GRAIN YIELD AND OTHER PARAMETERS OF WHEAT LINES ADAPTED TO HEAT STRESS, SOWN LATE DURING THE CROP SEASON 2016-2017

FUENTES-DÁVILA Guillermo, ROSAS-JÁUREGUI Ivón Alejandra, AYÓN-IBARRA Carlos Antonio, FÉLIX-FUENTES José Luis, FÉLIX-VALENCIA Pedro and TORRES-CRUZ María Monserrat

INIFAP, Campo Experimental Norman E. Borlaug, Apdo. Postal 155, km 12 Norman E. Borlaug, Cd. Obregón, Sonora 85000

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ABSTRACT

Twenty five advanced wheat lines, which included 12 sister lines, with tolerance to stress and the commercial durum wheat cultivar Movas C2009 as well as the commercial bread wheat cultivar Borlaug 100 were sown on January 12 and 31, 2017, 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, and a seed density of 100 kg ha-1. Average daily temperature (°C), maximum, minimum, relative humidity, and cold units were recorded from January 12 to May 15, 2017. The variables evaluated were: days to heading, plant height (cm), a thousand grain weight (g), and grain yield per plot (g). The average days for heading was 68 and the average plant height was 60 cm. The average a thousand grain weight was 41.6 g; the line KACHU#1 showed the highest weight with 52.9 g, while BAJ#1 showed the lowest weight 27.3 g. The average grain yield per plot was 294.5 g. Outstanding lines were VOROBEY with 460 g, KACHU#1 with 408 g, and PUB94.15.1.12/WBLL1 with 404 g, which were above 5 t ha-1. The average temperature was 19.08°C with a maximum of 37.7°C and a minimum of 5.02°C; the average relative humidity was 66.8%, and the number of cold units was 227.

Keywords: Wheat, Triticum sp., heat stress, grain yield, late sowing.

1. INTRODUCTION

Heat stress is generally defined as the rise of temperature above a threshold level during a period of time, enough to cause deleterious irreversible effect on plant growth and development (Wahid *et al*., 2007). However, heat stress is a complex phenomenon that will affect crops based on the intensity, duration, and rate of increase in temperature; the extent of occurrence in specific climatic zones, depends on probability and the period of high temperatures occurring during the day and/or the night (Wahid *et al*., 2007). High temperatures modify the quality of wheat grains, but its final effect, aside from the intensity and duration, will depend on the phenological stage of the plant when it occurs and the genotype (Savin, 2010). Heat stress occurs in all agricultural regions, and it is a universal and common stress that it is a serious threat to crop production worldwide (Hall, 2001). It has been calculated that yield reduction in winter cereals caused by high temperature during the grain-filling period, can reach from 10 to 15% (Wardalaw and Wrigley, 1994; Tewolde *et al*., 2006). Over 7 million hectares in approximately 50 countries are sown to wheat in tropical or sub-tropical areas defined as having temperatures higher than 17.5◦C in the coolest month of the growing season, and the largest area having these conditions is Southeast Asia, and there are significant areas in India and Bangladesh as well (Hede *et al*., 1999). Other areas are found in Sub-Saharan Africa (Fischer and Byerlee, 1991), and in Brazil, Thailand, Uganda, Mexico, Sudan, Egypt, Nigeria, and Syria (Reynolds *et al*., 1998). To meet

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the future demand of wheat worldwide, productivity in both favorable and marginal environments needs to increase. When the agricultural area expands, it is probable that crops in these new areas will experiment some stress levels, including heat stress. Most models forecast a temperature increase of 1-4ºC during the day and night; this is important because in some crops, high temperature during the night seems to be more damaging to the productivity than high temperature during the day (Hall, 1992). In winter crops of temperate zones, normally the temperature rises through crop ontogeny. The fact that flowering must take place with the lowest or without risk of a frost, determines that the sowing date of a particular genotype is of great importance, since the grain-filling period generally occurs under high temperature; therefore, high temperature and low water availability are the most common abiotic stresses in winter cereals (Wardlaw and Wrigley, 1994). The trend of wheat consumption and importation by developing countries in the warmer regions have caused serious concern and are a primary reason for them to increase local wheat production (Kohli *et al*., 1990). The support of the United Nations Development Programme since 1982 enabled wheat breeders from the International Maize and Wheat Improvement Center (CIMMYT) to expand research on the development of high yielding, disease resistant, semi-dwarf wheats adapted to the warmer, subtropical area of the world. Within the framework of breeding wheat for these nontraditional areas, CIMMYT generated the Stress Adaptive Trait Yield Nursery (SATYN) which consists of lines for drought-stressed areas and for heat stress conditions. These nurseries 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 (Reynolds and Payne, 2020). The objective of this work was to evaluate the performance of a set of wheat lines comprising the 6th SATYN, subjected to late sowing, and therefore, exposed to a warmer and shorter crop season.

2. MATERIALS AND METHODS

Twenty five advanced bread wheat lines from the 6th Stress Adapted Trait Yield Nurseries (SATYN), including 12 sister lines (Table 1) selected by the International Maize and Wheat Improvement Center´s wheat breeding for their tolerance to stress, and as regional checks the commercial durum wheat cultivar Movas C2009 which has shown grain yield between 5.9 and 7.6 t ha^{-1} with two, three, and four complementary irrigations, respectively, in experimental plots (Félix-Fuentes *et al*., 2011), as well as the commercial bread wheat cultivar Borlaug 100 with an average grain yield of 6.1 and 7.0 t ha^{-1} with two and four complementary irrigations, respectively, in experimental plots (Chavez-Villalba *et al*., 2021) in northwest Mexico, were sown on January 12 and 31, 2017, 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.

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Table 1. Advanced bread wheat lines from the 6th Stress Adaptive Trait Yield Nursery from CIMMYT, sown on January 12 and 31, 2017, at the Norman E. Borlaug Experimental Station in the Yaqui Valley, Sonora, Mexico.

No.	Pedigree and selection history
1	MOVAS C2009
2	JNRB.5/PIFED/5/BJY/COC//PRL/BOW/3/SARA/THB//VEE/4/PIFED PTSS08GHB00011S-0SH-099SHB-099SHB-099SHB-28Y-0Y
3	JNRB.5/PIFED/5/BJY/COC//PRL/BOW/3/SARA/THB//VEE/4/PIFED PTSS08GHB00011S-0SH-099SHB-099SHB-099SHB-135Y-0Y
4	JNRB.5/PIFED/5/BJY/COC//PRL/BOW/3/SARA/THB//VEE/4/PIFED PTSS08GHB00011S-0SH-099SHB-099SHB-099SHB-72Y-0Y
5	JNRB.5/PIFED/5/BJY/COC//PRL/BOW/3/SARA/THB//VEE/4/PIFED PTSS08GHB00011S-0SH-099SHB-099SHB-099SHB-143Y-0Y
6	JNRB.5/PIFED/5/BJY/COC//PRL/BOW/3/SARA/THB//VEE/4/PIFED PTSS08GHB00011S-0SH-099SHB-099SHB-099SHB-10Y-0Y
7	JNRB.5/PIFED/5/BJY/COC//PRL/BOW/3/SARA/THB//VEE/4/PIFED PTSS08GHB00011S-0SH-099SHB-099SHB-099SHB-123Y-0Y
8	JNRB.5/PIFED/5/BJY/COC//PRL/BOW/3/SARA/THB//VEE/4/PIFED PTSS08GHB00011S-0SH-099SHB-099SHB-099SHB-32Y-0Y
9	JNRB.5/PIFED/5/BJY/COC//PRL/BOW/3/SARA/THB//VEE/4/PIFED PTSS08GHB00011S-0SH-099SHB-099SHB-099SHB-52Y-0Y
10	JNRB.5/PIFED/5/BJY/COC//PRL/BOW/3/SARA/THB//VEE/4/PIFED PTSS08GHB00011S-0SH-099SHB-099SHB-099SHB-76Y-0Y
11	JNRB.5/PIFED/5/BJY/COC//PRL/BOW/3/SARA/THB//VEE/4/PIFED PTSS08GHB00011S-0SH-099SHB-099SHB-099SHB-23Y-0Y
12	JNRB.5/PIFED/5/BJY/COC//PRL/BOW/3/SARA/THB//VEE/4/PIFED PTSS08GHB00011S-0SH-099SHB-099SHB-099SHB-66Y-0Y
13	JNRB.5/PIFED/5/BJY/COC//PRL/BOW/3/SARA/THB//VEE/4/PIFED PTSS08GHB00011S-0SH-099SHB-099SHB-099SHB-89Y-0Y
14	SOKOLL/WESTONIA PTSS08GHB00016S-099SHB-099Y-099SHB-099Y-146Y-0Y
15	SOKOLL/WESTONIA PTSS08GHB00016S-099SHB-099Y-099SHB-099Y-155Y-0Y
16	SOKOLL/WESTONIA PTSS08GHB00016S-099SHB-099Y-099SHB-099Y-136Y-0Y
17	BCN/WBLL1//ROLF07 PTSS07GHB00006S-0GHB-0Y-099B-5Y-0Y
18	SERI/BAV92//PUB94.15.1.12/WBLL1 PTSS09GHB00019S-0SHB-099Y-099B-19Y-0Y
19	SOKOLL/WBLL1 PTSS02Y00021S-099B-099Y-099B-099Y-213B-0Y
20	PUB94.15.1.12/WBLL1 PTSS02Y00027S-011Y-0B-0Y-0B-7Y-0M-0SY-0Y-0Y
21	WBLL4//OAX93.24.35/WBLL1

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	PTSS02B00110T-0TOPY-0B-0Y-0B-24Y-0M-0SY-0Y-0Y
22	SOKOLL CMSS97M00316S-0P20M-0P20Y-51M-010Y-0Y
23	BAJ #1 CGSS01Y00134S-099Y-099M-099M-13Y-0B
24	FRANCOLIN#1 CGSS01B00056T-099Y-099M-099M-099Y-099M-14Y-0B
25	BORLAUG 100 F2014 CMSS06Y00605T-099TOPM-099Y-099ZTM-099Y-099M-11WGY-0B-0MEX
26	KACHU #1 CMSS97M03912T-040Y-020Y-030M-020Y-040M-4Y-2M-0Y
27	VOROBEY CMSS96Y02555S-040Y-020M-050SY-020SY-27M-0Y-0B

These sowing dates are considered late and not recommended for commercial cultivation; optimum dates for wheat sowing in southern Sonora are between November 15 to December 15, otherwise, plants will be expose to heat stress (Figueroa-López *et al*., 2011). 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. Other management activities followed the technical recommendations by Figueroa-López *et al*. (2011). The daily average temperature (°C), the maximum and minimum, relative humidity, and the number of cold units, were recorded from January 12 to May 15, 2017 by the weather station CIANO-910, located in block 910 in the Yaqui Valley (Torres-Cruz *et al*., 2021); this station belongs to the automated weather station network of Sonora (REMAS, 2022). Cold units were calculated as the temperature > 0.1°C to < 10°C that occurs in a given hour. The variables evaluated were: days to heading, plant height (cm), a thousand grain weight (g), and grain yield (g) after harvesting 0.8 $m^2$from each plot with a sickle, and threshing was carried with a Pullman stationary thresher.

3. RESULTS AND DISCUSSION

Wheat is a cool-season crop, but it can grow in many different agroclimatic zones, and although production is concentrated between latitudes 30 - 60°N and 27 - 40°S, wheat can be grown beyond these limits, with an optimum growth temperature of about 25°C (Briggle and Curtis, 1987). Average maximum temperatures occurred since the week of January 12-18, 2017 and continued throughout the season (Figure 1); the range was 25.9 to 37.7°C. Weeks where the maximum temperature reached more than 30°C were February 2-8; March 9-15, 16-22, 23-29; March 30 to April 5, 6-12, 13-19, 20-26; April 27 to May 3, 4-10, and 11-15. Although the minimum temperature fluctuated between 5.02 to 13.7°C, there was a consistency of the persistence of hours above 25°C: from January 15 to February 7, occurrence of such temperatures initiated at 1 pm, from February 8 to March 16 at 11 am, from March 17 to April 14 at 10 am, and from April 15 to May 15 at 9 am. The number of hours with continuous temperature above 25°C ranged from 1 to 12, and as the season progressed the higher the number of sets of hours above 25°C (for 4 continuous hours there were 6 occurrences, for 5 h there

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were 9, for 6 h there were 6, for 7 h there were 8, for 8 h there were 13, for 9 h there were 10, for 10 h there were 17, for 11 h there were 9, and for 12 h there were 5 occurrences). It is clear that the group of lines were subjected to heat stress from early plant development.

The overall average of the group for heading was 68 days, being the earliest lines SOKOLL/WESTONIA (PTSS08GHB00016S-099SHB-099Y-099SHB-099Y-155Y-0Y) (line 15), PUB94.15.1.12/WBLL1 (line 20), BAJ #1 (line 23), and VOROBEY (line 27), and the latest ones with 74 days JNRB.5/PIFED/5/BJY/COC//PRL/BOW/3/SARA/ THB//VEE/4/PIFED (PTSS08 GHB00011S-0SH-099SHB-099SHB-099SHB-10Y-0Y) (line 6) and with 73 sister lines JNRB.5/PIFED/5/BJY/COC//PRL/BOW/3/SARA/THB// VEE/4/PIFED (PTSS08GHB00011S-0SH-099SHB-099SHB-099SHB-52Y-0Y) (line 9), (PTSS08GHB00011S…….23Y-0Y) (line 11), and (PTSS08GHB00011S……89Y-0Y) (line 13) (Figure 2). The average plant height of the group was 60 cm. The shortest lines were JNRB.5/PIFED/5/BJY/COC//PRL/BOW/3/SARA/THB//VEE/4/PIFED (PTSS08GHB000 11S-0SH-099SHB-099SHB-099SHB-135Y-0Y) (line 3) and sister line (PTSS08GHB 00011S……10Y-0Y) (line 6), and SOKOLL/WESTONIA (PTSS08GHB00016S-099SHB-099Y-099SHB-099Y-146Y-0Y) (line 14) with 50 cm, while lines BAJ#1 (line 23), SOKOLL (line 22), and VOROBEY (line 27) showed the highest height with 75 and 70 (the last two), respectively (Figure 2).

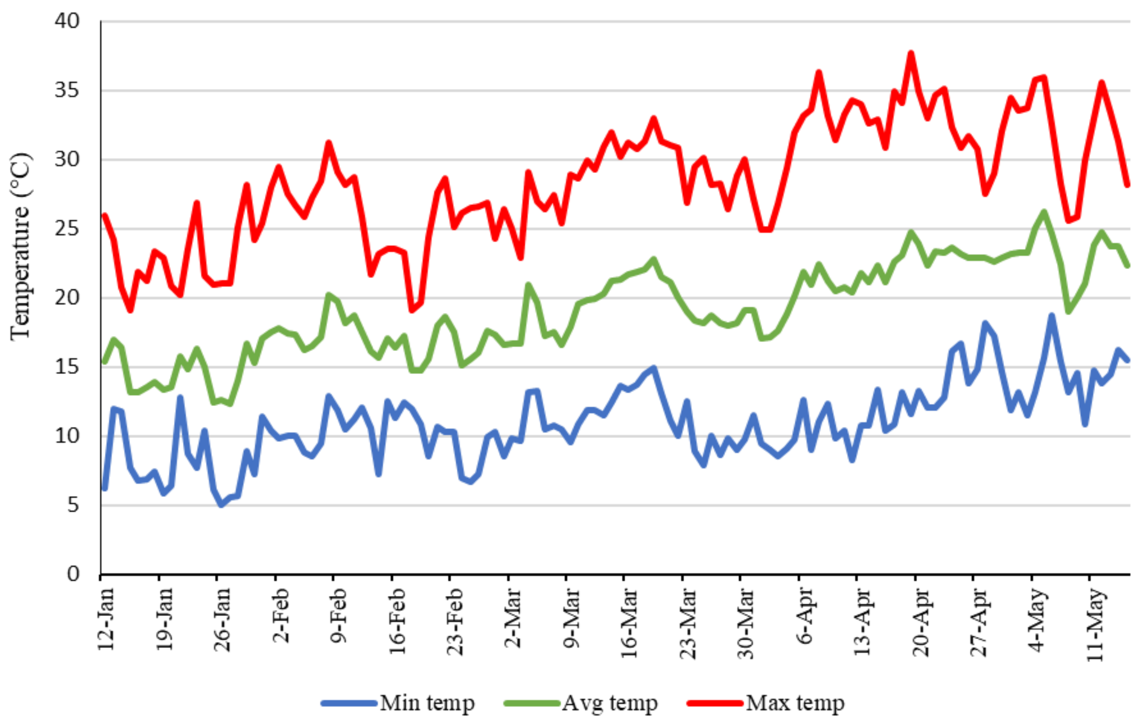

Figure 1. Average temperature from January 12 to May 15, 2017, recorded from the weather station CIANO-910, at the Norman E. Borlaug Experimental Station in the Yaqui Valley, Sonora, Mexico.

Commercial durum wheat cultivar Movas C2009 had a shortage of about 11 days to heading as compared to the recommended sowing dates (Félix-Fuentes *et al.*, 2011) and perhaps a greater shortage in relation to physiological maturity, although this parameter was not recorded. In the case of commercial bread wheat cultivar Borlaug 100, the shortage was about 10 days to heading (Chavez-Villalba *et al.*, 2021). Similarly, in both cultivars height was reduced in 33 cm for Movas C2009 and 32 for Borlaug 100. The average weight of a thousand grains was 41.6 g (Figure 2); the line KACHU#1 (line 26) showed the highest weight with 52.9 g, followed by durum wheat cultivar Movas C2009 (No. 1) and PUB94.15.1.12/WBLL1 (line 20) with 50.6 and 50.1 g, respectively, while BAJ#1 (line 23) showed the lowest weight with 27.3 g. The average grain weight per plot of the group was 294.5 g; outstanding lines were VOROBEY (460 g) (line 27), KACHU#1 (408 g) (line 26), and PUB94.15.1.12/ WBLL1 (404 g) (line 20) which were above 5 t ha^{-1} (Figure 3), and the lines FRANCOLIN#1 (line 24), JNRB.5/PIFED/5/BJY/COC//PRL/BOW/3/SARA/THB//VEE/4/PIFED (PTSS 08GHB00011S……32Y-0Y) (line 8), (PTSS08GHB000 11S…….76Y-0Y) (line 10), and (PTSS08GHB00011S…….52Y-0Y) (line 9) were above 4 t ha^{-1}. The best phenotype was shown by the sister lines JNRB.5/PIFED/5/BJY/COC//PRL/BOW/3/SARA/THB//VEE/4/ PIFED (PTSS08GHB00011S-0SH-099SHB-099SHB-099SHB-52Y-0Y and PTSS08GHB 00011S……76Y-0Y), and SOKOLL/WBLL1.

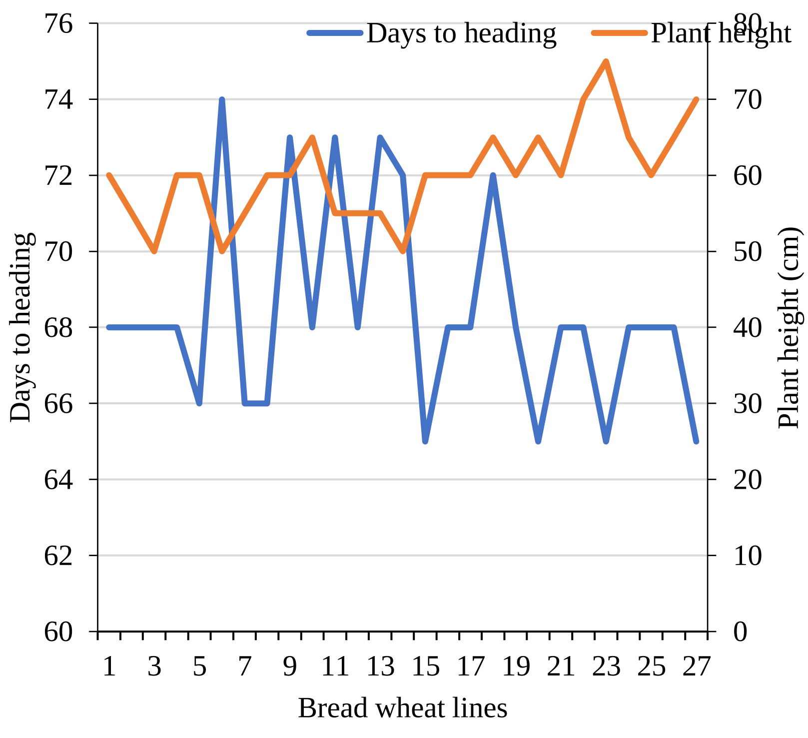

Figure 2. Average days to heading and plant height of durum wheat cultivar Movas C2009 (1), bread wheat cultivar Borlaug 100 (25), and 25 advanced bread wheat lines adapted to stress, sown late on January 12 and 31, 2017, at the Norman E. Borlaug Experimental Station in the Yaqui Valley, Sonora, Mexico.

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The average temperature during the period of the study was 19.08°C with a maximum of 37.7°C and a minimum of 5.02°C, which is lower than a common range of temperature during the crop season in this region; the average relative humidity was 66.8%, while the number of cold units was only 227. Despite the rather low average, maximum, and minimum temperature, the number of cold units was also low, if compared to the crop season 2011-2012 in the Yaqui Valley, where a historic grain yield of 7.02 t ha^{-1} was obtained (Ochoa Neira, 2012) and 765 cold units were recorded; the average cold units from crop seasons 2005 to 2015 was 666 with a maximum of 808 in 2005-2006 and a minimum of 281 in 2014-2015 (Moreno Dena *et al*., 2018). Félix-Valencia *et al*. (2009) reported that based on the accumulation of 340 cold units with a grain yield of 4.63 t ha^{-1}, for each increment of 100 cold units, grain yield increases by 330 kg. Also, despite the low number of cold units recorded, five lines showed a grain yield above the 4 t ha^{-1}, while three were above 5 t ha^{-1}. The commercial durum wheat cultivar Movas C2009 which produced an average grain of 6.62 t ha^{-1} in experimental plots (Félix-Fuentes *et al*., 2011), showed sensitivity to the short season and to the heat stress primarily during the flowering stage, with the consequent grain yield of 3.2 t ha^{-1}, as it has been also reported by Rosas-Jáuregui *et al*. (2017) in a December 29, 2015 late sowing date with 3.45 t ha^{-1}. They indicated that the low yield was attributed to the heat stress and shortage of cold units (440). In the case of commercial bread wheat cultivar Borlaug 100 which had shown an average grain yield of 6.55 t ha^{-1} in experimental plots (Chavez-Villalba *et al*., 2021), its performance was more stable under the conditions of this work as it was able to produce 4.45 t $ha^{-1.}$ This cultivar has shown acceptable adaptability as shown by the grain yield in five regions out of six, throughout Mexico; Borlaug 100 overcame three other commercial bread wheat cultivars by as much as 41% (Chavez-Villalba *et al*., 2021).

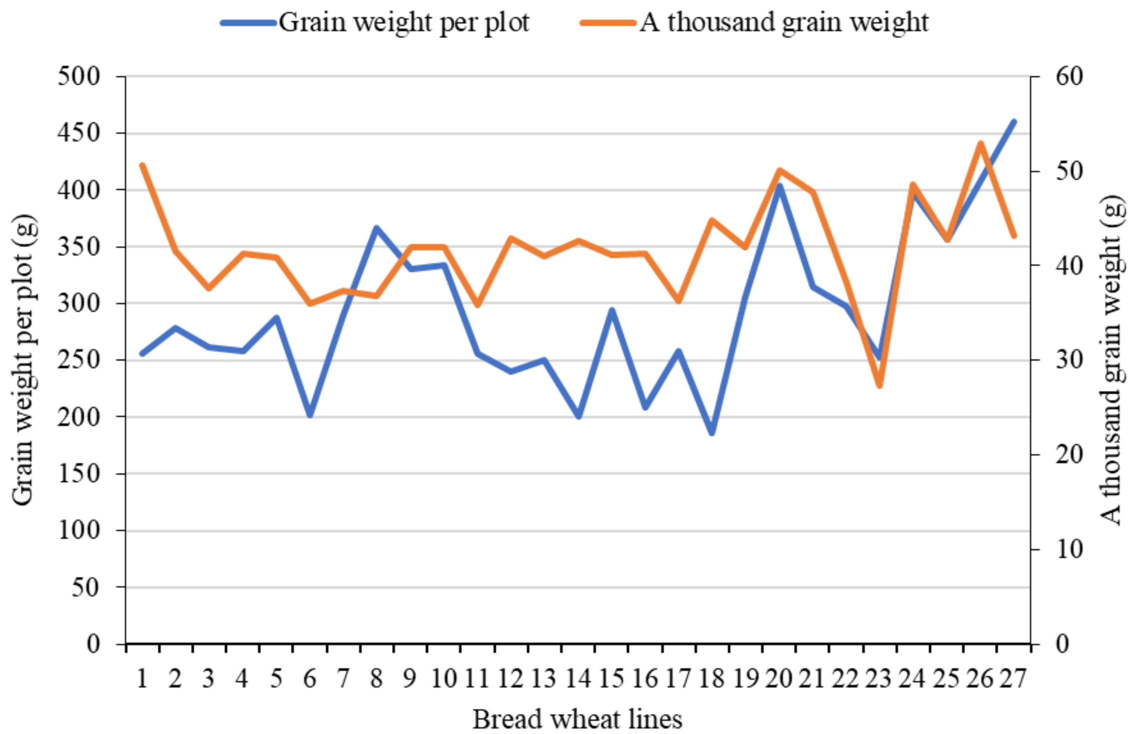

Figure 3. Average grain weight per plot and a thousand grain weight of durum wheat cultivar Movas C2009 (1), bread wheat cultivar Borlaug 100 (25), and 25 advanced bread wheat lines adapted to stress, sown late on January 12 and 31, 2017, at the Norman E. Borlaug Experimental Station in the Yaqui Valley, Sonora, Mexico.

4. CONCLUSIONS

The average heading of the 6th Stress Adapted Trait Yield Nurseries sown late on January 12 and 31, 2017, was 68 days and 60 cm for plant height. The line KACHU#1 showed the highest a thousand grain weight with 52.9 g, while BAJ#1 the lowest weight with 27.3 g. The average grain yield per plot was 294.5 g, highlighting the lines VOROBEY (460 g), KACHU#1 (408 g), and PUB94.15.1.12/WBLL1 (404 g), which were above 5 t ha^{-1}. The average temperature during the period of study was 19.08°C with a maximum of 37.7°C and a minimum of 5.02°C; the average relative humidity was 66.8%, and the number of cold units was 227.

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