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# COMPARATIVE ANALYSIS OF EARLY ESTABLISHMENT PERFORMANCES OF PERENNIAL WHEAT GENOTYPES

*Deniz ISTIPLILER**

*Ege University, Faculty of Agriculture, Department of Field Crops, Izmir, Türkiye*
**Corresponding author's email: deniz.istipliler@ege.edu.tr*

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## ABSTRACT

**Perennial wheat (*Triticum aestivum* L. × *Thinopyrum* spp.) presents a promising alternative to conventional annual wheat for sustainable agriculture, offering advantages such as enhanced soil health and reduced environmental impact. This study evaluated the early establishment performances of 20 perennial wheat genotypes sourced from diverse donors alongside two commercial wheat varieties under rain-fed conditions in Bornova, Izmir, Türkiye. Two separate field trials were conducted over two growing seasons (2018/19 and 2020/21), assessed key yield components, including plant height (PH), spike number (SN), spike length (SL), thousand grain weight (TGW), and overall grain yield (GY). Results showed that perennial wheat genotypes exhibited higher plant height and spike length compared to common wheat but had lower grain numbers per spike and TGW. On average, perennial wheat achieved 40% of the grain yield of commercial wheat varieties, with significant variability among genotypes. Notably, the genotype Pw18 demonstrated satisfactory grain yield performance, achieving 5.21 tons ha$^{-1}$, close to common wheat yields evaluated in the study. These findings highlight the potential of specific perennial wheat genotypes for further development in sustainable cropping systems. However, further investigation is needed to assess the quality characteristics of these genotypes, which will be crucial for their potential use.**

**Keywords: perennial wheat, yield, annual wheat, comparison**

## INTRODUCTION

Perennial wheat, a hybrid derived from the crossbreeding of traditional wheat (*Triticum aestivum* L.) and wild perennial relatives such as *Thinopyrum spp*., represents a significant advancement in agricultural science aimed at addressing both food security and environmental sustainability challenges (Zhang et al., 2011; Jaikumar et al., 2012). In light of complex global challenges such as climate change, pandemics, and political conflicts impacting agricultural production worldwide, the sustainability of current food production systems is increasingly being challenged (Erenstein et al., 2022). The growing demand for food, driven by exponential population growth and shifting consumption patterns, is further strained by the limited availability of arable land (Zheng et al., 2021). Furthermore, contemporary agricultural practices have adversely affected the environment, including soil erosion, greenhouse gas emissions, and water contamination, despite their capacity to enhance crop yields (Monfreda et al. 2008, Liu et al., 2023). Under these circumstances, the efforts should be focused on ensuring food security while considering the environmental health and socio-economic situation (Chapman et al., 2022).

Perennial crops can be considered a promising option for the sustainability of agricultural production. Perennial crops don’t need to be planted each year. Instead, they can regrow after the harvest for a couple of years, which would reduce the cost of production and field management (Soto-Gómez and Pérez-Rodríguez, 2022). The cultivation of perennial crops has the potential to enhance soil health by stimulating the activity density and soil richness of ground beetles (Burmeister, 2021), isolate the carbon and help to utilise the nutrients and water more effectively by their deep root systems (DeHaan et al., 2020). This speciality makes them more stable regarding yield properties during drought periods (Vico and Brunsell, 2018). Moreover, perennial crops have a superior by-product potential than their annual options, thanks to their higher aboveground biomass production (Soto-Gómez and Pérez-Rodríguez, 2022).

Perennial wheat (*Triticum aestivum* L. × *Thinopyrum* spp.) is a novel and promising hybrid species as a sustainable alternative to the annual wheat (Jaikumar et al., 2012). The attempts to develop perennial wheat has started by Soviet scientists in the 1930s (Jaikumar et al., 2012; Tsitsin, 1939; DeHaan and Ismail, 2017), today the efforts are ongoing to provide new perennial wheat cultivars that can meet the demands of wheat growers. In general, the key properties in perennial wheat breeding are achieving a considerable grain yield and the plants staying long in the field (longevity) and meeting the essential quality characteristics (Hayes et al., 2018). Perennial plants generally allocate fewer resources to reproduction structures and prioritize their survival over multiple years (Bazzaz et al., 1987; Vico and Brunsell, 2018). The perennial wheat cultivars bred so far have 30% lower grain yield than commercial annual bread wheat (Baronti et al., 2022) and often reduce more after the first year of cultivation (Hayes et al., 2018), so the grain yield stands for as one of the most critical traits in perennial wheat development. In planning plant production activities, farmers tend to focus on the yield rather than other traits.

In perennial crops, the early establishment performance of a cultivar is crucial in terms of soil health and fertility. Perennial wheat is known for developing a deep and extensive root system that enhances soil structure and increases organic matter content (Kurmanbayeva et al., 2024a). This root development is complemented by the canopy's ability to protect the soil surface from erosion and nutrient leaching, which is particularly beneficial in regions prone to soil degradation (Bell et al., 2010). Therefore, the initial performance of perennial wheat lines becomes a significant factor in farmers' decision-making processes. Given that grain yield is a quantitative trait influenced by both genotype (G), environment (E), and their interaction (G × E) (Shewaye and Solomon, 2018; Mohamed, 2013), it is essential to assess the early establishment performance of perennial wheat germplasm across different environments. Although numerous studies have explored perennial wheat in terms of its future potential and agronomic evaluation (DeHaan et al., 2017; Glover et al., 2010; Hayes et al., 2018), there is limited research evaluating the early establishment performance of various perennial wheat lines. This study aims to evaluate the adaptation and early establishment performance of 20 perennial wheat genotypes, sourced from diverse perennial donors, in comparison with two commercial bread wheat cultivars to explore the potential of perennial wheat as a sustainable option for future agricultural systems

## MATERIALS AND METHODS

### *Plant material and experimental site*

A field experiment was conducted during the 2018/19 and 2020/21 wheat growing seasons, spanning the period from November to June. A total of 20 perennial wheat genotypes with different genotypic backgrounds (Table 1) provided by the International Maize and Wheat Improvement Center (CIMMYT) and 2 standard bread wheat (*Triticum aestivum* L.) varieties, *cv.*Basribey and *cv.*Masaccio were used as plant material. These varieties are known for their high yield potential and good adaptation to the Mediterranean climate conditions where the experiment was conducted. The experimental site was situated at an altitude of 6 meters (38°34'45" N, 27°1'22" E) in Bornova Plain, Izmir, Türkiye. The soil profile at depths of 0-20 cm and 20-40 cm was characterized as silt-clay with a pH of 8.2 and clay-loamy with a pH of 7.8, respectively. The climate data obtained from the Turkish State Meteorological Service for the 2018/19 and 2020/21 growing seasons in Izmir is shown in Table 2.

**Table 1.** The origin and identification of perennial wheat genotypes used in the study.

| Accession Number | Genotype No | Name | Origin | Donor Wheatgrass |
|---|---|---|---|---|
| 160018 | Pw1 | WHEAT-AGROPYRON PONTICUM PARTIAL AMPHIPLOID | OTHER | *Th.ponticum* |
| 160020 | Pw3 | WHEAT-AGROPYRON PONTICUM PARTIAL AMPHIPLOID | USA | *Th.ponticum* |
| 160008 | Pw4 | PI573182/BFC2-4//BFC2-N/3/PI440048/4/(TAM110/PI401201//JAG & 2137)/5/(PI636500/PI414667//PI414667/3/(PI573182/PI314190//BFC1-FF)) | US-TLI | *Th.intermedium* |
| 160012 | Pw5 | (KEQIANG/NANDA2419)/AG.INTERMEDIUM//WHEAT | CHINA | *Th.intermedium* |
| 160009 | Pw8 | PI634318/PI414667 | US-TLI | *Th.junceiforme* |
| 160022 | Pw9 | WHEAT-AGROPYRON INTERMEDIUM PARTIAL AMPHIPLOID | RUSSIA | *Th.intermedium* |
| 160019 | Pw10 | VILMORIN 27*2/AG.INTERMEDIUM | FRANCE | *Th.intermedium* |
| 160014 | Pw11 | WHEAT-AGROPYRON INTERMEDIUM PARTIAL AMPHIPLOID | RUSSIA | *Th.intermedium* |
| 160011 | Pw12 | (KEQIANG/NANDA2419)/AG.INTERMEDIUM//WHEAT | CHINA | *Th.intermedium* |
| 160017 | Pw13 | WHEAT-AGROPYRON PONTICUM PARTIAL AMPHIPLOID | US-OSU | *Th.ponticum* |
| 160006 | Pw14 | TAM110/PI401201//JAG & 2137 | US-TLI | *Th.intermedium* |
| 160021 | Pw15 | T.DURUM/AG.ELONGATUM | CIMMYT | *Th.elongatum* |
| 160004 | Pw16 | MADSEN//CHINESE SPRING/PI531718 | US-WSU | *Th.elongatum* |
| 160007 | Pw17 | TAM110/PI401201//JAG & 2137/3/PI520054/4/PI401168/5/(TAM110/PI401201//JAG & 2137) | US-TLI | *Th.intermedium* |
| 160013 | Pw18 | HEZUO#2/AG.INTERMEDIUM//WHEAT | CHINA | *Th.intermedium* |
| 160015 | Pw19 | WHEAT-AGROPYRON PONTICUM PARTIAL AMPHIPLOID | RUSSIA | *Th.ponticum* |
| 160017 | Pw20 | WHEAT-AGROPYRON PONTICUM PARTIAL AMPHIPLOID | US-OSU | *Th.ponticum* |
| 160017 | Pw21 | WHEAT-AGROPYRON PONTICUM PARTIAL AMPHIPLOID | US-OSU | *Th.ponticum* |
| 160017 | Pw22 | WHEAT-AGROPYRON PONTICUM PARTIAL AMPHIPLOID | US-OSU | *Th.ponticum* |
| 160017 | Pw23 | WHEAT-AGROPYRON PONTICUM PARTIAL AMPHIPLOID | US-OSU | *Th.ponticum* |

**Table 2.** Meteorological parameters (Monthly averages for temperature and humidity, monthly total rain amount) for İzmir in two experimental years (2018/19 and 2020/21).

| | | December | January | February | March | April | May | June |
|---|---|---|---|---|---|---|---|---|
| **2018/19** | Temperature (C°) | 15.1 | 8.7 | 8.7 | 9.9 | 13.1 | 16.4 | 21.7 |
| | Rain (mm) | 38.8 | 97.4 | 119.6 | 50.0 | 58.6 | 16.9 | - |
| | Humidity (%) | 74.5 | 79.2 | 84.7 | 75.6 | 65.7 | 62.5 | 61.0 |
| **2020/21** | Temperature (C°) | 12.4 | 10.5 | 10.7 | 10.4 | 15.8 | 21.6 | 24.9 |
| | Rain (mm) | 172.8 | 164.0 | 62.6 | 129.6 | 33.2 | 0.2 | 16.8 |
| | Humidity (%) | 74.8 | 73.3 | 66.3 | 65.2 | 63.2 | 56.6 | 55.1 |

*Experimental design*

The experimental design utilized a randomized complete block design, with three replications and each replication consisting of one-meter-long row plots, and the distance between the rows was 50 cm. Sowing was conducted separately for each year following the method described by Hayes et al. (2018). Seeds of all wheat cultivars used in the study were hand-sowed at a rate of 25 seeds per row, ensuring a final seed density of 50 seeds per square meter. Due to the low regrowth rates of all perennial wheat genotypes after the first-year harvest in 2019, the experiment was repeated (replanting) in 2021 using the same genotypes. The same sowing pattern was applied for the perennial wheat genotypes and the commercial bread wheat cultivars.

*Field management*

The seeds were sown on December 1st, 2018, and November 20th, 2020 harvested on June 20th, 2019, and June 14th, 2021. Composite fertilizer (15.15.15), consisting of nitrogen (N), phosphorus ($P_2O_5$), and potassium ($K_2O$), was applied to the experimental field at a rate of 0.33 ton $ha^{-1}$ at the beginning of the experiment. Additionally, 0.14 ton $ha^{-1}$ of ammonium sulfate fertilizer (21%) was applied during the initial stage of wheat's stem elongation at Z31 (Zadoks Stage = 31, Zadoks et al., 1974). The plants were grown under rain-fed conditions.

*Data collection and analysis*

Every single plant of each wheat genotype was sampled separately. Five representative plants per row were selected for the measurements, excluding the edges of the rows. Plant height (cm), spike length (cm), plant biomass (kg $ha^{-1}$), thousand grain weight (g), spike number (number $m^{-2}$), and plant yield (g $plant^{-1}$) were determined following the Wheat Special Report (No: 32) of CIMMYT (Bell and Ficher, 1994). After sampling, the border plants were removed, and the remaining plants were harvested for each plot. Then the wheat grains were threshed using a plot thresher, and grain yield (ton/ha) was calculated.

*Statistical analysis*

ANOVA was employed to assess the effects of the factors, and treatment means were compared using the least significant difference test (LSD) at a significance level of 0.05. All statistical analyses were conducted using the R software v.4.0.4 (R Core Team, 2021). The built-in function aov used to perform ANOVA, then the agricolae package (Mendiburu, 2023) was used for LSD test. Microsoft Excel (Microsoft Corporation, 2018) was used for visualization.

## RESULTS AND DISCUSSION

The yield components of 20 perennial wheat genotypes were evaluated during the first year alongside two common wheat varieties (*Triticum aestivum* L.). Based on the analysis of variance, the differences between the genotypes were found statistically significant for all measured traits (Table 3). Besides, the years' effect was significant for four traits: spike length, spike number per square meter, grain number per spike, and grain yield. The genotype-by-year interaction effect was significant only for plant height and grain number per spike traits (Table 3).

**Table 3.** The mean squares observed from ANOVA for observed traits and variation sources

| *Variation Sources / Traits* | Plant height (cm) | Upper Internode length (cm) | Spike length (cm) | Spike number $m^{-2}$ | Grain Number $spike^{-1}$ | Thousand Grain Weight (g) | Grain Yield (ton $ha^{-1}$) |
|---|---|---|---|---|---|---|---|
| **Genotype** | 1753.29** | 338.09** | 40.27** | 12496** | 574.09** | 173.49** | 162.27** |
| **Year** | 86.81 | 1.34 | 180.24** | 514360** | 2012.57** | 8.46 | 1775.41** |
| **G x Y** | 164.18* | 38.27 | 6.31 | 9152 | 271.12** | 9.88 | 44.77 |
| **Replication** | 207.14 | 19.73 | 10.62* | 16992* | 374.24* | 60.13** | 206.10** |

** : p < 0.01 , *: p < 0.05

On average, the plant height of the perennial wheat genotypes was consistent at 94 cm. However, the plant height of the standard wheat varieties increased in 2021, reaching 70 cm compared to 61 cm in 2019 (Figure 1). Remarkably, the perennial genotype Pw15 exhibited significantly greater plant height (133 cm) than the other perennial genotypes, while Pw16, Pw17, and Pw18 displayed relatively shorter heights, ranging from 71 to 85 cm across both years. The greater plant height of perennial wheat compared to common wheat has also been reported by Baronti et al. (2022). Similarly, in the present study, spike length in perennial wheat was approximately 5 cm longer than in common wheat in both years (Figure 1). The average spike length for perennial wheat was 14.8 cm, aligning with the findings of Pogna et al. (2013), who recorded a spike length of 14.3 cm, around 3 cm longer than common wheat. In addition to spike length, the upper internode length of perennial wheat genotypes averaged 37.5 cm, exceeding that of the common wheat varieties (29.6 cm) in both seasons (Figure 1). Kurmanbayeva et al. (2024b) reported that perennial wheat genotypes typically have four internodes, with five being rare. The greater plant height and relatively lower number of nodes (data not shown) observed in the perennial genotypes suggest that the plants have longer internodes in the upper part and throughout the stem.

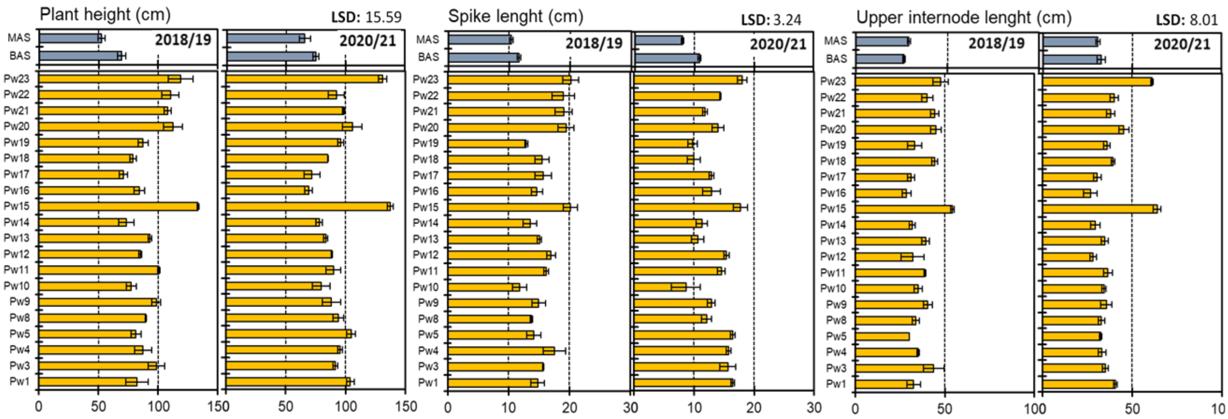


**Figure 1.** Comparison of plant heights (cm), spike length (cm) and upper internode length (cm) among 20 perennial wheat genotypes during the initial year of their growth cycle. The blue bars, presented above the figure, represent the plant heights of common wheat cultivars (*Triticum aestivum* L.), including Masaccio (MAS) and Basribey (BAS).

Grain yield is generally determined by the number of spike per unit area, the number of grains per spike, and the thousand-grain weight (TGW) (Xie et al., 2016; Tatar et al., 2020). In the current study, the average spike number, grain number per spike, and TGW for the common wheat varieties were 206 spikes $m^2$, 50 grains spike$^{-1}$, and 37.7 g, respectively (Figure 2). In comparison, the perennial wheat genotypes had lower values of 19% in spike number (167 spikes $m^2$), 38% in grain number per spike (37 grains spike$^{-1}$), and 26% in TGW (28.1 g) compared to standard wheat genotypes. The lower grain number per spike in perennial wheat genotypes is likely due to the increased distance between spikelet, despite the longer spike length, as noted by Clark et al. (2019). Yan et al. (2022) also reported fewer spikelet per spike in perennial wheat lines, ranging from 17 to 24 spikelet. Despite the generally lower values of the grain yield components in perennial wheat, specific genotypes exhibited superior traits. Spike number is an important agronomic trait in yield formation and it depends on the productive tillering capacity of the plants (Fu et al., 2023) Pw14 had a notably higher spike number (246 spikes $m^{-2}$), while Pw12 and Pw17 showed higher grain numbers per spike (51 grains spike$^{-1}$), and Pw19 had the highest TGW (45.4 g) among the perennial wheat genotypes in the current study.

The average grain yield of perennial wheat genotypes was 2.5 tons ha$^{-1}$ in the first year (2018/19) and 0.99 tons ha$^{-1}$ in the second year (2020/21) (Table 4). In common wheat, the average grain yield was 4.82 tons ha$^{-1}$ in the first year and 3.92 tons ha$^{-1}$ in the second year. Among the perennial genotypes, Pw4 (6.20 tons ha$^{-1}$) and Pw18 (6.13 tons ha$^{-1}$) achieved the highest grain yields in the first year, while Pw18 continued to perform well in the second year with a yield of 4.29 tons ha$^{-1}$. For comparison, the common wheat variety BAS had the highest yields in both years, with 5.15 tons ha$^{-1}$ and 4.55 tons ha$^{-1}$, respectively. This variability in yield values may be attributed to differences in climatic conditions between the two years. The relatively low precipitation in April and May, a critical period for yield formation, may have contributed to the lower yield observed in the second year (Table 2). These findings align with a previous study that reported a significant effect of drought during the grain-filling stage on wheat grain yield (Tatar et al., 2020).

Grain yield reductions in perennial wheat may result from resource trade-offs between reproductive growth, regrowth, and winter survival (Jaikumar et al., 2012). According to Bell et al. (2008), perennial wheat could become economically viable if it achieves 40% of the grain yield of annual wheat, especially when combined with forage production. In this study, the average grain yield of perennial wheat (1.75 tons ha$^{-1}$) was 40% of the grain yield of the common wheat varieties (4.37 tons ha$^{-1}$) (Table 4). However, there was substantial variability in the grain yield among perennial wheat genotypes, ranging from 0.16 to 5.21 tons ha$^{-1}$. Pw18 was particularly promising, with an average yield of 5.21 tons ha$^{-1}$, despite showing no standout performance in other yield components. Pw4 also demonstrated high performance, with a yield (4.06 tons ha$^{-1}$) approaching that of the common wheat varieties (Table 4).

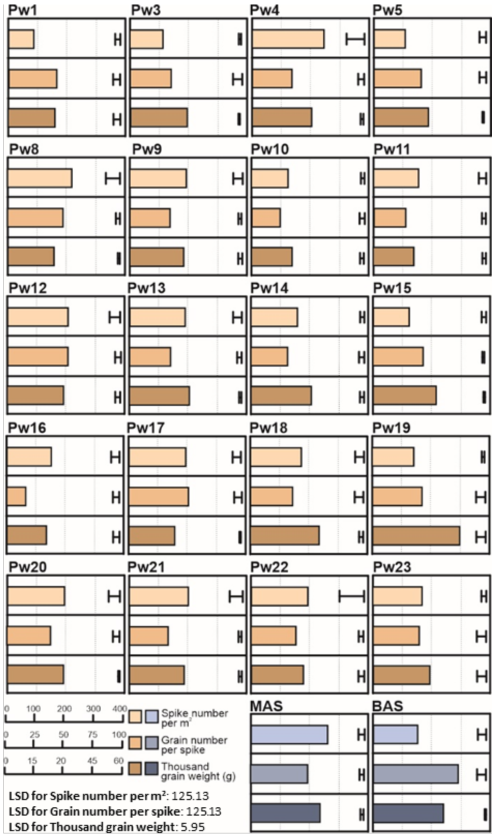


**Figure 2.** Spike number per m$^2$, grain number per spike, and thousand grain weight (g) among 20 perennial wheat genotypes during the initial year of their growth cycle. The blue bars, presented below the figure, represent the plant heights of common wheat cultivars (*Triticum aestivum* L.), including Masaccio (MAS) and Basribey (BAS).

**Table 4.** Comparison of grain yields (ton ha$^{-1}$) among 20 perennial wheat genotypes during the initial year of their growth cycle.

| **Genotypes** | | **Grain Yield (ton ha$^{-1}$)** | | |
|---|---|---|---|---|
| | | **2018/19** | **2020/21** | **Mean** |
| **Perennial Wheat** | *Pw1* | 0.82 ±0.30 | 0.79 ±0.17 | 0.80 |
| | *Pw3* | 1.42 ±0.28 | 0.84 ±0.31 | 1.13 |
| | *Pw4* | 6.20 ±0.02 | 1.93 ±0.26 | 4.06 |
| | *Pw5* | 0.74 ±0.22 | 1.33 ±0.20 | 1.04 |
| | *Pw8* | 3.02 ±1.55 | 1.20 ±0.24 | 2.11 |
| | *Pw9* | 2.89 ±1.07 | 0.77 ±0.22 | 1.83 |
| | *Pw10* | 1.15 ±0.64 | 0.26 ±0.12 | 0.71 |
| | *Pw11* | 1.44 ±0.77 | 0.39 ±0.10 | 0.92 |
| | *Pw12* | 0.65 ±0.20 | 0.66 ±0.02 | 0.66 |
| | *Pw13* | 3.65 ±0.49 | 0.41 ±0.033 | 2.03 |
| | *Pw14* | 2.46 ±0.74 | 1.14 ±0.41 | 1.80 |
| | *Pw15* | 2.51 ±0.44 | 1.04 ±0.15 | 1.78 |
| | *Pw16* | 0.18 ±0.08 | 0.14 ±0.02 | 0.16 |
| | *Pw17* | 3.32 ±0.74 | 1.12 ±0.10 | 2.22 |
| | *Pw18* | 6.13 ±0.98 | 4.29 ±0.43 | 5.21 |
| | *Pw19* | 2.18 ±0.47 | 0.89 ±0.22 | 1.53 |
| | *Pw20* | 3.15 ±0.54 | 0.47 ±0.06 | 1.81 |
| | *Pw21* | 3.04 ±0.93 | 0.40 ±0.09 | 1.72 |
| | *Pw22* | 2.63 ±1.17 | 0.68 ±0.22 | 1.65 |
| | *Pw23* | 2.50 ±0.09 | 1.01 ±0.08 | 1.76 |
| | **Mean** | **2.50** | **0.99** | **1.75** |
| **Common Wheat** | *MAS* | 4.49 ±0.76 | 3.29 ±0.19 | 3.89 |
| | *BAS* | 5.16 ±0.04 | 4.55 ±0.80 | 4.86 |
| | **Mean** | **4.82** | **3.92** | **4.37** |
| | **LSD** | **0.86** | | |

In general, perennial wheat varieties have not surpassed 60–75% of common wheat yields, with significant yield declines after the first year (Pimentel et al., 2012). Jaikumar et al. (2012) reported that perennial wheat produced grain yields of 1.0 to 1.6 tons $ha^{-1}$ - around 50% of North America's common wheat yield (2.7 tons $ha^{-1}$). Other studies have shown that perennial wheat genotypes can achieve between 18% and 64% of the yield of conventional common wheat varieties, though persistence varies widely (Scheinost et al., 2001; Bell et al., 2010).

In conclusion, perennial wheat genotypes exhibited higher plant height, spike number, and upper internode length than common wheat varieties. However, despite having more spikes per unit area, they showed lower grain numbers per spike and TGW. Significant variability was observed in the yield components of the perennial wheat genotypes. On average, perennial wheat yielded 40% of the grain yield of common wheat. Pw18 was particularly promising among the tested genotypes for its first-year grain yield performance relative to other genotypes. Further investigation is needed to assess the quality characteristics of these genotypes, which will be crucial for their potential use.

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## LITERATURE CITED

Baronti, S., E. Galassi, F. Ugolini, F. Miglietta, L. Genesio, F.P. Vaccari, P. Cacciatori and L. Gazza. 2022. Agronomic and ecophysiological evaluation of an early establishment of perennial wheat lines in Central Italy. Genet. Resour. Crop Evol. 69: 619-633.

Bazzaz, F. A., N. R. Chiariello, P. D. Coley and L. F. Pitelka. 1987. Allocating resources to reproduction and defense. BioScience. 37(1): 58-67.

Bell, L.W., F. Byrne, M.A. Ewing and L.J. Wade. 2008. A preliminary whole-farm economic analysis of perennial wheat in an Australian dryland farming system. Agric. Syst. 96: 166–174.

Bell, L.W., L.J. Wade and M.A. Ewing. 2010. Perennial wheat: a review of environmental and agronomic prospects for development in Australia, Crop & Pasture Science. 61: 679–690.

Burmeister, J. 2021. Promotion of ground beetles by integrating perennial energy crops into existing agricultural landscapes. Biomass and Bioenergy. 146: 105973.

Chapman, E. A., H. C. Thomsen, S. Tulloch, P. M. Correia, G. Luo, J. Najafi, L.R. Dehaan, T.E. Crews, L. Olsson, P.O. Lundquist, A. Westerbergh, P.R. Pedas, S. Knudsen and M. Palmgren. 2022. Perennials as future grain crops: opportunities and challenges. Frontiers in Plant Science. 13: 898769.

Clark, I., S.S. Jones, J.P. Reganold, K.A. Sanguinet and K.M. Murphy. 2019. Agronomic Performance of Perennial Grain Genotypes in the Palouse Region of the Pacific Northwest, USA. Front. Sustain. Food Syst. 3:39.

DeHaan, L., S. Larson, R. L. López-Marqués, S. Wenkel, C. Gao and M. Palmgren. 2020. Roadmap for accelerated domestication of an emerging perennial grain crop. Trends in Plant Science. 25(6): 525-537.

DeHaan, L.R. and B.P. Ismail. 2017. Perennial cereals provide ecosystem benefits. Cereal Foods World. 62(6): 278-281.

Erenstein, O., N. Poole and J. Donovan. 2022. Role of staple cereals in human nutrition: Separating the wheat from the chaff in the infodemics age. Trends in Food Science & Technology. 119: 508-513.

Fu, H., R. L. Bohuslavskyı and L. Atramentova. 2023. Einkorn wheat tillering: models of inheritance. Turkish Journal Of Field Crops. 28(2): 229-234.

Glover, J. D., J. P. Reganold, L. W. Bell, J. Borevitz, E. C. Brummer, E. S. Buckler, C. M. Cox, T. S. Cox, T. E. Crews, S. W. Culman, L. R. DeHaan, D. Eriksson, B. S. Gill, J. Holland, F. Hu, B. S. Hulke, A. M. H. Ibrahim, W. Jackson, S. S. Jones, S. C. Murray, A. H. Paterson, E. Ploschuk, E. J. Sacks, S. Snapp, D. Tao, D. L. Van Tassel, L. J. Wade, D. L. Wyse and Y. Xu. 2010. Increased food and ecosystem security via perennial grains. Science. 328(5986): 1638-1639.

Hayes, R. C., S. Wang, M. T. Newell, K. Turner, J. Larsen, L. Gazza, J. A. Anderson, L. W. Bell, D. J. Cattani, K. Frels, E. Galassi, A.I. Morgounov, C. K. Revell, D. B. Thapa, E. J. Sacks, M. Sameri, L. J. Wade, A. Westerbergh, V. Shamanin, A. Amanov and G.D. Li. 2018. The performance of early-generation perennial winter cereals at 21 sites across four continents. Sustainability. 10(4):1124.

Jaikumar, N. S., S. S. Snapp, K. Murphy and S. S. Jones. 2012. Agronomic assessment of perennial wheat and perennial rye as cereal crops. Agronomy Journal. 104(6): 1716-1726.

Kurmanbayeva, M., A. Kusmangazinov, Z. Makhatov, D. Karabalayeva, N. Yerezhepova, and B. Murzabayev. 2024a. Positive Effects of Perennial Wheat on Soil Fertility, Carbon Stocks and Microbial Biomass in South-Eastern Kazakhstan. Polish Journal of Environmental Studies, 33(2):1791-1799.

Kurmanbayeva, M., B. Sarsenbek, A. Kusmangazinov, D. Karabalayeva and N. Yerezhepova. 2024b. Anatomical and morphological features, and productivity of six perennial wheat varieties in the agroecological conditions of the Almaty region, Kazakhstan, BIO Web of Conferences, 100, 04048.

Liu, Y., W. Song, A. Song, C. Wu, J. Ding, X. Yu, J. Song, M. Liu, X. Yang, C. Jiang, H. Zhao, W. Song, D. Liu, X. Yang, Q. Song, X. Li, L. Cui, H. Li and Y. Zhang. 2023. The improvement of agronomic performances in the cold weather conditions for perennial wheatgrass by crossing *Thinopyrum intermedium* with wheat-Th. intermedium partial amphiploids. Frontiers in Plant Science. 14:1207078.

Mendiburu, F.D. 2023. agricolae: Statistical Procedures for Agricultural Research. R package version 1.3-7, https://CRAN.R-project.org/package=agricolae.

Mohamed, N.E.M. 2013. Genotype by environment interactions for grain yield in bread wheat (*Triticum aestivum* L.). Journal of Plant Breeding and Crop Science. 7(5):150-157.

Monfreda, C., N. Ramankutty and J. A. Foley. 2008. Farming the planet: 2. Geographic distribution of crop areas, yields, physiological types, and net primary production in the year 2000. Global biogeochemical cycles. 22(1).

Pimentel, D., D. Cerasale, R.C. Stanley, R. Perlman, E.M. Newman, L.C. Brent, A. Mullan and D.T. Chang. 2012. Annual vs. perennial grain production, Agriculture, Ecosystems & Environment. 161: 1-9.

Pogna, N.E., E. Galassi, R. Ciccoritti, E. Stefanis, D. Sgrulletta, P. Cacciatori, L. Gazza and A. Bozzini. 2013. Evaluation of nine perennial wheat derivatives grown in Italy, In: Perennial Crops for Food Security, Proceedings of The FAO Expert Workshop, ed. Batella et al., ISBN 978-92-5-107998-0.

R Core Team.2021. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Scheinost, P.L., D.L. Lammer, X. Cai, T.D. Murray and S.S. Jones. 2001. Perennial wheat: the development of a sustainable cropping system for the U.S. Pacific Northwest. American Journal of Alternative Agriculture. 16:147–151.

Shewaye, Y. and T. Solomon. 2018. Performance of Bread Wheat (*Triticum aestivum* L.). Line Originating from Various Sources. Open Access J. of Agri. Res. 3(4):2474-8846.

Soto-Gómez, D. and P. Pérez-Rodríguez. 2022. Sustainable agriculture through perennial grains: Wheat, rice, maize, and other species. A review. Agriculture, Ecosystems & Environment. 325:107747.

Tatar, O., U. Cakalogullari, F. Aykut Tonk, D. Istipliler and R. Karakoc, 2020. Effect of drought stress on yield and quality traits of common wheat during grain filling stage, Turkish Journal of Field Crops. 25: 236-244.

Tsitsin, N. 1939. Science of the service of Soviet agriculture.

Vico, G. and N. A. Brunsell. 2018. Tradeoffs between water requirements and yield stability in annual vs. perennial crops. Advances in water resources. 112: 189-202.

Xie, Q., S. Mayes and D.L. Sparkes. 2016. Preanthesis biomass accumulation of plant and plant organs defines yield components in wheat, European Journal of Agronomy. 81: 15-26.

Yan, W., X. Jin, B. Jiang, X. Qi, Y. Chen, X. Li, X. Liu, Y. Ren, L. Cui, Q. Song, H. Li, B. Friebe, J. Li and Y. Zhang. 2020. Development and Molecular Cytogenetic Characterization of Cold-Hardy Perennial Wheatgrass Adapted to Northeastern China. Front. Plant Sci. 11:582.

Zadoks, J.C., T.T. Chang and C.F. Konzaki. 1974. A decimal code for the growth stages of cereals. Weed Research. 14(6):415-421.

Zhang, Y., L. Jiang, Y. Li, C. Tian, W. Zhang, J. Li and Z. Xiao. 2011. Perennial grain crops: a new option for the future food and ecoagricultural environment. Advanced Materials Research. 361-363:1463-1466.

Zheng, J. C., H. Zhang, J. Yu, Q. W. Zhan, W. Y. Li, F. Xu, G. J. Wang, T. Liu and J. C. Li. 2021. Late sowing and nitrogen application to optimize canopy structure and grain yield of bread wheat in a fluctuating climate. Turkish Journal of Field Crops. 26(2):170-179.