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COMPARATIVE ASSESSMENT OF THE YIELD COMPONENTS OF THE TETRAPLOID WHEAT WORLD COLLECTION

Nowadays, a large number of cultivars of various origins are attracted to the wheat breeding improvement, and as a result, an assessment of the accessions’ yield in various agroclimatic conditions is required. Genotype-environment interaction is the main reason for the fact that in different years and (or) in other conditions of cultivation, cultivars and lines differ in rank according to the level of the yield. The study aims to investigate the suitability and adaptability of accessions of world tetraploid wheat collection, including durum wheat cultivars, to the Kazakhstan conditions. Three hundred twenty-eight (328) tetraploid wheat accessions of different genetic and geographical origin were grown in 2 randomized replicates in two contrasting regions of Kazakhstan – Kostanay region on the North and Almaty region on the South-east of the country. Phenological observations and structural analysis were conducted following Dospekhov and the Zadoks scale. Correlations coefficients among all characters (days to tillering, days to booting, days to heading, days to anthesis, days to maturity, plant height, peduncle length, number of fertile spikes per plant, spike length, number of kernels per spike, weight of kernels per spike, number of kernels per plant, 1000 kernels weight) were computed using GraphPad software.

To assess the contribution of genotypic and environmental variability to the total phenotypic variation of yield and the main economically valuable traits, we evaluated the genotype-environment interaction. Productive and adapted accessions for the both Almaty and Kostanay regions were selected. The data of phenological observations and structural analysis will be used in a genome-wide association study for the traits, related to productivity and quality.

Key words: tetraploid wheat, cultivar, yield, phenology, pre-breeding, genotype x environment interaction.

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Introduction

Wheat (Triticum) is a plant genus within the grass family (Poaceae). Tetraploid wheats (2n = 4x = 28 chromosomes) consist of: "naked" cultivated grain species – durum wheat (T. durum), English or pollard wheat (T. turgidum), Persian wheat (T. persicum, T. carthlicum), Khorasan wheat (T. turanicum), Ethiopian (T. aethiopicum), Polish wheat (T. polonicum), wild species – wild emmer (T. dicoccoides), Araratian wild emmer or Armenian wild emmer (T. araraticum), cultivated hulled wheat spe-
cies – timopheevi or Zanduri (T. timopheevi), Colchis emmer (T. karamyschevii), T. palaeo-colchicum, T. georgicum, emmer (T. dicoccum), Ispahan emmer wheat (T. ispahanicum) [1]. T. durum (durum wheat) is the only tetraploid species with significant agricultural importance; it is the second most cultivated species of wheat after common wheat.

Wheat breeding programs aim to improve yield and grain quality, adaptability and resistance to adverse environmental factors. An ideal cultivar with high yield and any other desirable traits should possess high genetic potential and low degree of variability in the various growing conditions [2]. Knowledge of both genetic and environmental factors is essential for understanding yield-limiting factors and developing breeding strategies for significant yield improvement [3]. Crop breeders work to develop cultivars that have high yield in various agronomic environments, and the most adapted cultivars created in the areas of their cultivation. At the same time, landraces, as well as the best representatives of the foreign breeding, wild relatives and cultivated species utilize in the breeding programs.

Yield is a complex polygenic trait and for cereals consists of three main components: number of productive spikes per plant, number of grains per spike and the weight of 1000 grains [4]. The formation of a quantitative trait is influenced by both multiple loci, and environmental conditions, and the interaction of this genotype with the environment [5]. The limiting factor of the environment usually determines the spectrum of genes determining the average value and genetic dispersion of a quantitative trait.

Leading centers for the study of genetics and breeding of durum wheat are concentrated mainly in the countries of the European Union and North America, as well the international organizations like CIMMYT, ICARDA, IRTA, and others. Scientists are working to investigate the relationship between yield and yield components; to identify genotypes demonstrating high yield in various agro-climatic conditions. Thus, in Russia [6], a comparative estimation of winter wheat cultivars of Australian breeding was made in terms of phenological observations, winter hardiness, and yield in the conditions of the Central zone of the Krasnodar region. Podlesnyh N. et al. [7] studied the peculiarities of the organogenesis stages, yield, and quality of two winter wheat species under the conditions of the Voronezh forest-steppe region. The effectiveness of agro-technical cultivation methods of winter wheat was assessed taking into account the characteristics of cultivars and types of fertilizers in the Rostov region by Zelensky N. et al. [8]. In Mexico, the effect of the experimental warming effects on phenology and grain yield components of wheat using CIRNO C200 durum wheat cultivar was evaluated [9]. A field study was carried out under rainfed conditions in North Jordan to assess phenological variation using a heat-accumulated system and its relation with yield in sixteen durum wheat genotypes [10]. The effect of day length, temperature and solar radiation on phenology and yield of durum wheat were investigated at two contrasting regions of Mexico and Spain [3]. Nine widely grown wheat cultivars and an advance line of local breeding were evaluated for days to heading, days to maturity and yield components at two regions of Pakistan [5]. Yield and phenology of 40 wheat accessions were investigated in India [11]. Yield and correlation between agrometeorological indices at the maturation stage of 8 durum wheat accessions were estimated in Tunisia [12]. Novaro P. et al. [13] studied the effect of agro-climatic conditions on kernel shape and semolina yield in Italy. The yield of 228 durum wheat cultivars and 96 lines of different geographical origin was estimated in two regions of Africa [14]. The effect of changes in duration of durum wheat developmental phases caused by breeding in Spain and Italy during the 20th century and its impact on yield was studied in Spain and Italy [15]. The correlation between yield and growth stages of bread and Iranian durum wheat was established [16]. Musynov K. et al. [17] presented the results of yield evaluation of spring bread wheat cultivars originated from different countries in the agro-climatic conditions of Northern Kazakhstan. Breeding durum wheat material of Siberian and Kazakhstan research institutes from KASIB nurseries was screened for drought tolerance, yield, yield stability and plasticity in diverse conditions of Kazakhstan and Russia [18].

Durum wheat breeding is more challenging due to its biological characteristics. Weak drought tolerance during grain development reduces grain size formation. Breeding based on environmental testing and correlation analysis can lead to the selection of the best genotypes with the desired productivity. Thus, there is a need to assess the adaptability and productivity of tetraploid wheat accessions, including cultivars and lines of foreign breeding in the conditions of Kazakhstan.

Field experiments were conducted to study the suitability and adaptability of the tetraploid wheat cultivars/lines representing world breeding to the conditions of Kazakhstan.
To achieve this goal, it was necessary to solve the following tasks:

– to conduct a phenological evaluation of the tetraploid wheat collection on the experimental fields of Kazakh Research Institute of Agriculture and Plant growing (Almaty region) and the Karabalyk breeding station (Kostanay region) under rainfed conditions;
– to study the productivity level of cultivars and lines in two growing conditions;
– to assess the correlations between the phenological phases, yield components and productivity of durum wheat cultivars and lines;
– to select accessions with high yield for the use in breeding programs.

Understanding the effect of agro-climatic conditions on yield and productivity, establishing correlations between yield and its components, as well as development phases, can help breeders to accelerate the improvement of the cultivars’ genetic potential.

Material and research methods

Materials

Three hundred twenty-eight (328) accessions of tetraploid wheat of various origins – *T. turgidum* ssp. *durum* (241), *Triticum turgidum* ssp. *earthlicum* (12), *Triticum turgidum* ssp. *dicoccoides* (7), *Triticum turgidum* ssp. *dicoccum* (14), *Triticum turgidum* ssp. *polonicum* (18), *Triticum turgidum* ssp. *turanicum* (20), *Triticum turgidum* ssp. *turgidum* (9), landraces and others (7) from countries in Europe, Transcaucasia, Asia, the Middle East, North and South America, Africa, Australia as well as international organizations involved in wheat breeding – ICARDA, INRA-Morocco, IRTA-Spain (Fig. 1) were used in this study.

The seeds were provided by the Department of Agricultural and Food Sciences of the University of Bologna (DISTAL), Research Centre for Cereal and Industrial Crops (CREA), Karabalyk breeding station of the Ministry of Agriculture of the Republic of Kazakhstan.

Evaluation of field data

Field experiments were established at experimental sites of Kazakh Research Institute of Agriculture and Plant growing (KRIAPG, Almaty region) and Karabalyk breeding station (KBS, Kostanay region) on April 13, 2018 and May 15, 2018, respectively. Kostanay region is characterized by a sharply continental climate with an average annual temperature of 3.1°C and a precipitation amount of 250-350 mm. The Almaty region has a continental climate with an average yearly temperature of 7.8°C and precipitation of 300-516 mm. The meteorological conditions of 2018 are presented in Table 1. For durum wheat, the biological air minimum temperature required for the of vegetative organs formation is 5°C, and 12°C is necessary for the generative organs forming [19]. The vegetation period of 2018 turned out to be quite beneficial for the growth and development of the grain crop both in terms of temperature and the amount of precipitation.

![Figure 1](image_url)

**Figure 1** – Distribution of samples of the tetraploid wheat collection by species (a) and geographic origin (b)
Table 1 – Air temperature and precipitation at the experimental sites in 2018 (April-August)

| Month | Almaty region (KRIAPG) | Kostanay region (KBS) |
|-------|------------------------|-----------------------|
|       | $T_{\text{min}}, ^\circ C$ | $T_{\text{max}}, ^\circ C$ | $T_{\text{mean}}, ^\circ C$ | Amount of precipitation, mm | $T_{\text{min}}, ^\circ C$ | $T_{\text{max}}, ^\circ C$ | $T_{\text{mean}}, ^\circ C$ | Amount of precipitation, mm |
| April | 11.3 | 14.6 | 12.5 | 81.6 | -0.5 | 7.7 | 4.0 | 32.4 |
| May   | 12.6 | 22.7 | 16.3 | 124.9 | 6.0 | 16.6 | 12.1 | 32.7 |
| June  | 16.8 | 28.1 | 22.3 | 29.3 | 11.6 | 20.7 | 17.0 | 46.5 |
| July  | 19.0 | 31.5 | 25.2 | 32.3 | 17.5 | 26.8 | 22.8 | 78.7 |
| August| 19.0 | 30.3 | 24.4 | 43.5 | 13.9 | 21.5 | 18.3 | 39.6 |

Asangali 20 and Nauryz 2 were used as standard cultivars in Kostanay and Almaty regions, respectively. Phenological observations were carried out in accordance with the Zadoks scale [20], where the plant growth phase is observed when the corresponding traits appear in 50% of the plants – Z10: first leaf through coleoptile; Z14: 4 leaves unfolded; Z21: main shoot and 1 tiller; Z31: 1st node detectable; Z39: flag leaf/collar just visible; Z45: boot swollen; Z59: emergence of head complete; Z65: anthesis 50%. The maturation stage is observed when the spike in half of the plants (50%) completely lost its green color.

Yield analysis of wheat and its components was carried out according to [21]. In the structural analysis, five plants were selected from each of the two randomized replicates. The following traits were recorded: plant height, peduncle length, number of fertile spikes per plant, spike length, number of kernels per spike, weight of kernels per spike, number of kernels per plant, 1000 kernels weight.

Statistical analysis
The correlation analysis was calculated using GraphPad software (https://www.graphpad.com/). The genotype-environment interaction (GEE Bi-Plot) analysis was calculated by using GenStat software (VSN International, 2011).

Research results and discussion
Phenological analysis and phenotyping of a durum wheat collection, consisting of 328 tetraploid wheat accessions grown in two regions of Kazakhstan – in the north (KBS, Kostanay region) and southeast (KRIAPG, Almaty region) of the country were carried out. The results of the comparative study are presented in Table 2.

As it is shown in Table 2, maximum and average values of the weight of kernels per plant (WKP) and the 1000 kernels weight (TKW) were higher in the south-east region. The average values of these traits exceeded those for standard cultivars for each region.

The analysis of Pearson correlations showed positive relationships between the weight of kernels per plant (WKP) and the number of fertile spikes ($r = 0.47$, $p <0.0001$), the number of kernels per spike ($r = 0.54$, $p <0.0001$), weight of kernels per spike ($r = 0.58$, $p <0.0001$), and TKW ($r = 0.25$, $p <0.0001$). Table 3 represents accessions of tetraploid wheat with the highest ranking on productivity traits – weight of kernels per spike, WKP, and TKW weight in the conditions of Almaty region. Among them several durum wheat T. *turgidum* ssp. *durum* (mainly representatives of breeding programs of Italy, France, and US) cultivars as well as accessions of *turanicum* (4), *carthlicum* (3), *dicoccum* (2), *turgidum* (2), *polonicum* (1) species were occurred. Some genotypes were distinguished by two or more traits; they are highlighted in bold (Table 3).

The highest values of yield components among the cultivars of Kazakhstan breeding in the conditions of Almaty region showed the following accessions: Gordeiforme 254, Kargala 69, Kostanayskaya 52, Kharkovskaya 9, Kargala 9, Kargala 71. Positive correlations were found between WKP and the number of fertile spikes, NFS ($r = 0.88$, $p <0.0001$) and TKW ($r = 0.54$, $p <0.0001$) for the tetraploid wheat collection under the Kostanay region conditions. The most productive genotypes for this region were identified, among which the cultivars Barcarol, Bronte, and Parsifal were in the top twenty ranked for two productivity traits (Table 4).
Comparative assessment of the yield components of the tetraploid wheat world collection

Table 2 – The results of a comparative analysis of phenological and phenotypic data of the tetraploid wheat collection under the conditions of Kostanay and Almaty regions

| Trait | Kostanay region | Almaty region |
|-------|-----------------|---------------|
|       | min | max | mean | min | max | mean |
| TT    | 12  | 16  | 14,5±0,06 | 14  | 18  | 15,1±0,03 |
| BT    | 32  | 37  | 34,5±0,07 | 40  | 55  | 42,1±0,11 |
| HT    | 49  | 55  | 52,2±0,08 | 48  | 71  | 54,6±0,27 |
| AT    | 51  | 57  | 54,3±0,07 | 51  | 91  | 61,1±0,39 |
| MT    | 85  | 89  | 87,0±0,08 | 85  | 103 | 91,8±0,2  |
| PH    | 48  | 115 | 65,3±0,86 | 49,7| 135,5| 78,6±1,21 |
| PL    | 14  | 58  | 26,6±0,48 | 19,4| 54  | 30,9±0,42 |
| NFS   | 1   | 2,3 | 1,4±0,01 | 1   | 6,2 | 2,3±0,04 |
| SL    | 4   | 12  | 6,5±0,08 | 4,8 | 17,5| 7,7±0,11 |
| WKP   | 0,9 | 5,4 | 2,9±0,04 | 0,6 | 8,1 | 3,7±0,07 |
| TKW   | 30,5| 49,2| 39,0±0,29| 19,2| 65,8| 43,3±0,38 |

TT – Seedling emergence-Tillering, BT – Seedling emergence-Booting, HT – Seedling emergence-Heading, AT – Seedling emergence-Anthesis, MT – Seedling emergence-Maturity; PH – Plant height, cm; PL – Peduncle length, cm; NFS – Number of fertile spikes; SL – Spike length, cm; WKP – Weight of kernels per plant, g; TKW – 1000 kernels weight, g

Table 3 – Accessions of tetraploid wheat with the highest values of yield components in the conditions of the Almaty region

| Cultivar/line name | Weight of kernels per spike, g | Cultivar/line name | 1000 kernels weight, g | Cultivar/line name | Weight of kernels per plant, g |
|--------------------|--------------------------------|--------------------|------------------------|--------------------|--------------------------------|
| TAGANROG           | 3.6                            | PI362067           | 65.8                   | PI191145           | 8.1                            |
| PI157985           | 3.0                            | PI191599           | 64.8                   | ZENIT              | 4.8                            |
| PRODURA            | 2.3                            | KAMUT              | 63.0                   | PI341800           | 3.1                            |
| QUADAROTO          | 2.2                            | 208911             | 58.9                   | PI157985           | 3.0                            |
| SAN CARLO          | 2.2                            | DUETTO             | 57.7                   | PI94755            | 2.7                            |
| TIZIANA            | 2.0                            | PI192641           | 57.6                   | PI343446           | 2.6                            |
| SANSONE            | 2.0                            | Adamello           | 57.6                   | NARTINO            | 2.5                            |
| CHIARA             | 2.0                            | MG4330/66          | 56.8                   | ARISTO             | 2.3                            |
| OFANTO             | 2.0                            | PI352514           | 56.4                   | MG5344/1           | 2.3                            |
| AVISPA             | 2.0                            | PI223171           | 56.2                   | PRODURA            | 2.3                            |
| OROBEL             | 1.9                            | SANSONE            | 55.1                   | PRIMADUR           | 2.2                            |
| TITO               | 1.9                            | CICLOPE            | 54.0                   | 208911             | 2.2                            |
| PI286547           | 1.9                            | PI623656           | 53.8                   | MG5416/1           | 2.2                            |
| TRINAKRIA          | 1.9                            | PI113393           | 53.7                   | QUADAROTO          | 2.2                            |
| ARISTO             | 1.8                            | PI306665           | 53.7                   | MG4330/66          | 2.2                            |
| DUETTO             | 1.8                            | PI387479           | 53.5                   | SAN CARLO          | 2.2                            |
| MG4330/66          | 1.8                            | Alemanno           | 53.4                   | AVISPA             | 2.2                            |
| ARCOBALENO         | 1.8                            | ARCANGELO         | 53.4                   | NORMANNO          | 2.1                            |
| 208911             | 1.8                            | MG5344/1          | 52.7                   | PI115816           | 2.1                            |
| GRANIZO            | 1.8                            | MG4328/61          | 52.7                   | LATINO             | 2.1                            |
Table 4 – Accessions of tetraploid wheat with the highest values of yield components in the Kostanay region

| Cultivar/line name | TKW, g | Cultivar/line name | WKP, g |
|-------------------|--------|--------------------|--------|
| Colosseo          | 49.2   | Lloyd              | 5.4    |
| Exeldur           | 48.0   | MG5300/1           | 4.8    |
| Ariosto, San Carlo, PI191145, PI192641, PR22D89 | 47.8 | MG5416/1 | 4.6 |
| Imhotep           | 47.6   | Auroch             | 4.5    |
| Cosmodur, Barcarol| 47.3   | AC Navigator       | 4.4    |
| Virgilio, 5-BIL42 | 47.2   | Barcarol, Claudio, Gallareta, Mindum | 4.3 |
| Gianni, Tiziana, Granizo | 47.1 | Ariesol, Durex, Taganrog, | 4.1 |
| MG5300/1, Creso, PI94755 | 47.0 | MG4328/61, MG5293/1 | 4.0 |
| Bronte            | 46.6   | PI573182, Karel     | 4.0    |
| Parsifal          | 46.5   | Altar 84, Bronte, Parsifal, Vic | 3.8 |

Thus, a positive correlation between WKP and TKW was detected with a high probability (p <0.0001) for both conditions. The distribution of accessions of the collection by WKP is presented in Figure 2. It should be noted that the Italian cultivars Granizo, Taganrog, Tiziana, and lines PI191145 (*turgidum*), MG4328/61 (*dicoccoides*) were distinguished in terms of productivity both in the north and the south-east of the country (Tables 3 and 4). In addition, the positive correlations between the WKP and NFS under both conditions (r = 0.89 and r = 0.47, p <0.0001) were observed.

The results obtained are coincident with information collected from studying genotype-environment interactions (Fig. 3). GGE BiPlot analysis based on yield characteristics in two growth conditions, divided wheat groups with different origins by region. According to some research works, a biplot analysis provides adequate information about genotype-environment interactions [22]. In case the set of tested genotypes has cultivars that have been well studied for their ecological adaptability, they can be considered as reference cultivars. Getting into one cluster with a reference cultivar is likely to indicate that the genotype belongs to a specific agroecological group [23]. High PC1 values (high average yield) and low PC2 values (high stability) are characteristics of the “ideal” cultivar in these agroecological conditions [24].

The results of the analysis using the GGE Biplot method suggested that PC2 effectively distinguished the northern and south-eastern conditions of Kazakhstan. According to the graph of analysis of the main components the most adapted in the conditions of Kostanay region were the following accessions: Lloyd, Gallareta, MG 4328/61, MG5416/1, MG5300/1, Auroch; in the

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**Figure 2** – The distribution of accessions of the tetraploid wheat collection by weight of kernels per plant in Kostanay (a) and Almaty (b) regions
Comparative assessment of the yield components of the tetraploid wheat world collection

In the formation of the spike, the environmental conditions play a decisive role which includes the provision of plants with rich moisture and nutrients, the lighting regime, and the temperature. The weight of kernels per spike in the conditions of the Almaty region ranged between 0.3-6.0 g, with an average value of 1.99 g (1.9 g for the local standard Nauryz-2). The number of kernels per spike ranged between 16.5-65.3, with an average value of 44.2. Negative correlations were found (p <0.0001) between this trait with plant height (PH) and spike length (SL).

Positive correlations (p<0.0001) were also found for the spike length (SL) trait and phenological phases – BT (seedling emergence-booting), HT (seedling emergence-heading), AT (seedling emergence-flowering), MT (seedling emergence-maturity), as well as with morphometric indicators associated with productivity – PH (plant height) and PL (peduncle length). Its values in phenotyped samples of the collection varied in the south-east of the country, on average, from 4.8 to 17.5 cm, with an average value of 7.7 cm (Fig. 4). The majority of the accessions of the studied collection had middle-length spikes (8.0-10.0 cm). The smallest value of the SL was 3.4 cm in the conditions of the Almaty region (Arcangelo, Appulo, 1st replication, Fig. 4a), the largest one was 11.5 cm (MG5444/235, Fig. 4b) with an average value for the entire collection of 6.1 ± 0.11. The SL values in the conditions of the Kostanay region ranged from 4.0 to 12.0 cm (average – 6.5 cm).

Figure 3 – Graph of the GGE method, which shows the environmental effect based on the yield data of accessions of the tetraploid wheat collection

Figure 4 – Durum wheat accessions differing in the spike length

The peduncle length (PL), as well as the stem length, is subject to significant fluctuations depending on the agricultural background of the crop and the weather conditions of the year. V.A. Savitskaya et al. [25] noted that the proportion of peduncle length in different groups (short stem,
middle stem, and long stem) of the total stem length is almost the same and corresponds to deviations of the stem parameter. A significant positive correlation was found between PL and plant height (PH) in both conditions.

The results obtained will be used in further genome-wide association studies for productivity, adaptability, and grain quality.

**Conclusion**

This study focuses on the evaluation of the suitability and adaptability of world breeding tetraploid wheat cultivars and lines to the conditions of Kazakhstan. Field experiments were established, phenological observations and structural analysis of the crop were carried out. The most productive in the conditions of the Almaty region were cultivars/lines: PI157985, Produra, Quadrato, San Carlo, Sansone, Avispa, Ariosto, Duetto, MG4330/66, 208911; in the conditions of Kostanay region: MG5300/1, Barcarol, Bronte, Parsifal. Italian varieties Granizo, Taganrog, Tiziana and samples PI191145 (*turgidum*), MG4328/61 (*dicoccoides*) were distinguished in terms of productivity in both conditions. 328 cultivars and lines of tetraploid wheat were analyzed according to the specifics of the “genotype-environment” response using the method of multidimensional scaling (a biplot analysis). The most adapted in the conditions of Kostanay region were the cultivars/lines: Lloyd, Gallareta, MG5416/1, MG5300/1, Auroch; in the conditions of Almaty region: 208911, PI191145, 1809, Bradano. The results of phenological observations and structural analysis will be used in a genome-wide association study for traits related to productivity and quality.

Thus, as a result of environmental testing of the tetraploid wheat collection of various origins in Kostanay and Almaty regions, a comparative assessment and ranking of the analyzed 328 accessions were carried out for phenological phases and development, morphometric indicators and productivity. The most productive accessions were identified for each region separately, and both conditions. The results of phenological observations and structural analysis will be used in a genome-wide association study for traits related to productivity, adaptability and grain quality of tetraploid wheat.

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