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Grain yield of bread wheat cultivars Borlaug 100 F2014 and CIANO M2018 during the 2023-2024 crop season in experimental plots

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Abstract

Wheat (*Triticum* spp.) is one of the three most cultivated cereals worldwide, and in Mexico it is an essential cereal in the population diet, due to its nutritional contribution and low cost. This study evaluated grain yield and thousand grain weight of commercial cultivars Borlaug 100 F2014 and CIANO M2018 during the 2023-2024 fall-winter crop season at the Norman E. Borlaug Experimental Station, in the Yaqui Valley, Sonora, Mexico. The experiment was conducted in plots arranged in a completely randomized design with three replications. Standard practices of fertilization, irrigation, and pest management were applied. The daily average temperature (°C), the maximum and minimum, relative humidity, cold and heat units, and precipitation were recorded from December 15, 2023 to May 15, 2024. Results showed that the average thousand grain weight was 48.95 g for CIANO M2018 with a range of 46.67 to 51.99, and 46.13 g for Borlaug 100 F2014, with a range of 45.50 to 46.97 g, while the average grain yield per plot for cultivar CIANO M2018 was 822.67 g (equivalent to 6.84 t ha^{-1}) with a range from 6.65 to 7.08 t ha^{-1}, and 780 g (equivalent to 6.50 t ha^{-1}) with a range of 6.43 to 6.53 t ha^{-1} for cultivar Borlaug 100 F2014. The average temperature was 17.9 °C with a maximum of 35.8 °C and a minimum of 1.6 °C; the average relative humidity was 60.8 %; there were 2.5 mm of precipitation, and the number of heat and cold units was 233 and 494, respectively.

Keywords: Wheat; *Triticum aestivum*; Grain Yield; Thousand Grain Weight

1. Introduction

Wheat (*Triticum spp.*) is one of the three most important staple grains worldwide, along with rice (*Oryza sativa* L.) and maize (*Zea mays* L.), contributing approximately one-fifth of the total caloric intake of the human population [1]. It is the most widely cultivated crop, with around 220 million hectares worldwide, with China, India, Russia, and the United States being the main producing countries [2]. Mexico ranks 29th in global production, with an output of approximately 3.86 million tons [3]. In Mexico, wheat is considered an essential staple grain in the national diet due to its nutritional value and low cost, being available in both rural and urban areas [4]. Production takes place under both irrigated and rainfed conditions, with nearly 90 % concentrated in the states of Sonora, Guanajuato, Sinaloa, Baja California, Jalisco, and Chihuahua [5]. However, there is a contrast in demand: while durum wheat (*Triticum durum* Desf.) shows surpluses destined for export, the country maintains a structural deficit of bread wheat (*Triticum aestivum* L.), which necessitates the importation of millions of tons each year [6]. In 2023, imports reached approximately 5.18 million tons, mainly from the United States and Canada [7]. Sonora is the main wheat-producing state, and the crop represents a strategic activity

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due to its economic importance and its historical role in the Green Revolution. However, it faces limitations such as the presence of Karnal bunt (*Tilletia indica* Mitra), a disease that affects bread wheat more severely [8]. This problem has contributed to the increase in bread wheat imports [9] and to the regional preference for durum wheat, which offers higher yields, greater disease resistance, and broad acceptance in international markets [10].

Figure 1 Phenotypic characteristics of bread wheat cultivar Borlaug 100 F2014

In southern Sonora, cultivar Borlaug 100 F2014 [11] (Figure 1) remains predominant, covering between 70.6 **%** and 93.7 % of the area planted with bread wheat during the 2019-2020 to 2023-2024 crop seasons [12,13,14,15,16], due to its yield stability and resistance to leaf rust (*Puccinia triticina* Eriks.) and to yellow or stripe rust (*Puccinia striiformis* Westend. f. sp*. tritici* Eriks.). However, its reaction of moderate susceptible to susceptible to Karnal bunt and the limited adoption of new cultivars such as CIANO M2018, which has shown superior yields in experimental trials [17], restrict the genetic diversification of wheat production in the region. This cultivar had a low initial rate of adoption by farmers, just 3,798 ha in 2022-2023 [15], but in crop season 2023-2024 the area grown with CIANO M2018 increased to 15,157 ha [16]. The present study aimed to compare the grain yield and thousand grain weight of the commercial bread wheat cultivars Borlaug 100 F2014 and CIANO M2018 during the 2023-2024 crop season in the Yaqui Valley**,** Sonora, Mexico, in order to provide useful information to strengthen national bread wheat production and reduce dependence on imports.

2. Materials and methods

The experiment was carried out during the 2023-2024 fall-winter crop season at the Norman E. Borlaug Experimental Station (CENEB), which belongs to the National Institute of Forestry, Agriculture, and Livestock Research of Mexico (INIFAP), located in block 910 of the Yaqui Valley in the state of Sonora, Mexico (27º22′3.01″ N and 109º55′40.22″ W; 37 m above sea level). The climate of the region is classified as hot dry (BW(h)) and extremely hot (BSo) according to Köppen's classification, as modified by García [18]. The bread wheat cultivars CIANO M2018 and Borlaug 100 F2014 (Table 1) were sown on December 2, 2023, at a rate of 100 kg of seed ha^{-1}. Plots consisted of two beds, each 3 m long and spaced 0.8 m apart, arranged in a completely randomized design with three replications.

Table 1 Commercial bread wheat cultivars evaluated for grain yield at the Norman E. Borlaug Experimental Station, during the 2023-2024 fall-winter crop season, in the Yaqui Valley, Sonora, Mexico

Cultivar	Pedigree and history selection
CIANO M2018	STLN/MUNAL#1//2*BORL14 CMSS12B00828T-099TOPY-099M-0SY-42M-0WGY-300Y
Borlaug 100 F2014	ROELFS07/4/BOW/NKT//CBRD/3/CBRD/5/FRET2/TUKURU//FRET2 CMSS06Y00605T-099TOPM-099Y-099ZTM-099Y-099M-11WGY-0B-0MEX

Fertilization consisted of 150 kg ha^{-1} of urea applied before sowing, plus 100 kg ha^{-1} of urea and phosphorus before the first complementary irrigation, and an additional 100 kg ha^{-1} of urea before the second irrigation. One germination irrigation and three complementary irrigations were applied during the growing season. The phytosanitary management included: Control of broadleaf weeds with Full-mina 4 [19] and Starane Ultra (300 mL ha^{-1}) [20] at the tillering stage (Zadoks stage 22-26) [21]. Control of narrowleaf weeds with Axial XL (400 mL ha^{-1}) [22] at the stem elongation stage (Zadoks stage 35). Control of the greenbug aphid (*Schizaphis graminum* Rondani) with Nim-Canela (1000 mL ha^{-1}) [23] at heading (Zadoks stage 51); when adequate control was not achieved, Muralla Max (200 mL ha^{-1}) [24] was applied at flowering (Zadoks stage 65). The daily average temperature (°C), the maximum and minimum, relative humidity, cold and heat units, and precipitation were recorded from December 15, 2023 to May 15, 2024 by the CIANO-910 weather station, located in block 910 of the Yaqui Valley [25]. This station is part of the automated weather station network of Sonora [26]. Cold units were defined as the number of hours with temperatures between 0.1 and 10 °C, and heat units as the number of hours with temperatures exceeding 30 °C [27]. The variables evaluated were thousand grain weight (g) and grain yield (t ha^{-1}). An area of 1.2 m^2 from each plot was harvested manually with a sickle, and threshing was carried out using a stationary Pullman thresher. The ANOVA and mean comparison was performed with R (4.5.1).

3. Results and discussion

Throughout the evaluation period, the average temperature fluctuated between 17.9 and 24.8 °C (Figure 2). Maximum temperatures reached 35.8 °C, with a lower limit of 18.7 °C, while minimum temperatures ranged from 1.6 to 17.4 °C. Consistent occurrences of temperatures above 30 °C were observed from April 14 to May 15 (Figure 3), during which 87 % of the total accumulated heat units (233) were recorded. However, isolated events reaching 30 °C for one to several hours were also detected earlier in the season, specifically on December 16 (2 h), 17 (2 h), 18 (1 h), 22 (4 h), March 21 (3 h), 22 (4 h), 28 (1 h), April 3 (2 h), and 10 (6 h). 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 [28,29]. Cold unit (CU) accumulation started on December 15, 2023 and concluded on April 29, 2024, with a total accumulation of 494 units.

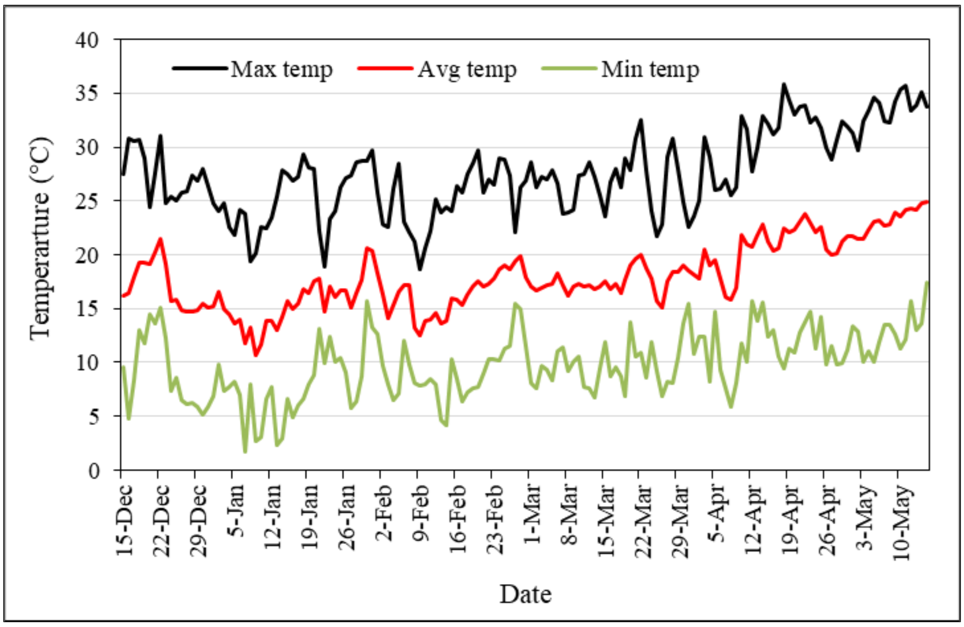

Figure 2 Average temperatures from December 15, 2023 to May 15, 2024, recorded from the weather station CIANO-910, at the Norman E. Borlaug Experimental Station in the Yaqui Valley, Sonora, Mexico

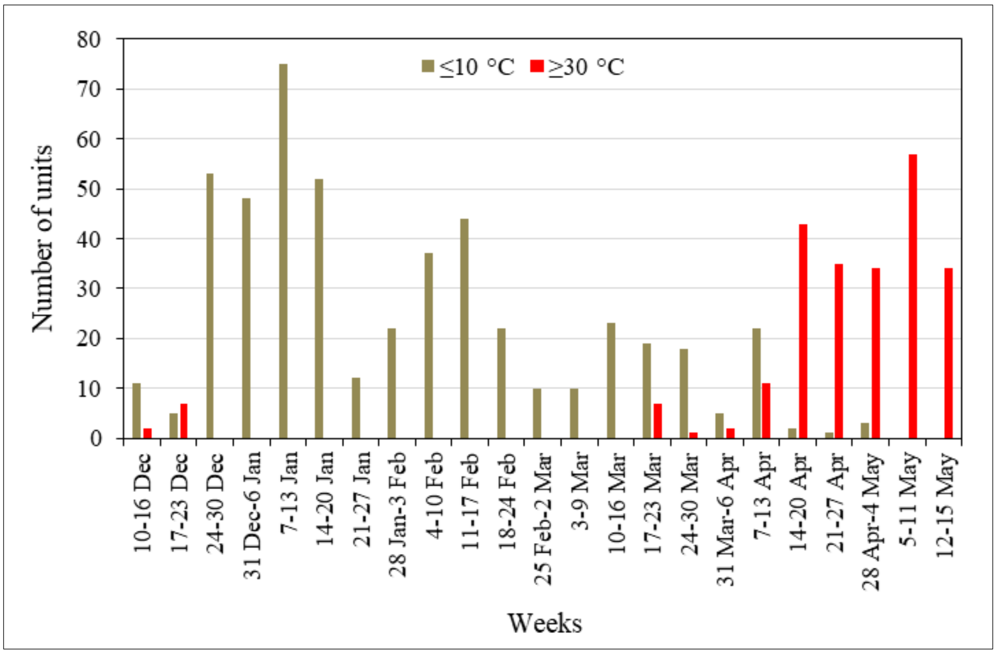

Figure 3 Number of cold and heat units accumulated from December 15, 2023 to May 15, 2024, recorded from the weather station CIANO-910, at the Norman E. Borlaug Experimental Station in the Yaqui Valley, Sonora, Mexico

Félix-Valencia *et al.* [30] reported that maximum grain yields above 9.5 t ha^{-1} have been observed during wheat crop seasons where more than 670 CU are accumulated. Weeks with more than 20 CU accumulated were: December 24-30 (53 CU), December 31-January 6 (48 CU), January 7-13 (75 CU), January 14-20 (52 CU), January 28-February 3 (22 CU), February 4-10 (37 CU), February 11-17 (44 CU), February 18-24 (22 CU), March 10-16 (23 CU), and April 7-13 (22 CU). The average thousand grain weight was 48.95 g for CIANO M2018 with a range of 46.67 to 51.99, and 46.13 g for Borlaug 100 F2014, with a range of 45.50 to 46.97 g (Figure 4). Baillot *et al.* [31] indicate that thousand-grain weight is a key component of yield, depending on the position of the grain within the spike and its filling. Abiotic stresses such as heat and drought reduce grain size and number, affecting total yield, while stresses at any growth stage impact final yield, those occurring during the grain-filling stage are the most critical [32].

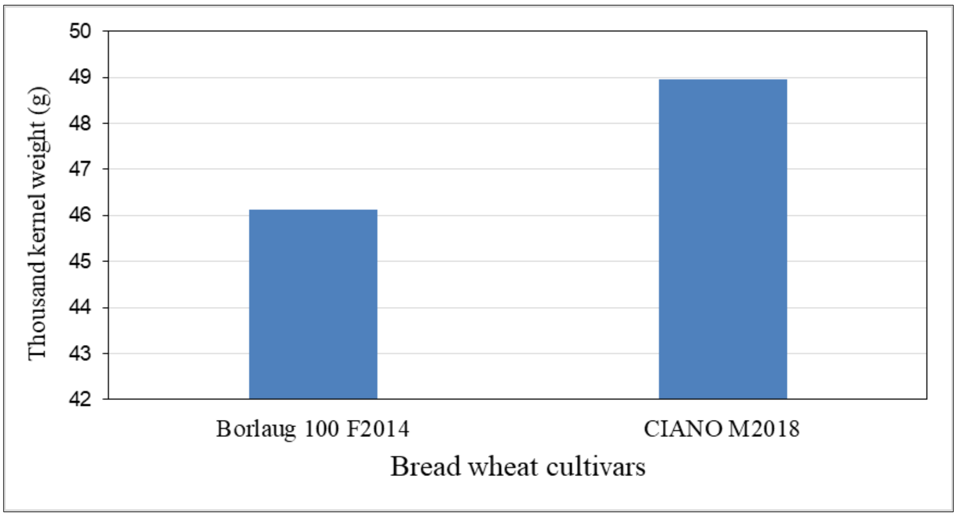

Figure 4 Thousand grain weight of commercial bread wheat cultivars evaluated during the 2023-2024 crop season in the Valle del Yaqui, Sonora, Mexico

Heat and drought stress at all stages of plant development influence important morphological traits [33]. To adapt to these harsh environments, considerable efforts have been made to produce genetically tolerant plants and to understand the mechanisms behind stress tolerance [34]. The average grain yield per plot for cultivar CIANO M2018 was 822.67 g (equivalent to 6.84 t ha^{-1}) with a range from 6.65 to 7.08 t ha^{-1}, while for cultivar Borlaug 100 F2014 it was 780 g (equivalent to 6.50 t ha^{-1}) with a range of 6.43 to 6.53 t ha^{-1} (Figure 5). To identify the genomic regions responsible for grain yield under stress conditions, the analysis of yield components is crucial [35]. Grain weight is considered the most important and heritable trait among these components [36]. This trait is closely associated with grain shape-related traits, such as grain length, grain width, and grain diameter [37]. Improving grain weight and shape-related traits under stress conditions is a promising approach to increasing wheat production [38]. Moreover, the detection of shape-related traits through image analysis can provide an easy and accurate means to evaluate yield components. The difference in the average grain yield between cultivars was 355 kg in favor of CIANO M2018 under the conditions of the study, but the ANOVA did not detect statistical differences.

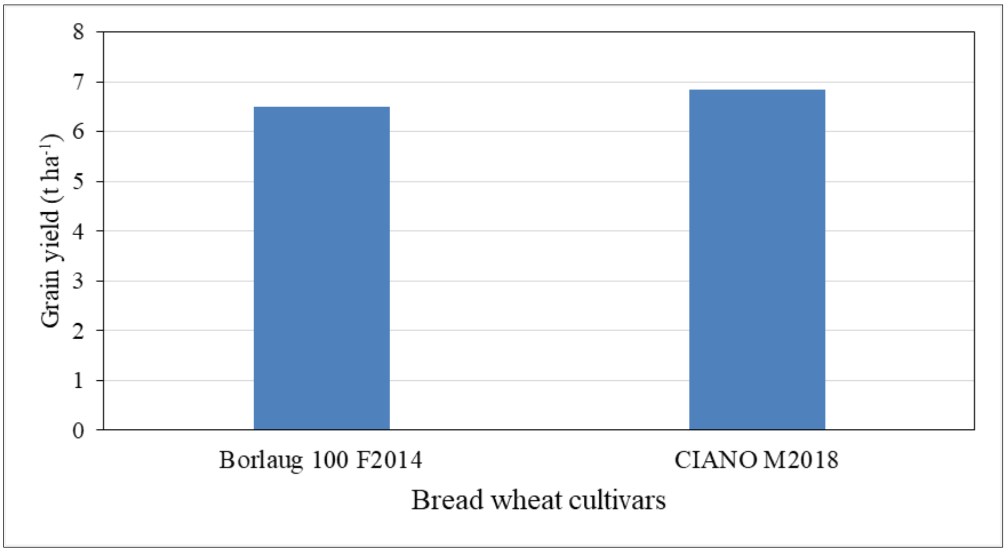

Figure 5 Grain yield of commercial bread wheat cultivars evaluated during the 2023-2024 crop season in the Yaqui Valley, Sonora, Mexico

Cultivar CIANO M2018 showed an average of 1.58 y 6.27 % higher grain yields than Borlaug 100 F2014 under four and two complementary irrigations, respectively, over three cropping seasons at CENEB [17], and yielded 7.19, 3.25, and 4.90 % more under four complementary irrigations in trials conducted in the states of Sonora, Sinaloa, and Baja California. However, a separate study reported that Borlaug 100 F2014 outperformed CIANO M2018 by 1.47 t ha^{-1} [39]. Similarly, Díaz-Ceniceros *et al*. [40] reported that CIANO M2018 achieved an average grain yield of 7.84 t ha^{-1} in commercial validation plots, while Borlaug100 F2014 yielded an average of 8.27 t ha^{-1}. The new cultivar showed its maximum yield potential in the Benito Juárez validation plot with a yield of 9.13 t ha^{-1}, showing a difference of 55 kg ha^{-1} compared to Borlaug100 F2014. On the other hand, Fuentes-Dávila *et al*. [41] reported that under heat and drought stress conditions during the 2022-2023 crop season, CIANO M2018 showed a grain yield of 4.4 t ha^{-1} and Borlaug 100 F2014 4.7 t ha^{-1}, and under the same conditions in crop season 2023-2024, they both showed a grain yield of 5 t ha^{-1} [42]. During the crop growing season, two processes occur simultaneously: growth (biomass increase) and development (morphological and physiological progression). Both processes are genetically regulated and influenced by the environment [43]. According to García [44], wheat yield depends on the number of grains per unit area and grain weight, the latter being more sensitive to climatic conditions. Félix-Fuentes *et al*. [45] highlight that cultivar Borlaug 100 F2014 possesses outstanding traits that can serve as a genetic basis for new materials, combining good industrial quality and disease resistance. However, cultivar CIANO M2018 shows genetic improvement aimed at higher yield potential and better grain filling, factors that explain the observed advantage in this study.

4. Conclusion

The average thousand grain weight was 48.95 g for CIANO M2018 with a range of 46.67 to 51.99, and 46.13 g for Borlaug 100 F2014, with a range of 45.50 to 46.97 g.

The average grain yield per plot for cultivar CIANO M2018 was 822.67 g (equivalent to 6.84 t ha^{-1}) with a range from 6.65 to 7.08 t ha^{-1}, and 780 g (equivalent to 6.50 t ha^{-1}) with a range of 6.43 to 6.53 t ha^{-1} for cultivar Borlaug 100 F2014.

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

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

The authors declare that No conflict of interest.

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