Study of a Collection of Hulled Wheat Species in the Conditions of the Central Region of the Non-Chernozem Zone

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Abstract. Hulled wheat species represent a unique reservoir of genetic diversity for modern breeding, offering resilience to biotic and abiotic stresses. However, their adaptability and productivity in the Central Region of the Non-Chernozem Zone of Russia remain insufficiently studied. The aim of this work was to evaluate a collection of 9 accessions of hulled spring wheat (*Triticum ispahanicum* and *Triticum dicoccum*) under the agroclimatic conditions of the CRNZ in 2021. Field and laboratory methods were employed to assess morphological traits, phenology, and yield structure elements. The results revealed substantial inter-accession diversity among the accessions. Accessions No. 15, 17, 19, and 11 were identified as the most promising, combining optimal plant height, high productive tillering, and maximum grain mass per plant. The identified accessions are recommended as donors for breeding programs targeting organic and low-input systems in the Non-Chernozem Zone. The novelty of the study lies in a comprehensive assessment of these hulled wheat species in the specific soil and climatic conditions of the CRNZ, identifying valuable donor traits for regional breeding programs aimed at enhancing yield stability and stress tolerance.

1 Introduction

Hulled wheat species, including spelt (Triticum dicoccum) and Isfahan wheat (Triticum ispahanicum), have attracted increasing attention from researchers and breeders worldwide. Their value lies in a combination of high nutritional quality, resistance to fungal diseases, adaptability to marginal soils, and lower requirements for agrochemical inputs [1, 2]. In the context of climate change and the need to reduce the environmental footprint of agriculture, hulled wheats are considered promising alternatives or complements to common wheat (*Triticum aestivum*) in organic and low-input farming systems.

Despite their potential, the cultivation and study of these species in the Russian Federation, particularly in the Non-Chernozem Zone with its specific soil and climatic challenges, are limited [4]. The Central Region of the Non-Chernozem Zone is characterized by soddy-podzolic soils, a relatively short growing season, uneven

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precipitation, and frequent temperature fluctuations. These conditions pose challenges for many modern wheat varieties, but may be suitable for more resilient hulled wheats.

The central problem is the lack of identified and adapted genetic material suitable for effective integration into breeding programs aimed at developing resilient and productive cultivars for this region. Previous studies have primarily focused on more common wheat species or were conducted in other agro-climatic zones [5-7]. There is a clear knowledge gap regarding the performance of diverse Triticum dicoccum and Triticum ispahanicum accessions under the specific constraints of the Central Region of the Non-Chernozem Zone.

Therefore, the aim of this work was to evaluate and describe a collection of hulled wheat accessions of different ploidy levels based on morphological traits and their adaptability to the conditions of the Central Region of the Non-Chernozem Zone, thereby identifying promising sources for breeding.

2 Materials and Methods

2.1 Materials

The research material consisted of 9 accessions of hulled spring wheat species provided by the Institute of General Genetics (Moscow*)* (Table 1). The accessions differed in ploidy, degree of domestication, and a complex of economically valuable traits.

Table 1. Accessions of hulled spring wheat species included in the study in 2021.

No	Species	Variety	Catalog Number / Origin
2	*Triticum ispahanicum*	var. ispahanicum	TRI 7260, Soviet Union
3	*Triticum ispahanicum*	var. ispahanorufum	TRI 19149, Iran
5	*Triticum dicoccum*	var. dicoccum	k-12946, Switzerland
7	*Triticum dicoccum*	var. rufum	k-20579, Spain
11	*Triticum dicoccum*	var. volgense	k-40032, Yugoslavia
14	*Triticum dicoccum*	var. unimiegei	k-15840, Morocco
15	*Triticum dicoccum*	var. arras	k-25459, Yemen
17	*Triticum dicoccum*	var. haussknechtianum	k-45543, Iran
19	*Triticum dicoccum*	var. serbicum	k-7356, Russia

Table 1 shows that the collection includes two species of hulled wheat: Triticum ispahanicum (accessions No. 2 and 3) and Triticum dicoccum (accessions No. 5, 7, 11, 14, 15, 17, 19). The geographic origin of the accessions spans Europe, Asia, and North Africa, which provides broad genetic diversity for adaptation studies. This diversity is essential for identifying donors suitable for the specific conditions of the Central Region of the Non-Chernozem Zone.

2.2 Methodology

The field experiment was conducted in 2021 at the Field Experimental Station of the Russian State Agrarian University - Moscow Timiryazev Agricultural Academy. The preceding crop was white mustard (Sinapis alba). Agronomic practices followed zonal recommendations for spring wheat cultivation. Sowing was carried out on May 12 with a seeding rate of 30 seeds per linear meter. The plot design consisted of single rows of 1 m length for each accession, without replication. Row spacing was 15 cm. No mineral fertilizers or plant protection products were applied to avoid masking the intrinsic adaptive potential of the accessions.

During the growing season, phenological observations were recorded: emergence date (50% of seedlings emerged), heading date (50% of spikes fully emerged), and waxy ripeness date (50% of spikes reached waxy ripeness). Plant height (from soil surface to spike tip, excluding awns) was measured at full maturity on 10 representative plants per accession.

At full maturity, plants were manually harvested from each 1 m row. The following yield structure components were measured in laboratory conditions: stem height (cm), productive tillering (number of productive stems per plant), total spikelets per spike (no.), developed spikelets per spike (no., excluding underdeveloped basal spikelets), rachis length (cm), spike density (spikelets per 10 cm of rachis, calculated), grains per spike (no.), grain mass per plant (g), and 1000 grain weight (g). For each accession, at least 10 randomly selected plants were analyzed. Data are presented as mean ± standard error (M ± m).

2.3 Conditions

The weather conditions during the growing season (May–August 2021) were characterized by temperatures close to the long-term average and uneven precipitation distribution with a deficit in July, which accelerated ripening (Figure 1). This drought provided a natural stress environment that helped evaluate drought tolerance among accessions.

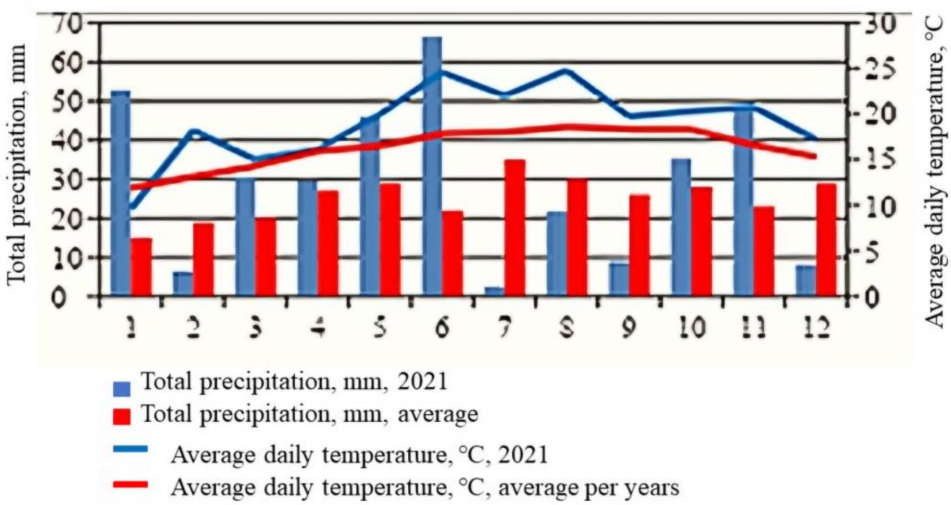

Figure 1. Meteorological conditions in 2021 (mean daily temperature, °C, and total monthly precipitation, mm).

3 Results

3.1 Analysis of Phenological Observation Results

The studied accessions differed in the dates of phenological phases; the data are presented in Table 2. All accessions showed uniform emergence on May 21. Heading dates varied from June 23 (accession 14) to July 1 (accessions 7, 19), indicating differences in earliness. Plant height varied from 60 to 80 cm (Table 2). Most accessions (3, 5, 7, 11, 15, 17, 19) corresponded to the optimal height range for the Central Region of the Non-Chernozem Zone (70-100 cm), while accession 2 (60 cm) was below the optimum.

Table 2. Plant height and dates of main phenological phases in wheat.

No	Emergence	Heading	Waxy Ripeness	Plant Height, cm
2	May 21	Jun 28	Jul 22	60
3	May 21	Jun 28	Jul 26	78
5	May 21	Jun 28	Jul 26	80
7	May 21	Jul 1	Jul 26	71
11	May 21	Jun 28	Jul 22	74
14	May 21	Jun 23	Jul 22	64
15	May 21	Jun 28	Jul 22	79
17	May 21	Jun 28	Jul 22	76
19	May 21	Jul 1	Jul 26	77

According to Table 2, all accessions emerged simultaneously, indicating uniform seed quality and favorable early-season conditions. The earliest heading was observed in accession No. 14 (June 23), while accessions No. 7 and No. 19 headed later (July 1). Waxy ripeness occurred between July 22 and July 26. Plant height varied from 60 cm (No. 2) to 80 cm (No. 5), with most accessions falling within the optimal range for the Central Region of the Non-Chernozem Zone (70–100 cm). Accession No. 2 was shorter than the optimum, which may limit biomass but could be beneficial for lodging resistance under high wind or rain conditions.

3.2 Yield Structure Elements

A detailed characterization of the yield potential was carried out by analyzing the yield structure (Table 3).

Table 3. Morphometric indicators of the yield structure of the studied wheat accessions.

No	Stem Height, cm	Productive Tillering, no./plant	Total Spikelets per Spike, no.	Developed Spikelets per Spike, no.	Rachis Length, cm	Spike Density, no./10 cm
2	55.84 ± 1.43	2.86 ± 0.24	12.93 ± 0.25	10.52 ± 0.38	7.52 ± 0.39	16.45 ± 0.35
3	77.81 ± 2.98	3.00 ± 0.26	18.63 ± 0.30	15.26 ± 0.43	7.15 ± 0.17	24.88 ± 0.49
5	80.03 ± 2.22	2.26 ± 0.16	18.14 ± 0.58	13.86 ± 0.67	4.63 ± 0.19	37.91 ± 1.07
7	71.24 ± 2.11	1.38 ± 0.19	16.57 ± 0.98	11.90 ± 0.92	7.51 ± 0.42	19.84 ± 1.16
11	73.93 ± 1.76	3.95 ± 0.37	14.98 ± 0.31	10.08 ± 0.72	5.53 ± 0.14	25.53 ± 0.42
14	64.53 ± 1.47	2.50 ± 0.29	18.60 ± 0.37	14.88 ± 0.51	4.64 ± 0.11	38.91 ± 1.34
15	79.76 ± 1.56	4.70 ± 0.50	18.87 ± 0.31	15.96 ± 0.57	4.60 ± 0.09	39.23 ± 1.06
17	76.73 ± 1.64	3.53 ± 0.44	13.27 ± 0.20	10.17 ± 0.47	4.95 ± 0.14	25.22 ± 0.69
19	77.18 ± 1.96	2.29 ± 0.21	19.68 ± 0.62	15.68 ± 1.00	7.92 ± 0.30	24.05 ± 0.58

Note: Data are presented as M ± m, where M is the mean value, m is the standard error.

The highest productive tillering was observed in accessions No. 15 (4.70) and No. 11 (3.95). The highest total number of spikelets per spike was recorded in accession No. 19 (19.68), and the highest number of developed spikelets was in No. 15 (15.96). Based on spike density (a calculated trait), accessions No. 5, 14, and 15 were classified as dense (more than 29 spikelets/10 cm), while accessions No. 2 and 7 had a loose spike.

Table 3 reveals substantial variation in yield structure components. The highest productive tillering was observed in accessions No. 15 (4.70) and No. 11 (3.95), indicating strong compensatory ability. The maximum total spikelets per spike were recorded in accession No. 19 (19.68), while the highest number of developed spikelets was found in No. 15 (15.96). Based on spike density, accessions No. 5, 14, and 15 were classified as dense-spiked (>29 spikelets/10 cm), whereas No. 2 and No. 7 had loose spikes. These differences suggest that different accessions employ distinct strategies for yield formation: some rely on high tillering, others on larger spike size.

3.3 Plant Productivity

Key productivity indicators are presented in Table 4.

Table 4. Productivity indicators of the studied wheat accessions.

No	Grains per Spike, no.	Grain Mass per Plant, g	1000 Grain Weight, g
2	12.76 ± 0.89	0.99 ± 0.11	34.22 ± 0.81
3	21.15 ± 1.70	1.55 ± 0.21	50.57 ± 18.37
5	23.26 ± 1.66	1.25 ± 0.13	26.77 ± 0.95
7	7.67 ± 1.60	0.47 ± 0.14	26.02 ± 4.66
11	16.58 ± 1.30	1.74 ± 0.27	27.12 ± 1.42
14	16.65 ± 0.81	1.35 ± 0.21	35.09 ± 1.15
15	15.87 ± 1.60	2.34 ± 0.33	34.69 ± 1.85
17	15.67 ± 1.23	1.76 ± 0.30	34.21 ± 1.28
19	23.92 ± 1.78	1.57 ± 0.18	32.54 ± 1.40

As shown in Table 4, the highest number of grains per spike was recorded in accessions No. 19 (23.92) and No. 5 (23.26). However, the highest grain mass per plant was achieved by accession No. 15 (2.34 g), followed by No. 17 (1.76 g) and No. 11 (1.74 g). This indicates that high grain number per spike does not always translate into high total yield per plant if tillering is low. The maximum 1000 grain weight was observed in accession No. 3 (50.57 g), but the large standard error suggests high heterogeneity. More stable TGW values were found in accessions No. 14, 15, 17, and 2 (34–35 g).

4 Discussion

The results of this study demonstrate the significant phenotypic diversity present in the collection of hulled wheat accessions when grown in the specific conditions of The Central Region of the Non-Chernozem Zone. This variability provides a valuable basis for selection.

Our findings on plant height are consistent with other studies conducted in similar climates. For instance, Popova (2017) also reported optimal plant heights for spelt in the range of 70-100 cm for stable standing [3]. Accession No. 2, which was below this optimum, confirms the data of Rogozina and Shaikova (2020) on the existence of shorter genotypes among hulled wheats, which may be less competitive in terms of biomass accumulation but potentially more resistant to lodging[4].

The variation in the duration of inter-phase periods, particularly the heading date, aligns with the findings of Rigin et al. (1994) on the genetic determinism of the rate of development in wheats[8]. The early heading of accession No. 14 could be an adaptive advantage in years with early drought, a phenomenon noted by Zelenev et al. (2019) for the Lower Volga region [7].

The high productive tillering and grain mass per plant observed in accessions No. 15 and 11 are key traits for yield formation. These results can be compared with the data of Kuzmich et al. (2021), who also identified spelt accessions with high productive tillering capacity in the Tula region [5]. However, unlike their findings, our study recorded a slightly lower 1000 grain weight for the most productive accessions, which may be a specific response to the soil and climatic conditions of the Central Region of the Non-Chernozem Zone or the genetic features of the studied varieties.

The identified accessions with dense spikes (No. 5, 14, 15) are of particular interest. As noted by later by Surin & Popova (2016), dense spikes can be associated with both higher yield potential and increased resistance to certain diseases and pests, although this requires further specialized study [9].

The high standard error for the 1000 grain weight of accession No. 3 indicates significant variability within this sample, which is consistent with the high heterogeneity often characteristic of local populations and landraces of hulled wheat, as discussed by Pounds (1998)[10].

Overall, the set of valuable agronomic traits (optimal height, high tillering, dense spike, high grain mass) identified in accessions No. 15, 17, 19, and 11 confirms their potential as sources of adaptability and productivity for breeding in the Central Region of the Non-Chernozem Zone, as previously suggested for other regions by Temirbekova et al. and Sidorenko et al. (2017)[11].

Limiting factors of the CRNZ and their implications for hulled wheat selection. The Non-Chernozem Zone is characterized by a complex of limiting factors: low fertility of soddy-podzolic soils, a deficit of available phosphorus and potassium, a short frost-free period, and high probability of summer droughts. These factors make it difficult to realize the yield potential of intensive common wheat varieties. In contrast, hulled wheats, due to their evolutionary origin, often possess a more efficient root system and a lower requirement for mineral nutrition. Accession No. 15 (Yemen), despite its southern origin, demonstrated excellent tillering and grain mass under CRNZ conditions, indicating a wide adaptive plasticity. Accession No. 17 (Iran) showed stable TGW and good tillering, making it a candidate for further testing in soil with low phosphorus availability. The Russian-origin accession No. 19 exhibited the highest grains per spike, which may compensate for moderate tillering under optimal nutrition.

Practical recommendations for breeders**.** Based on the results obtained, the following practical steps are proposed: Include accessions No. 15, 17, 19, and 11 in hybridization programs to transfer high tillering and grain mass traits into adapted spelt or common wheat backgrounds. Evaluate these accessions under organic farming conditions (no mineral fertilizers) to confirm their low-input adaptability. Conduct a detailed analysis of grain quality (protein, gluten, micronutrients) for the most stable accessions.Perform multi-location trials across the CRNZ (Moscow, Tula, Vladimir, Ryazan regions) to assess genotype × environment interaction.

5 Conclusion

The conducted research revealed significant diversity among the studied hulled wheat accessions in terms of morphological traits and yield structure elements.

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Most accessions corresponded to the optimal plant height for the Central Region of the Non-Chernozem Zone (70-100 cm) and showed high field resistance.

The highest yield potential, determined by a complex of traits (productive tillering, number and mass of grains per plant), was identified in accessions No. 15 (T. dicoccum var. arras), No. 17 (T. dicoccum var. haussknechtianum), No. 19 (T. dicoccum var. serbicum), and No. 11 (T. dicoccum var. volgense).

Promising accessions are recommended for further in-depth study and use in breeding programs as sources of valuable agronomic traits. Special attention should be paid to accessions No. 15 and No. 17 for low-input and organic farming systems in the Non-Chernozem Zone.

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