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Grain yield of four durum wheat cultivars in the Yaqui Valley, Sonora, Mexico, during the 2023-2024 crop season

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Abstract

This study evaluated the grain yield potential of cultivars CENEB Oro C2017, Don Lupe Oro C2020, Noroeste C2021, and CIRNO C2008, during the 2023-2024 crop season. Sowing was carried out on December 13, 2023, at the Norman E. Borlaug Experimental Station in the Yaqui Valley, Sonora, Mexico. Experimental plots consisted of two beds measuring 3 m in length with two rows each, spaced 0.80 m apart, with three replications. The seeding rate was 100 kg ha^{-1}. Fertilization included the application of 150 kg ha^{-1} of urea before sowing, followed by irrigation for seed germination and three complementary irrigations during the crop season. The parameters evaluated were a thousand kernel weight (TKW, g) and grain yield (t ha^{-1}). CIRNO C2008 outperformed the other cultivars with an average of 53.4 g for TKW, while Noroeste C2021 showed the lowest avg TKW with 46.1 g. Grain yield analysis revealed significant differences among cultivars, with an overall mean of 5.74 t ha^{-1} and a range of 5.44 to 6.08 t ha^{-1}. CIRNO C2008 recorded the highest yield with 6.08 t ha^{-1}, outperforming Don Lupe Oro C2020 by 160 kg ha^{-1}, CENEB Oro C2017 by 580 kg ha^{-1}, and Noroeste C2021 by 640 kg ha^{-1}. The average temperature was 18.0 °C with a maximum of 35.8 °C and a minimum of 1.6 °C; the average relative humidity was 61.0 %; there were 8 mm of precipitation, and the number of heat and cold units was 240 and 507, respectively.

Keywords: Durum Wheat; *Triticum turgidum*; Grain Yield; TKW

1. Introduction

Wheat (*Triticum* spp.) is one of the most important cereals crops globally, second only to maize (*Zea mays* L.) [1]. It is widely recognized for its adaptability, high grain yield potential, diverse uses, and nutritional value, contributing around 21 % to the global food supply [2]. It occupies the largest share of cultivated land among all crops, spanning 222 million hectares worldwide, with 50 million hectares located in developing countries. A significant portion – approximately half - is grown under rainfed conditions, where farmers often face challenges such as irregular rainfall, low soil fertility, and extreme temperatures. In these environments, drought stands out as one of the major limiting factor for wheat production [3]. Durum wheat [*Triticum turgidum* subsp. *durum* (Desf.) Husn.], is one of the most essential cereal species cultivated worldwide [4] (Figure 1). It occupies about 13.7 million hectares and generates approximately 34.3 million ton of grain (averaged for the period 2018-2022) [5]. It is particularly valued for its high protein content and technological quality, especially in the pasta industry. Although the durum wheat area is relatively small on a global

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basis, accounting for about 6.2 % of the total cultivated wheat area and 4.5 % of the total wheat grain production, it represents a main crop and staple food for some Mediterranean regions and is the essential raw material of typical end-products (e.g., pasta, couscous, bulgur, several types of bread, etc.) consumed worldwide.

Figure 1 Phenotypic characteristics of durum wheat, an allotetraploid species (2n = 4x = 28, genome AABB) [6], expressed in cultivar CIRNO C2008

In 2021, durum wheat ranked third in global production volume, with China, India, Russia, and the United States as the main producers. Although Mexico is not among the world leaders, it ranked 34th, with a total production of 3.28 million ton [7]. In the national context, durum wheat represents a strategic crop due to its production surplus and its importance in both domestic and international markets. A significant share of its volume is destined for export and livestock feed. In 2021, durum wheat was cultivated in 14 states of the country, reaching a production of 1,782,299 ton [8]. The main producing regions are concentrated in northern Mexico, particularly in Sonora, Baja California, and Sinaloa, where the crop constitutes a significant source of economic income for farmers, in addition to being an essential component of national food security [9]. Commercial durum wheat cultivars are the result of a continuous breeding process aimed at meeting both industrial quality requirements and agronomic demands. In this regard, grain yield is a complex and polygenic trait, influenced by the interaction between genetics and the environment, as well as by the contribution of various morpho-agronomic traits. The evaluation of the association between yield and its components, as well as among the traits themselves, enables the definition of more effective selection strategies to increase productivity [10]. Despite its smaller share in the global market, Mexico has played a key role in the genetic improvement of durum wheat, driven by institutions such as the National Institute for Forestry, Agricultural and Livestock Research (INIFAP) and the International Maize and Wheat Improvement Center (CIMMYT). These efforts have focused on increasing yield, enhancing disease resistance, and improving the crop's adaptation to diverse agro-climatic conditions [11]. The objective of the present study was to determine the highest grain-yielding durum wheat cultivar in current use, during the 2023-2024 crop season in southern Sonora.

2. Materials and methods

The evaluation was carried out during the 2023-2024 fall-winter crop season, at the Norman E. Borlaug Experimental Station (CENEB) of the National Institute for Forestry, Agricultural and Livestock Research (INIFAP), located in block 910 of the Yaqui Valley, Sonora, Mexico (27°22'3.01" N, 109°55'40.22" W; 37 masl), in a clay soil with pH 7.8. The region is characterized by a warm climate [BW (h)] and extreme warm and dry [BS (h)], according to Köppen classification modified by García [12]. Four durum wheat cultivars were evaluated: CENEB Oro C2017 [13], Don Lupe Oro C2020 [14], Noroeste C2021 [15], and the regional check CIRNO C2008 [16], with a sowing date of December 13, 2023. The pedigree and selection history of each cultivar are presented in Table 1. Plots consisted of two 3 m long beds, each with two rows, and beds spaced 0.80 m apart, with three replications. Cultivars were established in a completely randomized block experimental design; the ANOVA was performed and mean comparison by Tukey´s test (p = 0.05) to determine statistical differences among cultivars [17].

Table 1 Commercial durum wheat cultivars evaluated at the Norman E. Borlaug Experimental Station during the 2023-2024 crop season in the Yaqui Valley, Sonora, Mexico

Cultivar	Pedigree and history selection
CENEB Oro C2017	CNDO/PRIMADUR//HAI-OU_17/3/SNITAN/4/JUPAREC2001/5/ CNDO/PRIMADUR//HAI-OU_17/3/SNITAN/6/RISSA/GAN// POHO_1/3/PLATA_3//CREX/ALLA*2/4/ARMENT//SRN_3/NIGRIS_4/3/CANELO_9.1 (CDSS07Y00184S-099Y-099M-12Y-1M-04Y-0B)
Don Lupe Oro C2020	SILVER_14/MOEWE//BISU_1/PATKA_3/3/PORRON_4/YUAN_1/4/PAGA_6/5/TARRO_1/2*YUAN_1//AJAIA_13/YAZI/3/BARNACLA_1/6/ALTAR84/STINT//SILVER_45/3/GUANAY/4/GREEN_14//YAV_10/AUK/5/SOMAT_4/INTER_8/7/SOOTY_9/RASCON_37//GUAYACANINIA/3/BSET/PNIO_3 (CDSS12B00145T-099Y-014M-14Y-3M-0Y-0100CEN)
Noroeste C2021	GHAT_4//MEUX/PNIO_1/5/PHON/4VRKS_3/3/AJAIA_12/F3 LOCAL (SEL.THIO.135.85) //PLATA _13/6/CIRNO C2008 (CDSS11B00325T-049Y-054M-39Y-0M)
CIRNO C2008 (check)	SOOTY_9/RASCON_37//CAMAYO (CGS02Y00004S-2F1-6Y-0B-1Y-0B)

The sowing density was 100 kg ha^{-1}. Fertilization was carried out with 150 kg ha^{-1} of urea at pre-sowing; subsequently, 100 kg ha^{-1} of urea and phosphorus were applied before the first complementary irrigation, and 100 kg ha^{-} of urea before the second. One irrigation for seed germination and three complementary irrigations were applied during the growing season. Weed control was carried out at the tillering stage (Zadoks stage 24) [18] using broadleaf herbicides Full-mina 4 [19] and Starane Ultra (300 mL ha^{-1}) [20]. For narrow-leaf weed control, Axial XL (400 mL ha^{-1}) [21] was applied during stem elongation (Zadoks stage 35). Foliar aphid control (*Schizaphis graminum* Rondani) began at the heading stage (Zadoks 51) using the organic insecticide Nim-Canela (1000 mL ha^{-1}) [22]. Due to low efficacy, it was replaced by Muralla Max (200 mL ha^{-1}) [23] at the flowering stage (Zadoks 65). The daily average temperature (°C), the maximum and minimum, relative humidity, the number of cold and heat units, and precipitation were recorded from December 15, 2023 to May 15, 2024 by the weather station CIANO-910, located in block 910 in the Yaqui Valley [24]; this station belongs to the automated weather station network of Sonora [25]. 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 [26]. The variables evaluated were: a thousand kernel weight (g) and grain yield (t ha^{-1}), after harvesting 1.6 m^2 from each plot with a sickle, and 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 15.3-23.2 °C (Figure 2), while for the maximum temperature it was 29.6-35.8 °C and 1.6-10.0 °C for the minimum temperature. The occurrence of temperatures above 30 °C were more consistent from April 10 (Figure 3) to May 15, where 89.1 % of the accumulated heat units (240) was recorded during that period of the evaluation. There were some days when the temperature reached 30 °C for 1 or several hours, like December 16 (2 hours), 17 (2), 18 (1), 22 (4), January 28 (1), 29 (2), 31(4), March 21 (3), 22 (4), 28(1), and April 3 (2). Heat stress induces significant physiological and morphological changes in plants, such as diminished seed germination and seedling development, reduced cell turgidity, and decreased water-use efficiency [27]. During the period of evaluation, the accumulation of cold units (CU) was detected from December 15, 2023 to even April 29, 2024, with a total of 507, being more prevalent up to April 9; therefore, 98.8 % of the total accumulated CU was recorded during that period of the evaluation. The accumulation of CU per week was as following: during the week of December 15 and 16, there were 11 CU, 5 in December 17-23, 53 in December 24-30, 48 in December 31-January 6, 75 in January 7-13, 52 in January 14-20, 19 in January 21-27, 28 in January 28-February 3, 37 in February

4-10, 44 in February 11-17, 22 in February 18-24, 10 in February 25-March 2, 10 in March 3-9, 23 in March 10-16, 19 in March 20-30, 5 in March 31-April 6, and 22 in April 7-13 (Figure 3). Every stage of wheat plant phenology is sensitive to temperature variations, with higher temperatures increasing metabolic activities and speeding up the physiological processes that govern growth and development [28]. The wheat plant also requires the accumulation of CU to prolong its biological cycle, which generally leads to increased grain yield [26]. If sowing is carried out after the period November 15 - December 15 in Southern Sonora, wheat plants will have poor tillering and increased exposure to heat stress [29].

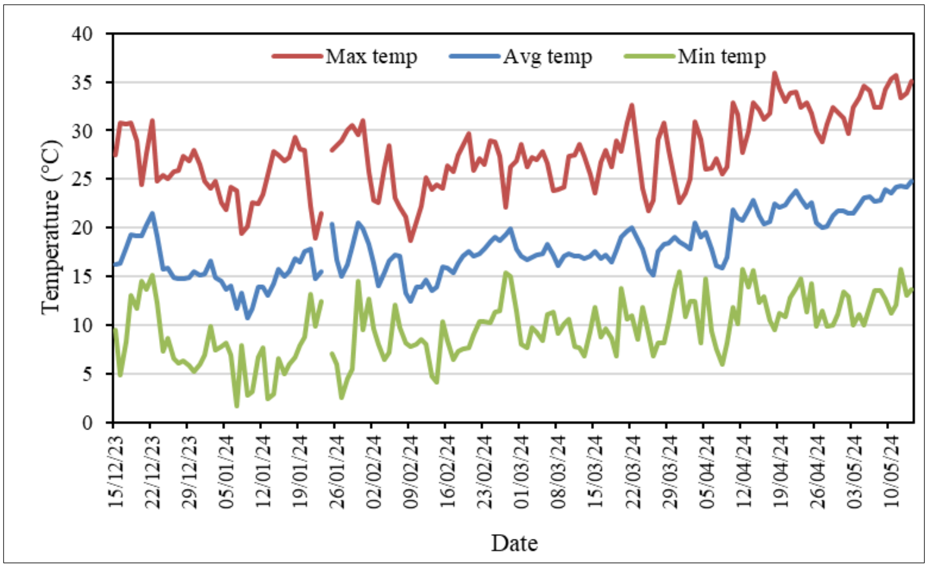

Figure 2 Average temperatures from December 15, 2023 to May 15, 2024, recorded from the weather station CIANO-910, at the Norman E. Borlaug Experimental Station in the Yaqui Valley, Sonora, Mexico, during the crop season 2023-2024

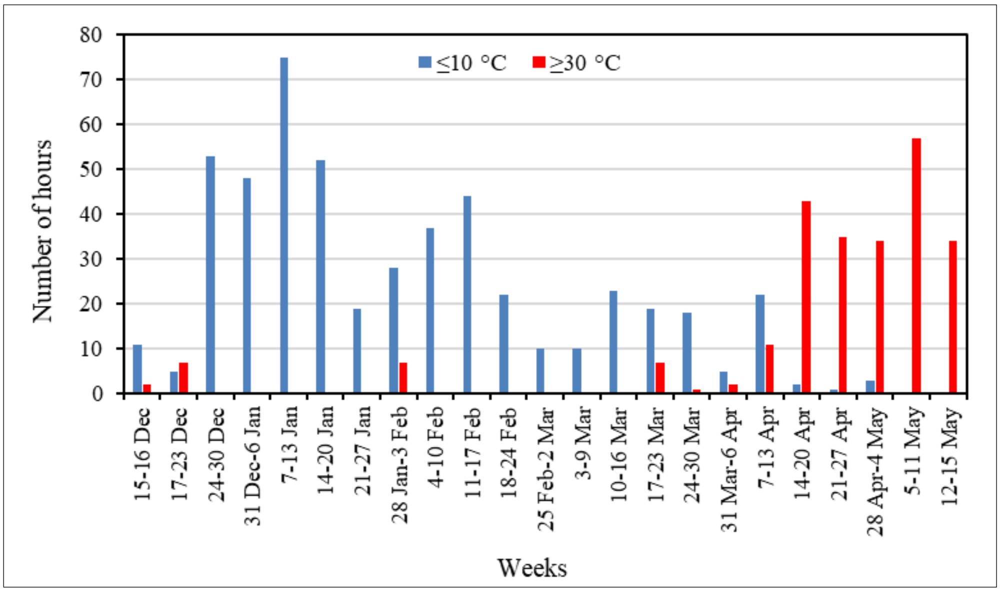

Figure 3 Number of cold and heat units accumulated from December 15, 2023 to May 15, 2024, recorded from the weather station CIANO-910, at the Norman E. Borlaug Experimental Station in the Yaqui Valley, Sonora, Mexico, during the crop season 2023-2024

The average TKW of the four cultivars was 49.81 g; CIRNO C2008 showed a difference of 3.6 g above the average (53.41 g), followed by Don Lupe Oro C2020 with a weight of 51.45 g, while CENEB Oro C2017 and Noroeste C2021 had values below the average, 48.21 and 46.17, respectively (Figure 4).

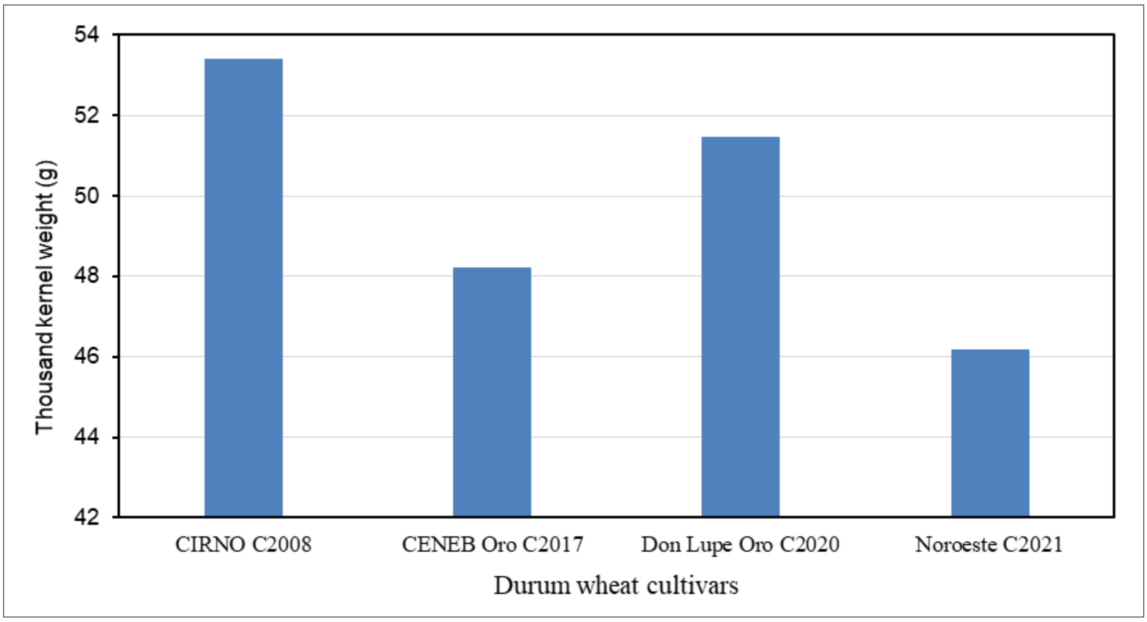

Figure 4 A thousand kernel weight (g) of four commercial durum wheat cultivars, evaluated at the Norman E. Borlaug Experimental Station during the 2023-2024 crop season, in the Yaqui Valley, Sonora, Mexico

The difference between CIRNO C2008 and Noroeste C2021 was 7.24 g. The difference between the highest and lowest TKW in each cultivar was 8.99 g for CENEB Oro C2017, 7.91 for CIRNO C2008, 6.13 for Don Lupe Oro C2020, and 5.58 g for Noroeste C2021. Several studies have shown that TKW has a positive and significant relationship with grain yield in both bread and durum wheat [30]. This association indicates that an increase in TKW can directly contribute to improving yield, especially when combined with an adequate number of grains per spike and spikes per unit area [31]. Under drought or high-temperature conditions, TKW is usually a more stable trait than grain number, making it a useful criterion for selection in breeding programs [32]. According to Baillot *et al*. [33], TKW is one of the components that determine grain yield in wheat; it represents the average weight of individual grains, which depends on their position within the spike and within the spikelet. It measures the mass of the wheat kernel and is an essential parameter for the selection of cultivars with the best physical and physiological seed quality. Higher TKW values are generally associated with greater potential for flour extraction or yield [34], as TKW is closely linked to grain size and the ratio of endosperm to germ and pericarp tissues [35]. Wheat breeders and flour millers use this method alongside test weight to more accurately characterize wheat kernel composition and estimate potential flour extraction [36]. TKW is an important trait in wheat breeding because of its phenotypic stability and relative high heritability, typically ranging from 0.6 to 0.8, making it a dependable and practical selection criterion for improving grain yield [37,38,39]. For example, a linear regression analysis of more than 1,850 Chinese wheat cultivars released since the 1920s revealed an increase in average TKW from 30.1 g in the 1920s to 38.4 g in the 2010s. Over the same period, average grain yield rose from 2.01 to 6.58 t ha^{-1}, underscoring the significant contribution of TKW improvement to overall yield gains [40]. In the case of durum wheat cultivated in the Valle del Yaqui, where climatic conditions can limit grain filling, the selection of genotypes with higher TKW could help maintain or increase yield, complementing the improvement of other productive components. Therefore, TKW represents a trait of great relevance both for genetic selection and for optimizing agronomic performance under local conditions.

Although the ANOVA did not detect statistical differences, grain yield analysis showed weight differences among the evaluated cultivars, with an overall average of 5.74 t ha^{-1} and a range from 5.44 to 6.08 t ha^{-1}. CIRNO C2008 achieved the highest yield with an average of 6.08 t ha^{-1} and a range of 5.80 to 6.25, surpassing Don Lupe Oro C2020 by 160 kg ha^{-1}, CENEB Oro C2017 by 580 kg ha^{-1}, and Noroeste C2021 by 640 kg ha^{-1} (Figure 5). Rosas-Jáuregui *et al*. [41] evaluated CIRNO C2008 and other three durum wheat cultivars in which the former outperformed CEVY Oro C2008 by 1,040 kg, Patronato Oro C2008 by 1,300, and Sáwali Oro C2008 by 1,010 kg. Ortiz-Avalos *et al*. [42] reported that CIRNO C2008 showed an average grain yield of 5.6 t ha^{-1} while Don Lupe Oro C2020 5.0 t ha^{-1}, in a trial in a certified organic field, but in another experiment in the same type of field, CIRNO C2008 yielded 8.0 t ha^{-1} while cultivar Baroyeca Oro C2013 6.9

t ha^{-1}. Chávez-Villalba *et al*. [43] reported that in evaluations carried out from crop season 2011-2012 to 2016-2017, CENEB Oro C2017 produced an average of 5.94 t ha^{-1} with four complementary irrigations and 5.25 with two, while CIRNO C2008 5.95 and 5.01 t ha^{-1}, respectively.

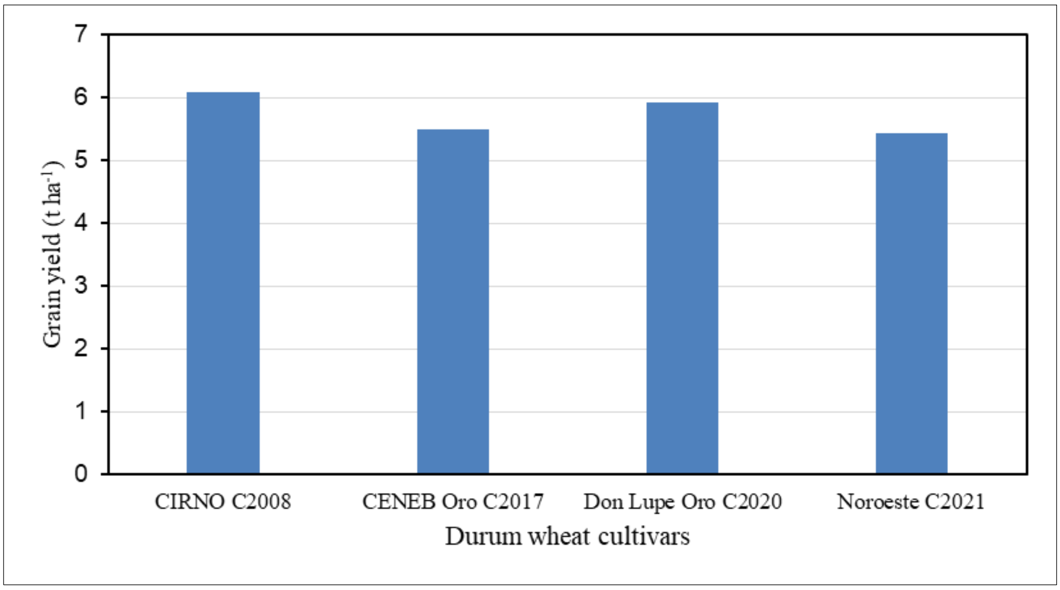

Figure 5 Grain yield (t ha^{-1}) of four commercial durum wheat cultivars, evaluated at the Norman E. Borlaug Experimental Station during the 2023-2024 crop season, in the Yaqui Valley, Sonora, Mexico

Borbón-Gracia *et al*. [14] reported that Don Lupe Oro C2020 in 34 experimental trials during crop seasons 2018-2019 to 2020-2021 produced an average of 6.94 t ha^{-1} while CIRNO C2008 6.38, and CENEB Oro C2017 6.64 t ha^{-1}. They also reported that Noroeste C2021 and other cultivars were evaluated during crop seasons 2018-2019 to 2021-2022 under several irrigation regimes, four sowing dates and in three locations, where Noroeste C2021 had an average of 7.37 t ha^{-1}, Don Lupe Oro C2020 7.14, CENEB Oro C2017 6.93, and CIRNO C2008 6.66 t ha^{-1} [15]. Despite the results described and that CIRNO C2008 lost its resistance to the leaf rust race BBG/BP_CIRNO [44], caused by the fungus *Puccinia triticina* E., farmers still prefer this cultivar which was grown in 201,915.87 ha, 167,019.95, and 152,946.81 ha, during crop seasons 2021-2022, 2022-2023, and 2023-2024, respectively in southern Sonora (Table 2) [45,46,47]. The maximum area grown with cultivar CENEB Oro C2017 was in crop season 2021-2022 with 4,050.68 ha, 15,033.28 ha for Don Lupe Oro C2020 in 2023-2024, and 520.75 for Noroeste C2021 in 2023-2024, which is expected to increase and replace CIRNO C2008. The differences found in our study which favor CIRNO C2008, reflect the genetic variability among the genotypes and suggest that the higher TKW of CIRNO C2008 contributed decisively to its superior yield, as reported by other studies in wheat [48,49].

Table 2 Area (ha) cultivated with four commercial durum wheat cultivars during three crop seasons in southern Sonora, Mexico

Cultivar	**Crop season**		
	2021-2022	2022-2023	2023-2024
CENEB Oro C2017	4,050.68	3,652.67	1,687.77
Don Lupe Oro C2020	83.37	3,957.61	15,033.28
Noroeste C2021	0	0	520.75
CIRNO C2008 (check)	201,915.87	167,019.95	152,946.81

The selection of experimental wheat germplasm with high TKW is an effective strategy for improving productivity, since this trait is strongly correlated with grain yield [50,51].

4. Conclusion

Cultivar CIRNO C2008 showed the highest a thousand kernel weight with an average of 53.41 g, followed by Don Lupe Oro C2020 with a weight of 51.45 g, CENEB Oro C2017 with 48.21 g, and Noroeste C2021 with 46.17 g.

Cultivar CIRNO C2008 showed the highest grain yield with an average of 6.08 t ha^{-1}, followed by Don Lupe Oro C2020 with 5.92 t ha^{-1}, CENEB Oro C2017 with 5.50 t ha^{-1}, and Noroeste C2021 with 5.44 t ha^{-1}.

The average temperature was 18.0 °C with a maximum of 35.8 °C and a minimum of 1.6 °C; the average relative humidity was 61.0 %; there were 8 mm of precipitation, and the number of heat and cold units was 240 and 507, 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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