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(RESEARCH ARTICLE)

Agronomic evaluation of durum wheat under organic production conditions in the Yaqui Valley, Sonora, Mexico

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Abstract

Wheat is one of the most important crops worldwide due to its nutritional value and wide industrial use. In Mexico, Sonora contributes the largest share of national production, and within this state, the Yaqui Valley represents the main production area. However, the increasing demand for food and the negative effects associated with conventional agriculture have encouraged the search for more sustainable production systems, such as organic farming. Under this approach, the present study evaluated the agronomic performance of two durum wheat varieties, Quetchehueca Oro C2013 and PD Chanate Oro C2023, under organic production conditions at CENEB-INIFAP. The varieties were established in paired plots, and yield components were assessed, including spike weight, grain weight per spike, number of grains per spike, biomass, 100-grain weight, test weight, and grain yield. Significant differences were observed in the number of grains per spike and test weight. Quetchehueca Oro C2013 showed higher spike weight and grain weight per spike, while PD Chanate Oro C2023 exhibited a higher number of spikes per m^2, greater 100-grain weight, and superior test weight, indicating higher grain density and quality. Total grain yield was 6.215 t ha^{-1} for Quetchehueca Oro C2013 and 6.264 t ha^{-1} for PD Chanate Oro C2023. It was concluded that both varieties are suitable for use in organic farming. Further evaluation under different environments and comparison with the regional control CIRNO C2008 is recommended to determine their yield stability.

Keywords: Organic farming; Yaqui Valley; Wheat; Varieties; Yield

1 Introducción

Wheat is one of the main sources of plant-based proteins and calories in human diets. It is the crop with the largest cultivated area worldwide and the second most produced cereal after maize [1]. Its high nutritional value and versatility make it a widely grown crop in many countries, both for food production and other industrial uses. Wheat grains are classified into two types: durum wheat, mainly used for pasta and semolina production, and bread wheat, used for bread, cookies, and general flour production. In Mexico, wheat production in 2023 reached 3,476,000 tons, with the states of Sonora, Baja California, and Guanajuato accounting for 78.4% of national production. In southern Sonora, which includes the municipalities of Cajeme, Navojoa, Benito Juárez, Etchojoa, Bacúm, San Ignacio Río Muerto, Huatabampo, Guaymas, and Empalme, 94.9% of the state's production was recorded [2].

The Organisation for Economic Co-operation and Development (OECD) and the FAO estimate that wheat consumption will increase by 12.0% over the next decade [1]. Greater food demand translates to a need for larger production areas; however, conventional agriculture cannot meet this demand because productivity cannot be further increased [3]. Moreover, continuing conventional agriculture could lead to soil problems, such as degradation and biodiversity loss

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[4]. Based on this, there is a need for alternative agricultural practices that conserve the environment while sustaining natural resources [5, 3]. Organic agriculture is a sustainable farming practice, as it is a production system that maintains and improves soil, ecosystem, and human health. It is fundamentally based on ecological processes, biodiversity, and locally adapted cycles, without using inputs with adverse effects. Organic agriculture combines tradition, innovation, and science to promote environmental stewardship and encourages fair relationships and a good quality of life for all participants [6]. In southern Sonora, research on organic agriculture has been conducted, evaluating locally available organic inputs for fertilization as well as commercial composts [7]. For pest and disease management, the primary recommendation in organic agriculture is the use of resistant varieties. Additionally, in organic systems, the performance of varieties may differ from conventional agriculture because the agronomic protocols commonly used in organic and conventional crop production differ significantly [8]. Crop yield and disease resistance are two objectives shared by varieties used in both conventional and organic farming. However, in organic systems, high nutrient use efficiency from organic fertilizers, competitiveness against weeds, and pest and disease resistance are also required. Similarly, processing quality parameters defined by millers and bakers, as well as nutritional quality parameters demanded by organic consumers, must be met [9]. Based on this, it is necessary to evaluate newly released varieties under organic production conditions in the region and always compare them with a regional check. The objective of this study was to evaluate the agronomic performance of the durum wheat varieties PD Chanate Oro C2023 and Quetchehueca Oro C2013 under organic production conditions.

2 Material and methods

The study was conducted at the Norman E. Borlaug Experimental Field (CENEB) of the National Institute for Forestry, Agricultural and Livestock Research (INIFAP), located in block 910 of the Yaqui Valley, Sonora, at an altitude of 38 m above sea level, at coordinates 27°22'06.41" N and 109°55'31.07" W. In an organically managed plot, the wheat varieties Quetchehueca Oro C2013 and PD Chanate Oro C2023 were established. The first variety was released by INIFAP and registered in the National Catalog of Plant Varieties (CNVV) under registration number TRI-150-260913, while the second was released by PIEAES, AC and registered under number TRI-201-270923.

Soil preparation involved incorporating the residue from the previous wheat crop. Two passes were made using a triple-bar harrow to incorporate both the leftover wheat straw and the weeds that grew during the summer. Fertilization was carried out by broadcasting 10 tons per hectare of raw chicken manure using a manure spreader (Figure 1). The following day, the manure was incorporated into the soil with a third pass of the triple-bar harrow. Pre-sowing irrigation and four supplementary irrigations were applied throughout the crop cycle. Sowing was carried out on December 18, 2024, using 77 kg ha^{-1} of seed for both varieties. For crop phytosanitary management, a targeted application was made to control aphids before the first supplementary irrigation using a consortium of entomopathogenic microorganisms at a dose of 2.5 g L^{-1} of water. This consortium included *Metarhizium anisopliae*, *Isaria fumosorosea*, *Isaria sinclairii*, *Beauveria bassiana*, *Bacillus thuringiensis*, *Serratia entomophila*, and *Streptomyces* sp. For weed control, one mechanical cultivation was performed with a tractor and three manual weedings. The evaluated yield components were spike weight (SW, g), grain weight per spike (GWPS, g), number of grains per spike (#GSP), number of grains per square meter (#GM^2), number of spikes per square meter (#SM^2), biomass per square meter (BM^2, kg), number of grains per square meter (GM^2), hectoliter weight (PH, kg hL^{-1}), 100-grain weight (100G, g), and grain yield (GY, t ha^{-1}). The varieties were compared using a paired-plot design, aimed at eliminating spatial variability present in the field. Four replications of each variety were selected. The experimental unit consisted of eight rows, each 110 meters long, with a row spacing of 0.80 meters. The harvestable plot comprised two rows, each two meters long, with 0.80 meters spacing between rows. Harvesting was carried out manually using a sickle. The collected samples were threshed using a stationary Pullman-type thresher, and subsequently, the grains were manually cleaned to remove straw and glume residues.

CENEB-INIFAP, November 2024

Figure 1 Manure spreader applying raw chicken manure

For the determination of spike weight (SW), grain weight per spike (GWPS), number of grains per spike (#GSP), number of grains per m^2 (#GM^2), number of spikes per m^2 (#SM^2), biomass per m^2 (BM^2), and grains per m^2 (GM^2), 50 spikes were selected per replication. The 100-grain weight (100G, g) was determined by weighing 100 randomly selected grains from each experimental unit. The hectoliter weight was calculated as the ratio between the weight (g) and volume (mL) of a grain sample, randomly taken from the harvested grains in each experimental unit. Grain yield (GY, t ha^{-1}) was obtained from the threshing of the harvestable plot in each experiment.

3 Results and discussion

Quetchehueca Oro C2013 showed an experimental grain yield of 5.87 t ha^{-1}. The best sowing dates for this variety are between November 15 and December 1, while yields decrease significantly with late sowings from December 15 to January 1. It produces amber-colored, semi-elliptical grains, 7.4 mm long and 3.6 mm wide, with an average weight of 64 mg, and produces between 10,751 and 14,100 grains per square meter. The average test weight is 81.3 kg hL^{-1} [10]. For the variety PD Chanate Oro C2023, currently no published information is available regarding grain yield, yield components, or physical and quality characteristics of the grain. This lack of data hinders an objective comparison of its agronomic performance with other commercial varieties and highlights the need for experimental evidence to comprehensively characterize its productive potential.

Among the evaluated variables, only the number of grains per spike (#GPE) and hectoliter weight (HW, kg hL^{-1}) showed significant differences; the remaining variables exhibited homogeneous behavior.

Quetchehueca Oro C2013 had a slightly higher spike weight (4.73 g vs. 4.64 g) and higher grain weight per spike (2.44 g vs. 2.32 g) compared to PD Chanate Oro C2023. This pattern suggests that C2013 may have a more robust spike structure, which could favor efficient assimilate distribution during grain filling [11]. However, the 100-grain weight is higher in PD Chanate Oro C2023 (5.03 g vs. 4.83 g), indicating that although its spikes are slightly lighter, the individual grains tend to be larger. This suggests a trade-off between grain number and grain size. PD Chanate Oro C2023 produces heavier grains, even if its spike is somewhat lighter. From a breeding perspective, spike weight has been used as an indirect trait for yield selection. One study reported that grain weight per spike is a reliable indicator for improving genetic yield, reflecting both spike fertility and grain-filling capacity [12]. However, other studies indicate that spikes with high biomass and many grains may generate intra-spike competition during grain filling, reducing individual grain weight [13, 14].

Grain weight, often measured as 1000-kernel weight (TKW), is a key component in determining wheat yield, as it represents the size or mass of individual seeds. This trait is highly informative because it reflects how efficiently the plant converts assimilates into grain biomass during filling, directly impacting commercial yield [15]. Grain weight has also been assessed using 100-grain samples with favorable results [16, 17].

Table 1 The average value of the evaluated variables, as well as the F value, coefficient of variation, and least significant difference for the variables with statistical differences.

Variable	Quetchehueca Oro C2013	PD Chanate Oro C2023	Fc	CV %	DMS
Spike weight (g)	4.73 a	4.64 a	1.98	1.93	
Grain per spike (g)	2.40 a	2.32 a	2.91	2.82	
100 grain weight (g)	4.83 a	5.03 a	3.60	2.99	
Grain per spike	50 a	46 b	32.0	2.08	2.25
Grains per square meter	11,560 a	11,900 a	0.99	4.12	
Spikes per square meter	263 a	278 a	3.56	4.08	
Biomass per square meter (kg)	1.245 a	1.290 a	4.24	2.41	
Hectoliter weight (kg hL-1)	79.9 b	81.5 a	96.0	0.29	0.52
Grain per square meter (kg)	0.612 a	0.617 a	0.87	1.23	
Grain yield t ha-1	6.215 a	6.264 a	0.66	1.38	

Quetchehueca Oro C2013 has 50 grains per spike, whereas PD Chanate Oro C2023 has 46, indicating a spike fertility advantage for the former. However, in terms of density per area, PD Chanate Oro C2023 has 11,900 grains m^2 versus 11,560 for Quetchehueca Oro C2013, and 278 spikes m^2 versus 263 for Quetchehueca Oro C2013. This suggests that PD Chanate Oro C2023 compensates for fewer grains per spike with a higher spike density. Other studies have observed that spikes per square meter can have a dominant effect on grain yield under certain conditions, showing that both spikes per m^2 and grains per spike explain a significant part of the variation in yield among genotypes and management practices [15]. This aligns with genetic improvement studies, where increasing grain number per unit area has been identified as a key driver of yield progress [18].

The number of grains per spike is one of the most critical components of wheat yield, along with spikes per unit area and individual grain weight. Among these, it is considered the most sensitive to environmental conditions and the one contributing the greatest variability to final crop yield [13, 14, and 19].

Biomass per square meter was slightly higher in PD Chanate Oro C2023 (1.290 kg) compared to Quetchehueca Oro C2013 (1.245 kg), suggesting a greater capacity for dry matter accumulation. The fact that PD Chanate Oro C2023 has higher biomass but only slightly higher grain yield suggests that the proportion of biomass allocated to grain is similar or slightly lower than in Quetchehueca Oro C2013. Classic wheat studies have shown that a closer relationship between total biomass and grain yield is favorable for yield improvement [20].

Hectoliter weight is a physical parameter reflecting grain filling, shape, size, and density. It is also critical for flour quality and milling efficiency [21]. Hectoliter weight is higher in PD Chanate C2023 (81.5 kg hL^{-1}) compared to Quetchehueca Oro C2013 (79.9 kg hL^{-1}). A higher HW may favor commercial grain quality, as it is often associated with denser grains and better milling quality. Some studies have also found a positive correlation between grain density and yield [22]. This could make PD Chanate Oro C2023 more attractive industrially, even if its yield advantage is small.

Reported yields are 6.215 t ha^{-1} for Quetchehueca Oro C2013 and 6.264 t ha^{-1} for PD Chanate Oro C2023; the difference is not significant but slightly favors PD Chanate Oro C2023. This indicates that the trade-offs between spike number, grains per spike, and grain size result in very similar yields between the two varieties. From a breeding perspective, PD Chanate Oro C2023 may have potential for adaptation to high-density planting environments, as it responds well to high spike density, allowing it to maintain or improve yield without maximizing grains per spike. Quetchehueca Oro C2013 may be limited by its lower spike density, and improvement could focus on increasing tiller production to raise yield per area.

Conditions in the Yaqui Valley, Sonora, Mexico, including irrigation regime, climate, and fertility, may favor high plant densities, giving an advantage to PD Chanate Oro C2023, which benefits from higher spike density. However, testing under different planting densities, fertilization regimes, or water stress would be valuable, as the relationship between density, spike number, and yield is environment-dependent. Recent studies have shown that increased planting density can compensate for late sowing yield losses [23]. Water stress could affect grain filling and photosynthetic rate during this stage. High temperatures and water stress in wheat have been observed to reduce photosynthesis and negatively impact yield [24]. Evaluating yield stability over multiple years or cycles is recommended to determine whether the slight advantage of PD Chanate Oro C2023 is consistent or environment-specific. Comparison with the regional check variety CIRNO C2008, still preferred by Yaqui Valley farmers despite leaf rust susceptibility, is also suggested.

A final recommendation is to evaluate recently released varieties under organic production to identify the most adaptable, and to use harvested grain as seed for subsequent cycles, as seed produced in low-input organic systems may adapt better due to soil biology and competition levels differing from conventional systems, with potential genetic transfer to conventional agriculture [25]. Over 95% of organic production uses varieties developed for high-input conventional systems, where agrochemicals can negatively affect performance in low-input organic conditions [26].

4 Conclusion

Both wheat varieties are suitable for organic farming. Quetchehueca Oro C2013 and PD Chanate Oro C2023 show similar yields, with subtle differences in yield components. Quetchehueca Oro C2013 produced more grains per spike, whereas PD Chanate Oro C2023 compensated with higher spike density and heavier grains. Higher spike density and biomass in PD Chanate Oro C2023 suggest good potential for high-density planting environments. It is recommended to evaluate the interannual stability of PD Chanate Oro and compare it with CIRNO C2008.

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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