S-0SHB-099B-099Y-099B-099Y-5Y-020Y-0B
18	CHEN/AE.SQUARROSA//2*OPATA/3/FINSI/5/W15.92/4/PASTOR//HXL7573/2*BAU/3/WBLL1 PTSS11Y00152S-0SHB-099B-099Y-099B-099Y-17Y-020Y-0B
19	SOKOLL CMSS97M00316S-0P20M-0P20Y-43M-010Y
20	BAJ #1 CGSS01Y00134S-099Y-099M-099M-13Y-0B
21	BORLAUG 100 F2014 CMSS06Y00605T-099TOPM-099Y-099ZTM-099Y-099M-11WGY-0B-0MEX
22	FRANCOLIN#1 CGSS01B00056T-099Y-099M-099M-099Y-099M-14Y-0B
23	KACHU #1 CMSS97M03912T-040Y-020Y-030M-020Y-040M-4Y-2M-0Y
24	SOKOLL/WBLL1 PTSS02Y00021S-099B-099Y-030ZTM-040SY-040M-31Y-OM-0SY-0B-0Y
25	BAV92/SERI CMSS96Y04084S-0Y-1B-93TLA-0B-0Y-106B-0Y-0Y-0Y-0Y
26	W15.92/4/PASTOR//HXL7573/2*BAU/3/WBLL1 PTSS02B00102T-0TOPY-0B-0Y-0B-11Y-0M-0SY-0B-0Y
27	SOKOLL/WBLL1 PTSS02Y00021S-099B-099Y-099B-099Y-207B-0Y

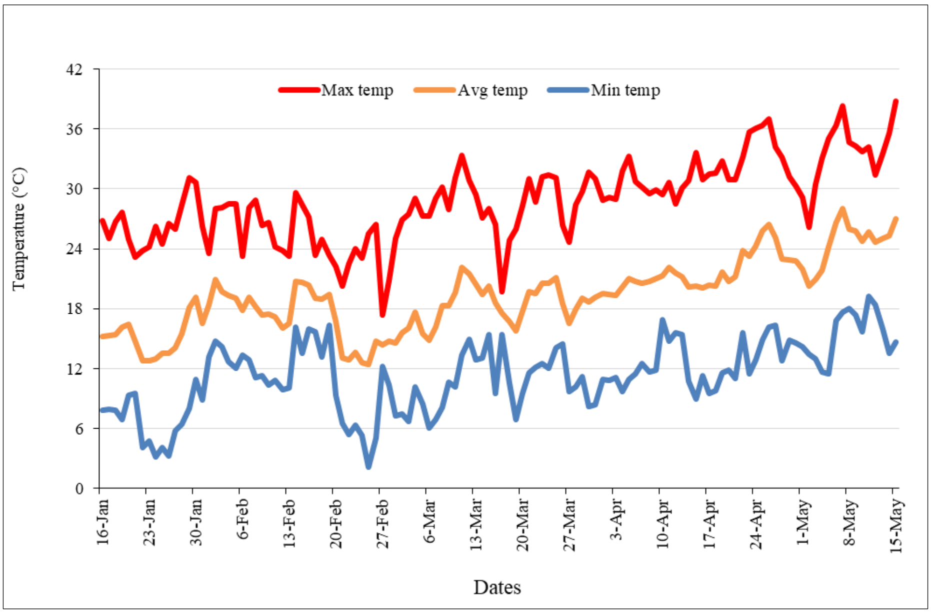

Figure 1 Average temperature from January 16 to May 15, 2018, recorded from the weather station CIANO-910, at the Norman E. Borlaug Experimental Station in the Yaqui Valley, Sonora, Mexico, during the crop season 2017-2018

The sowing dates of this work do not fall within the technical recommendations for commercial cultivation; the optimum dates for wheat sowing in southern Sonora, Mexico, are between November 15 to December 15, otherwise, generally, plants will not tiller properly and will be expose to heat stress [13]. The average days to heading of the group of lines and the two cultivars was 69 days, being the earliest with 66 CHEN/AE.SQ//2*WEAVER/3/BAV92/4/JARU/5/OLI2/SALMEJA/6/CROC_1/AE.SQUARROSA(205)//BORL 95/3/PRL/SARA//TSI/VEE#5/4/FRET2 (2), BAJ#1 (20) and FRANCOLIN#1 (22), and the latest with 71 d SOKOLL/3/PASTOR//HXL7573/2*BAU/4/ASTREB (3), SOKOLL/3/PASTOR//HXL7573/2*BAU/5/CROC_1/ AE.SQUARROSA(205)//BORL95/3/PRL/SARA//TSI/VEE#5/4/FRET2 (4), CROC_1/AE.SQUARROSA(256)/4/ PASTOR//HXL7573/2*BAU/3/WBLL1/5/BABAX/LR42//BABAX/3/ER2000 (6), IWA8612949/3/2*ATTILA*2/ PBW65//MURGA (PTSS13Y00137T-099B-099Y-5B-020Y-0B) (8), IRAN-880/3/2*ATTILA*2/PBW65/MURGA (PTSS13Y00139T-099B-099Y-9B-020Y-0B) (11), and SOKOLL/WBLL1 (PTSS02Y00021S-099B-099Y-099B-099Y-207B-0Y) (27) (Figure 3).

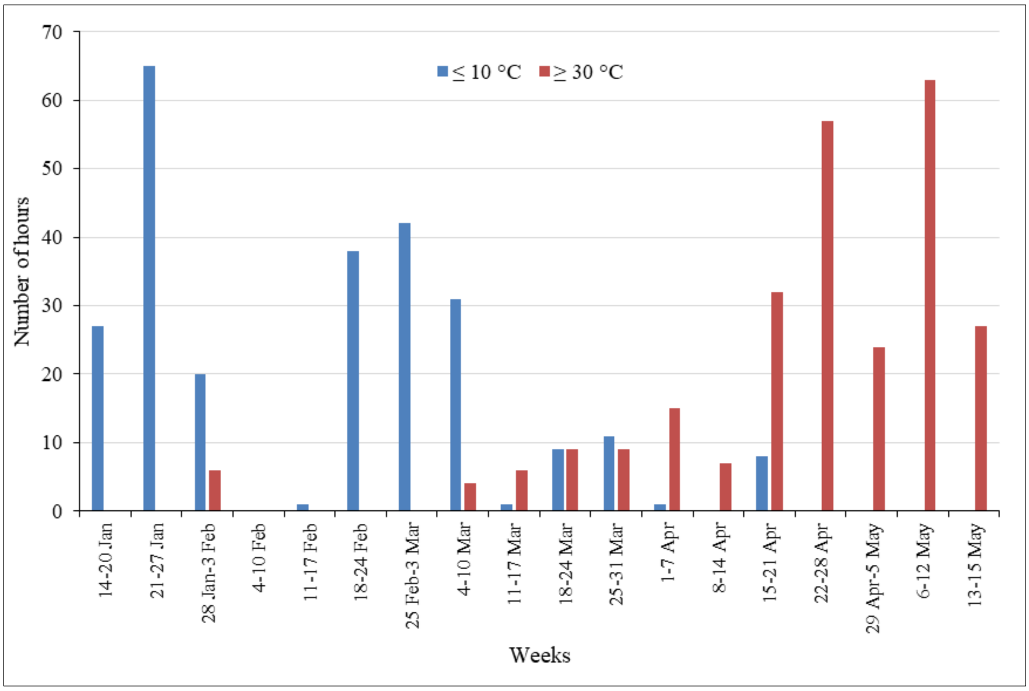

Figure 2 Number of cold and heat units accumulated from January 14 to May 15, 2018, recorded from the weather station CIANO-910, at the Norman E. Borlaug Experimental Station in the Yaqui Valley, Sonora, Mexico, during the crop season 2017-2018

The average plant height of the group was 84 cm; the shortest lines were VORB/4/PASTOR//HXL7573/2*BAU/3/ WBLL1 (PTSS11Y00143S-0SHB-099B-099Y-099B-099Y-22Y-020Y-0B) (15), cultivar BORLAUG 100 (21), and FRANCOLIN#1 (22) with 75 cm; IWA8612949/3/2*ATILLA*2/PBW65//MURGA (PTSS13Y00137T-099B-099Y-3B-020Y-0B) (7), and BAV92/SERI (25) showed a height of 100 and 95 cm, respectively (Figure 3). 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 this work the average was 69 days and 84 cm, respectively. Cultivars Borlaug 100 and Movas C2009 had 68 days for heading and 60 cm height in 2017, and 69 days for heading and 75 cm height for Borlaug 100 and 80 cm for Movas C2009 in this work. These results indicate that climatic condition were more stressful in 2017 since the highest average temperature in January was 28.22°C, 31.26 in February, 32.97 in March, 37.76 in April, and 36°C in the first 15 days of May, while in 2018 it was 26.39, 25.02, 28.40, 31.71, and 33.64°C, respectively. The average a thousand grain weight of the group was 41.3 g (Figure 4); the line SOKOLL/3/PASTOR//HXL7573/2*BAU/4/SOKOLL/WBLL1 (5) showed the highest weight with 46.3 g, followed by IWA8612949/3/2*ATILLA*2/PBW65//MURGA (PTSS13Y00137T-099B-099Y-3B-020Y-0B) (7) and CROC_1/AE.SQUARROSA(256)/4/PASTOR//HXL7573/2*BAU/3/WBLL1/5/BABAX/LR42//BABAX/3/ER2000 (6) with 46.2 and 45.3 g, respectively, while line FRANCOLIN#1 (22) showed the lowest a thousand grain weight with 36.2 g.

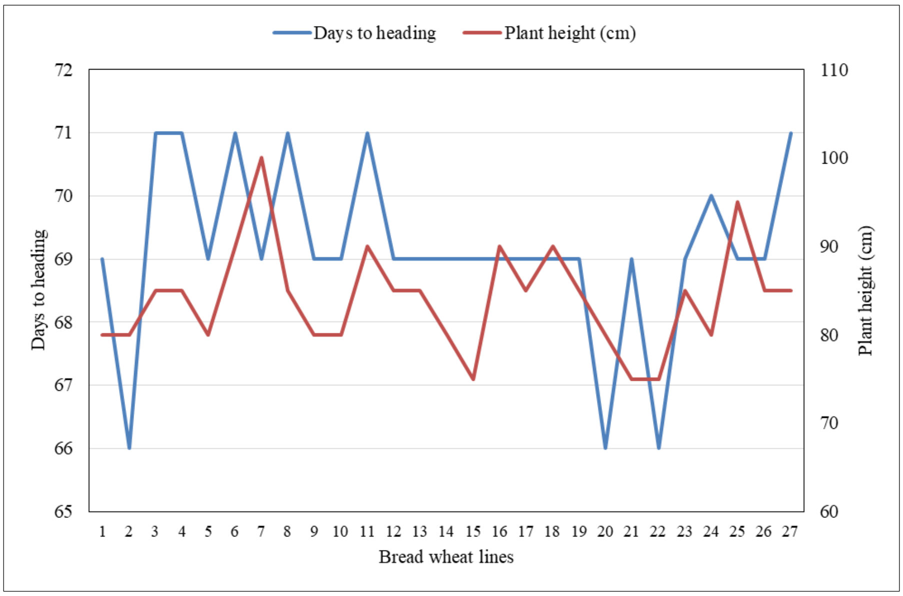

Figure 3 Average days to heading and plant height of durum wheat cultivar Movas C2009 (1), bread wheat cultivar Borlaug 100 (21), and 25 advanced bread wheat lines adapted to stress, sown late on January 16 and 30, 2018, at the Norman E. Borlaug Experimental Station in the Yaqui Valley, Sonora, Mexico

The average grain weight per plot of the group was 339.5 g, highlighting lines W15.92/4/PASTOR//HXL7573/2*BAU/3/WBLL1 (26) with 442 g, SOKOLL (19) with 426 g, and FRANCOLIN#1 (22) with 422 g (Figure 4) which correspond to 5.52 t ha^{-1}, 5.32, and 5.27 t ha^{-1}, respectively. Other lines that were above the 5 t ha^{-1} were SOKOLL/WBLL1 (PTSS02Y00021S-099B-099Y-030ZTM-040SY-040M-31Y-OM-0SY-0B-0Y) (24), VORB/4//PASTOR//HXL7573/2*BAU/3/WBLL1 (PTSS11Y00143S-0SHB-099B-099Y-099B-099Y-26Y-020Y-0B) (16), SOKOLL/WBLL1/4/PASTOR//HXL7573/2*BAU/3/WBLL1 (PTSS11Y00144S-0SHB-099SHB-099Y-099B-099Y-19Y-020Y-0B) (14), VORB/4//PASTOR//HXL7573/2*BAU/3/WBLL1 (PTSS11Y00143S-0SHB-099B-099Y-099B-099Y-22Y-020Y-0B) (15), and BAJ #1 (20), and cultivar Borlaug 100 (21).

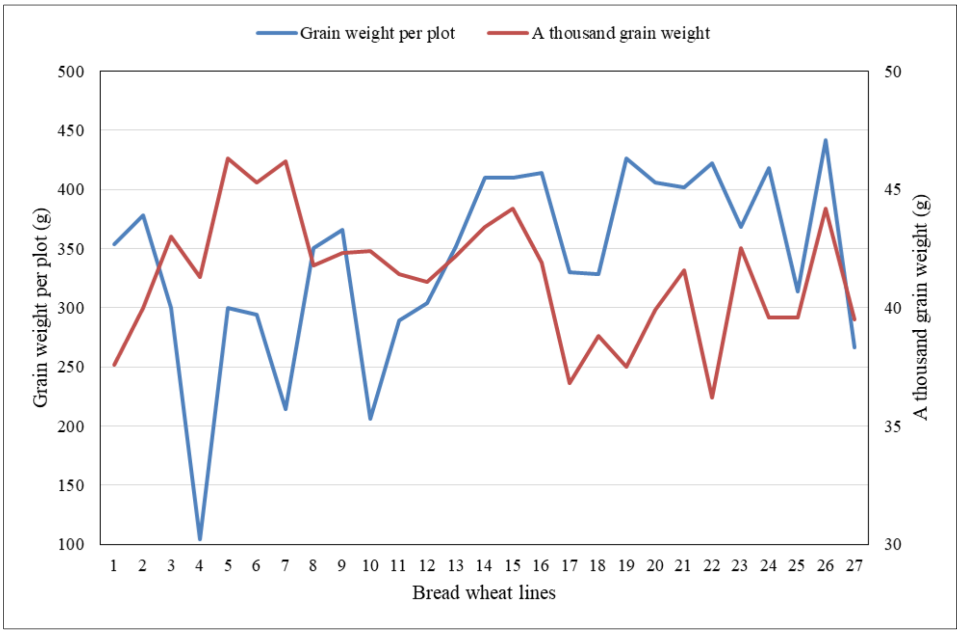

Figure 4 Average grain weight per plot and a thousand grain weight of durum wheat cultivar Movas C2009 (1), bread wheat cultivar Borlaug 100 (21), and 25 advanced bread wheat lines adapted to stress, sown late on January 16 and 30, 2018, at the Norman E. Borlaug Experimental Station in the Yaqui Valley, Sonora, Mexico

Similar to the year 2017 when 227 cold units were recorded [20], the number of CU was low with an accumulation of 254. Also, cultivar Movas C2009 showed sensitivity to the short season and the heat stress during the flowering stage onward yielding 4.42 t ha^{-1} of grain, while in 2017 it yielded 3.2, as it has been also reported by Jáuregui *et al*. [21]. On the other hand, cultivar Borlaug 100 as in 2017, showed more stability than Movas C2009 and produced 5.02 t ha^{-1} while in 2017 it produced 4.45. Chávez-Villalba *et al*. [12] reported that Borlaug 100 showed 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%. The best agronomic type was shown by the lines CHEN/AE.SQUARROSA//2*WEAVER/3/BAV92/4/JARU/5/OLI2/SALMEJA/6/CROC_1/AE.SQUARROSA (205)//BORL95/3/PRL/SARA//TSI/VEE#5/4/FRET2 (2) and SOKOLL/3/PASTOR//HXL7573/2*BAU/5/ CROC_1/AE.SQUARROSA(205)//BORL95/3/PRL/SARA//TSI/VEE#5/4/FRET2 (4). The average temperature during this work was 19.26°C with a maximum of 38.7°C and a minimum of 2.1°C; the average relative humidity was 64.0%; and there were 9.1 mm of precipitation.

4. Conclusion

The average days for heading of lines was 69 days and the avg plant height was 84 cm, although lines IWA8612949/3/2*ATILLA*2/PBW65//MURGA and BAV92/SERI showed a height of 100 and 95 cm, respectively.

The average a thousand grain weight of the group was 41.3 g; line SOKOLL/3/PASTOR//HXL7573/2*BAU /4/SOKOLL/WBLL1 showed the highest weight with 46.3 g, followed by IWA8612949/3/2*ATILLA*2/PBW65// MURGA and CROC_1/AE.SQUARROSA(256)/4/PASTOR//HXL7573/2*BAU/3/WBLL1/5/BABAX/LR42// BABAX/3/ER2000 with 46.2 and 45.3 g, respectively; while the line FRANCOLIN#1 showed the lowest TGW with 36.2 g.

The average grain yield per plot was 339.5 g. Outstanding lines were W15.92/4/PASTOR//HXL7573/2*BAU/3/ WBLL1 with 442 g, SOKOLL with 426 g, and FRANCOLIN#1 with 422 g which were above 5.27 t ha^{-1}. The average temperature was 19.26°C with a maximum of 38.7°C and a minimum of 2.1°C; the average relative humidity was 64.0%; there were 9.1 mm of precipitation, and the number of cold units was 254.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

The authors declare that no conflict of interest.

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