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PHENOTYPIC VARIATION OF WINTER WHEAT COLLECTION FROM CENTRAL ASIA HARVESTED IN KAZAKHSTAN

In this work, the ecological testing of 139 accessions of the winter wheat collection from Central Asia was conducted on the field plots of the Kazakh Research Institute of Agriculture and Plant Industry (Almaty region, South-east Kazakhstan) and Krasnovodopad Breeding Station (Turkestan region, South Kazakhstan) during 2020-2021 and 2021-2022 growing seasons. The collection was analyzed using 12 traits: heading date, seed maturation date, vegetation period, plant height, peduncle length, spike length, number of kernels per spike (NKS), number of productive spikes, weight kernel per plant, weight kernel per spike, thousand kernel weight (TKW) and yield per square meter (YM2). The Pearson correlation index showed positive correlations between yield component traits in the two studied regions. The average YM2 value of 107 and 134 accessions exceeded the local check cultivars in Almaty (Zhetisu) and Turkestan (Pamyat 47) regions, respectively. Seven cultivars (Karaspan, Mars 1, Pamyat, Dank, Zhamin, KYIAL, and Talimi) were revealed to be highly productive for three traits (NKS, TKW, and YM2) in two regions. The analysis of variance showed that genotype × environment interaction affected the studied traits of the winter wheat collection from Central Asia under Kazakhstan's conditions. The results of this research will be used for further studies related to the adaptation and productivity of winter wheat in the breeding program for the selection of best candidate lines and genome-wide association study for yield and yield-related traits in winter wheat.

Key words: winter wheat, genotype × environment interaction, yield components.

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Қазақстан жағдайында өсірілген ортаазиялық күздік бидай коллекциясының фенотиптік өзгергіштігі

Бұл зерттеу жұмысында 2020-2021 және 2021-2022 жылдардағы вегетациялық кезеңдер ішінде Қазақ егіншілік және өсімдік шаруашылығы ғылыми-зерттеу институтының (Алматы облысы, оңтүстік-шығыс) және Красноводопад ауыл шаруашылығы тәжірибе станциясының (Түркістан облысы, оңтүстік) тәжірибелік алқаптарында өсірілген Орта Азиялық күздік бидай коллекциясының 139 үлгісіне экологиялық тестілеу жүргізілді. Коллекция 12 белгі бойынша талданды: масақтану уақыты, пісу уақыты, вегетациялық кезең, өсімдіктің биіктігі, жоғарғы буын аралығының ұзындығы, масақтың ұзындығы, масақтағы дәндердің саны (МДС), өнімді масақтардың саны, өсімдіктен алынған дәндердің массасы, масақтағы дән массасы, 1000 дәннің массасы (МДМ) және 1 м² өнімділігі (М2Ө). Пирсон бойынша корреляция индексі зерттелетін екі аймақта өнімділікке байланысты белгілер арасындағы оң байланысты көрсетті. Коллекция сорттарының ішінде М2Ө орташа мәндер бойынша Алматы облысындағы сорт-стандарт (Жетісу) 107 үлгісі және Түркістан облыстарында Память 47 сортының 134 үлгісі асып түсті. Жеті сорт (Karaspan, Mars 1, Pamyat, Dank, Zhamin, KYIAL және Talimi) екі аймақта өнімділікке байланысты үш белгі (МДС, МДМ, М2Ө) бойынша жоғары көрсеткіштерді көрсетті. Орталық Азиядан келген күздік бидай коллекциясының дисперсиялық талдауы генотип × орта өзара қатынасының Қазақстан жағдайында зерттелген белгілерге әсерін көрсетті. Алынған нәтижелер

күздік бидайдың бейімделгіштігі мен өнімділігіне қатысты қосымша зерттеулер үшін, ең жақсы үміткер-линияларды таңдау үшін селекциялық бағдарламада және өнімділікке байланысты белгілерді толық геномдық ассоциативті талдау үшін пайдаланылуы мүмкін.
Түйін сөздер: күздік жұмсақ бидай, генотип × орта қатынасы, өнімділік компоненттері.

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Фенотипическая изменчивость коллекции озимой пшеницы из Средней Азии, выращенной в условиях Казахстана

В данной работе проведено экологическое тестирование 139 образцов коллекции озимой пшеницы из Средней Азии, выращенных на опытных полях Казахского научно-исследовательского института земледелия и растениеводства (Алматинская область, юго-восток) и Красноводопадской сельскохозяйственной опытной станции (Туркестанская область, юг) в течение вегетационных периодов 2020-2021 и 2021-2022 годов. Коллекция была проанализирована по 12 признакам: время колошения, время созревания, вегетационный период, высота растения, длина верхнего междоузлия, длина колоса, количество зерен в колосе (КЗК), количество продуктивных колосьев, масса зерен с растения, масса зерна с колоса, масса 1000 зерен (МТЗ) и урожайность с 1 м^2 (УМ2). Индекс корреляции по Пирсону показал положительную связь между признаками, связанными с урожайностью, в двух исследуемых регионах. Среди сортов коллекции 107 образцов превзошли по средним значениям УМ2 сорт-стандарт в Алматинской (Жетысу) и 134 образца сорт Память 47 в Туркестанской областях. Семь сортов (Karaspan, Mars 1, Pamyat, Dank, Zhamin, KYIAL и Talimi) продемонстрировали высокие показатели по трем признакам (КЗК, МТЗ, УМ2), связанным с урожайностью, в двух регионах. Дисперсионный анализ коллекции озимой пшеницы из Средней Азии показал влияние взаимодействия генотип × среда на изученные признаки в условиях Казахстана. Полученные результаты могут быть использованы для дальнейших исследований, связанных с адаптацией и продуктивностью озимой пшеницы, в программе селекции для отбора лучших линий-кандидатов, а также для полногеномного ассоциативного анализа признаков, связанных с урожайностью.
Ключевые слова: озимая мягкая пшеница, взаимодействие генотип × среда, компоненты урожая.

Introduction

The Central Asia region includes five former Soviet Union Republics, including Kazakhstan, Uzbekistan, Turkmenistan, Kyrgyzstan, and Tajikistan, and they collectively grow wheat in an area of over 15 million ha [1]. Kazakhstan is one of the top 10 bread wheat producers and exporters in the world marketplace [2,3]. According to the Foreign Agricultural Service of the US Department of Agriculture (USDA), wheat production in Kazakhstan in 2022-2023 is expected to reach 16.0 million tons [4]. In Uzbekistan, estimated production will increase to 6.6 million tonnes in 2022-2023. Wheat production in 2022-2023 in Kyrgyzstan and Tajikistan is expected to reach 593 thousand tons and 820 thousand tons, respectively [4]. By the year 2050, the wheat yield should increase by 60% to provide the world's population with sufficient protein [5].

Kazakhstan is traditionally a large area of production of high-quality grain of wheat. In Kazakhstan, wheat is mainly grown in the northern part of the country, with a major focus on the spring type of habitat. The main lands under winter wheat are located in the south and south-east regions of Kazakhstan [6]. The yield of winter crops is 25-30% higher than that of spring type because they productively use autumn and spring moisture. Early ripening of winter wheat makes it possible to carry out its harvesting in a warm, dry time, which positively affects the grain's technological qualities [7,8]. The development of new cultivars is the most important factor in increasing yields and improving the quality of agricultural products. It is important to study the agronomic traits to develop high-yielding and high-quality cultivars. Agronomic traits such as heading date, plant height, number of productive tillers, number of kernels per spike, spike length, thousand-kernel weight, harvest index, and kernel weight per spike are important factors affecting wheat yield [9,10].

The genotype and the environment dramatically affect the grain yield and its components. Genotypes are stable if they show only slight deviations in the genotype performance across various growing conditions. It has long been recognized that wheat productivity and grain quality vary considerably because of the genotype (G), environment (E), and their interaction (G × E), but there is no consensus about which of these factors is more important [11]. To increase the yield, the study of the effects of yield components provides the basis for its successful breeding program. Hence, yield increase can be improved more effectively because of the performance of yield components. Multiple genes usually control agronomic traits, and a large number of quantitative trait loci (QTL) for them have been reported on A, B, and D genomes in bread wheat [12,13,14].

There is a necessity to pay special attention to the breeding and genetic research of common wheat using the best resources from other countries and regions of the world in a breeding program, as well as to apply modern methods of molecular genetics, including new genomic technologies [14,15]. One of these methods is genome-wide association study (GWAS), which relies on genotypic and phenotypic variation assessment of quantitative traits in large and diverse collections [16,17,18]. As a result of an international workshop between participants of the countries of Central Asia and the UK, conducted by scientists from the UK and the Institute of Plant Biology and Biotechnology, the Central Asian Wheat Breeding Initiative (CAWBIN) was developed, where a special place was given to the breeding of winter wheat [19]. One of the major parts of the CAWBIN collection study is the evaluation of the agronomic traits performance of a winter wheat collection in the conditions of south and south-east Kazakhstan, the main areas for winter wheat growth in the country. The results may help to assess the CAWBIN collection for the selection of best candidate lines for further breeding purposes of winter wheat in these regions and play a vital role in the identification of new QTLs for agronomic traits with the following application of marker-trait association approach in breeding schemes.

Materials and мethods

Plant materials. The subject of the study is a winter wheat collection consisting of 139 accessions from Central Asian countries – Kazakhstan (KAZ, 42), Kyrgyzstan (KGZ, 52), Uzbekistan (UZB, 38), and Tajikistan (TJK, 11).

Assessment of the field data. All genotypes were tested in two regions of Kazakhstan – on the field plots of the Kazakh Research Institute of Agriculture and Plant Industry (KRIAPI, Almaty region, Southeast Kazakhstan) and Krasnovodopad Breeding Station (KBS, Turkestan region, South Kazakhstan) during 2020-2021 and 2021-2022 growing seasons. The collection was analyzed using 12 traits: heading date (HD, days), seed maturation date (SMD, days), vegetation period (VP, days), plant height (PH, cm), peduncle length (PL, cm), spike length (SL, cm), number of kernels per spike (NKS, pcs), number of productive spikes (NPS, pcs), weight kernel per plants (WKP, g), weight kernel per spike (WKS, g), thousand kernel weight (TKW, g) and yield per square meter (YM2, g/m^2). Studied accessions were planted in a random design in double rows and two replications per genotype. The distances between rows were 15 cm [20]. The standard cultivars "Zhetisu" and "Pamyat 47" were planted as check cultivars for KRIAPI and KBS, respectively. The meteorological data recorded during the trials are shown in Table 1.

Table 1 – Location, environment, and weather data at two regions in Kazakhstan

Site / Region	Almaty region (South-east of Kazakhstan)		Turkestan region (South Kazakhstan)	
Latitude / Longitude	43°21′ / 76°53′		41° 46′ / 69°45′	
Soil type	Light chestnut (humus 2.0-2.5%)		Light serozem (humus 1.1%)	
Conditions	Rainfed		Rainfed	
Year	2020-2021	2021-2022	2020-2021	2021-2022
Annual rainfall, mm	464.7	568.9	279.4	421.0
Mean temperature, °C	10.5	12.2	17.5	11.7
Max temperature, °C	26.9	26.5	31.6	23.3
Min temperature, °C	1.8	1.1	2.7	4.0

Statistical data analysis. The descriptive statistical analyses of all traits and the yield graph were conducted using MS Excel. Pearson correlation analysis, analysis of variance (ANOVA), variability of key yield traits, and principal component analysis (PCA) have been calculated using the Rstudio software [21].

Results and discussion

Phenotypic variability in yield components of the winter wheat collection in two regions of Kazakhstan

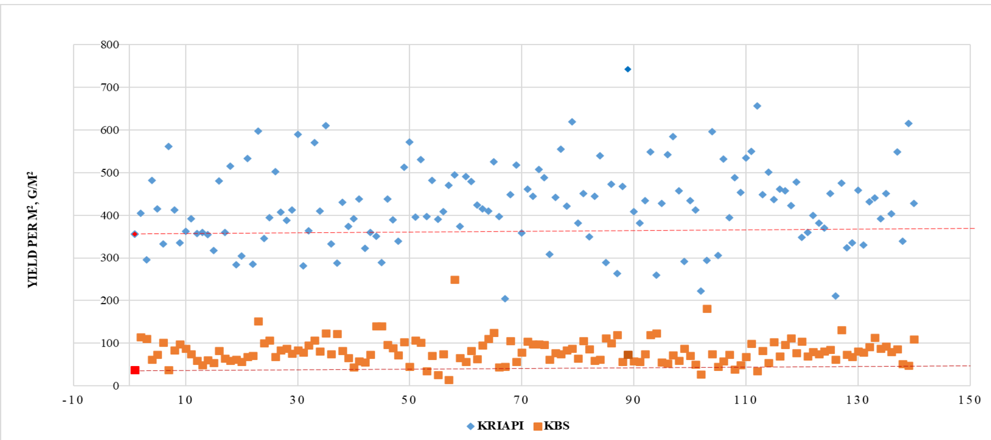
The phenotypic variability of studied traits was assessed in two regions over two years. The average PH was higher in samples grown in the Almaty region than in accessions harvested in the Turkestan region (Table 2). The means of the yield components (SL, NKS, WKS, TKW, and YM2) showed higher values at KRIAPI. However, the average NPS was higher at KBS in comparison to KRIAPI.

The average value of YM2 ranged from 80.9±2.55 g/m^2 (KBS) to 423.5±8.10 g/m^2 (KRIAPI). The analysis of the means for YM2 revealed that 107 and 134 accessions exceeded the local standard cultivar in south-east and south Kazakhstan, respectively (Figure 1).

In addition, the results of YM2 showed that the Central Asia winter wheat collection suits local environmental conditions (Figure 1). Seven cultivars (Karaspan, Mars 1, Pamyat, Dank, Zhamin, KYIAL, and Talimi) were revealed to be highly productive for three traits in two regions (Table 3). They can be successfully used for further breeding studies of winter wheat in Kazakhstan.

Table 2 – Average values of agronomic traits of winter wheat collection growing in two regions of Kazakhstan

Traits	Almaty region (KRIAPI)	Turkestan region (KBS)
Heading date (HD, days)	102.5±0.23	99.3±0.23
Seed maturation date (SMD, days)	35.8±0.18	36.7±0.24
Vegetation period (VP, days)	137.9±0.90	136.1±0.27
Plant height (PH, cm)	73.5±0.95	45.2±0.40
Peduncle length (PL, cm)	24.3±0.44	18.8±0.32
Spike length (SL, cm)	9.7±0.09	8.1±0.06
Number of productive spikes (NPS, pcs)	3.6±0.07	4.4±0.06
Number of kernels per spike (NKS, pcs)	46.7±0.42	39.90±0.40
Weight kernel per spike (WKS, g)	1.8±0.02	1.27±0.02
Weight kernel per plant (WKP, g)	7.9±0.11	5.1±0.12
Thousand kernel weight (TKW, g)	39.2±0.41	32.9±0.30
Yield per square meter (YM2, g/m^2)	423.5±8.10	80.9±2.55



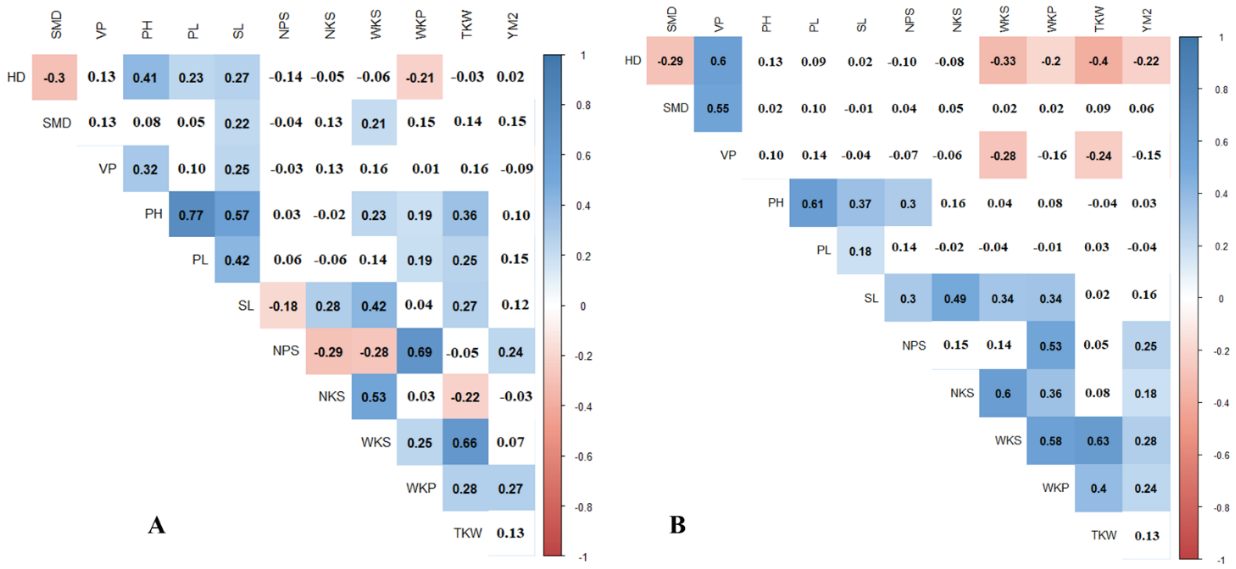
Note: check cultivar "Zhetisu" and "Pamyati 47" – red colour, accessions – blue and orange colour. Over the red line are samples with the highest YM2 values compared to the local check cultivar

Figure 1 – The range of averaged YM2 of winter wheat collection in two regions

Table 3 – The list of accessions of winter wheat collection showed the best average values for three yield components (NKS, TKW, and YM2) in two regions

Cultivars	Origin	KRIAPI			KBS		
		NKS, pcs	TKW, g	YM2, g/m^2	NKS, pcs	TKW, g	YM2, g/m^2
Karaspan	KAZ	51.3	45.5	359.1	41.8	31.0	64.3
Mars 1	UZB	54.4	43.3	479.4	37.3	35.4	82.1
Pamyat	UZB	51.9	43.0	525.3	47.3	35,7	124.4
Dank	KGZ	54.3	43.9	534.5	30.0	31.1	68.0
Zhamin	KGZ	51.6	47.1	549.6	37.8	34.7	99.8
KYIAL	KGZ	52.0	47.5	399.6	38.8	35.5	80.6
Talimi	KGZ	55.8	42.5	458.5	39.4	30.5	81.5
Local check cultivar		50.5	40.7	354.8	18.5	30.3	36.7

Pearson's correlation analysis of studied traits showed a negative correlation between HD with SMD and HD with WKP in both regions (Fig. 2). Also, it was revealed that SMD was favorable for higher yield components (WKS, WKP, and YM2) in KRIAPI. At the time, SMD was not a significant factor in the yield in KBS. The PH and PL positively correlated with yield components (SL, WKS, WKP, TKW) in KRIAPI. In addition, in KRIAPI, there was a predictable negative correlation between TKW and NKS. Expectedly, the PL was noted as highly significantly correlated with PH in both regions (Fig. 2). The correlation analysis at KBS showed the HD's negative influence on WKS, TKW, and YM2 (Fig. 2B) and a positive correlation between yield components (SL, NPS, NKS, WKS, WKP) (Fig. 2B).



Note: Correlations with $P < 0.05$ are highlighted in color. The color indicates positive (blue) or negative (red) correlation.

Figure 2 – Pearson's correlation index among means of 12 studied traits in winter wheat collection in two Kazakhstan regions in 2020-2022

The analysis of variance (ANOVA) for 12 traits showed a significant difference between three factors (genotype, region, year) for YM2 (6.35). In addition, a highly significant difference was observed for two factors (year and region) in all studied traits (Table 4). The ANOVA showed meaningful genotype-by-environments interaction (GEI) on studied traits of the winter wheat collection.

Table 4 – Analysis of variance of studies traits in the south-east of Kazakhstan.

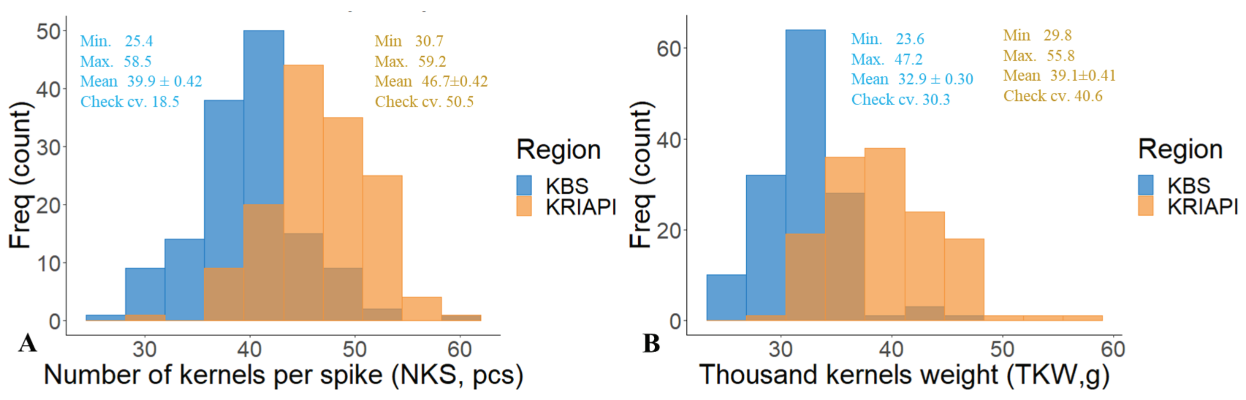
Factor	df	HD	SMD	PH	PL	SL	NPS
		F-value					
Genotype (G)	142	1.649 ***	0.602	4.090***	2.061***	0.673	1.124
Year (Y)	1	9735.907***	637.352***	563.079***	220.863***	5.220*	44.033 ***
Region (R)	1	143.862 ***	6.867**	2040.203***	178.558***	11.602***	84.263***
G:Y	141	2.010 ***	0.542	0.795	0.823	0.560	0.874
G:R	138	1.877***	0.362	2.971***	1.331*	0.316	1.061
Y:R	1	5499.367 ***	12.312***	1292.122***	786.465***	1.131	0.899
G:R:Y	132	0.758	0.400PH	1.088	0.819	0.296	0.812

Factor	df	NKS	WKS	WKP	TKW	YM2
		F-value				
Genotype (G)	155	0.727	1.199	0.639	2.850***	5.116***
Year (Y)	1	6.975**	129.654***	58.686 ***	282.944***	3487.223***
Region (R)	1	42.656***	200.414***	0.048	222.147***	9168.193***
G:Y	154	0.609	0.609	0.520	0.994	5.046***
G:R	150	0.784	0.849	0.546	1.372*	6.703***
Y:R	1	0.434	26.327***	7.821 **	64.386***	2454.963***
G:R:Y	144	0.585	0.669	0.464	0.723	6.353***

Note: P – values are provided with a significance level shown by the asterisks; * P < 0.05, ** P < 0.01, *** P < 0.001

Variability in yield components

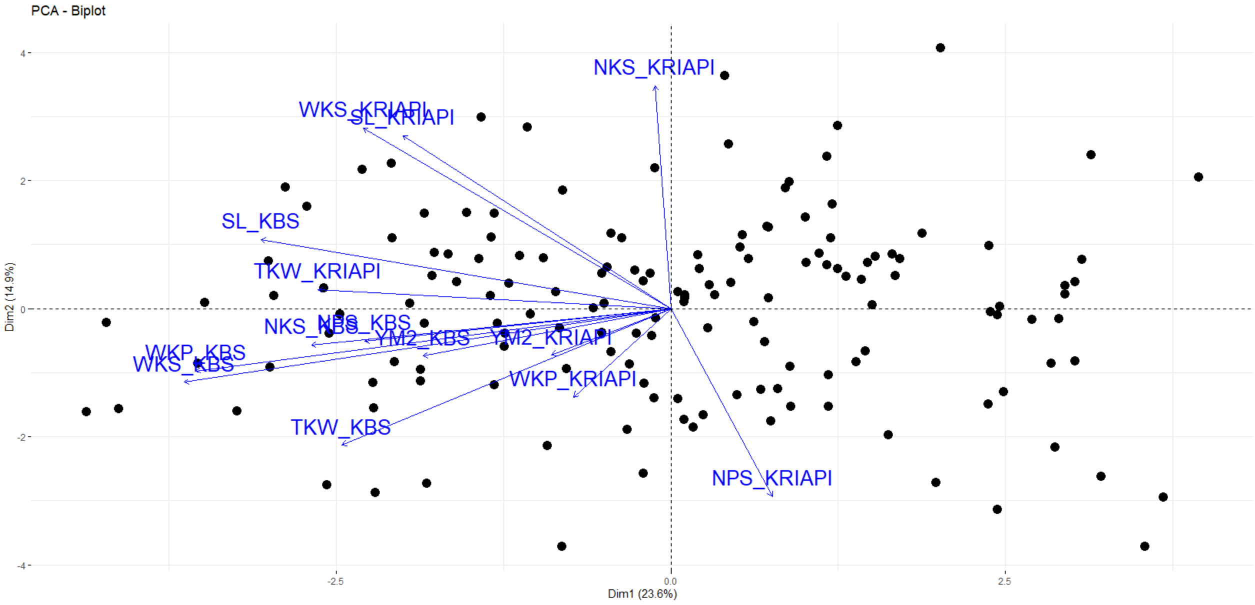
Yield is a complex trait that is associated with main components, such as the number of productive spikes, number of spikelets per spike, SL, NKS, kernel size, and TKW [22]. The correlation analysis showed that PH, SL, NKS, and TKW are the major yield components for the studied regions (Fig. 2), and the phenotypic variability of these four traits was marked by the wide range indicated in Table 2. The mean of NKS ranged from 39.9 pcs (KBS) to 46.7 pcs (KRIAPI). The NKS assessment showed that thirty-three samples of the collection exceeded the check cultivar " Zhetisu" in the Almaty region (Fig. 3A). The values of the TKW, another important yield trait, were varied from 32.9 g (KBS) to 39.1 g (KRIAPI) (Fig. 5B). The evaluation of TKW values suggested that the 50 and 101 accessions exceeded the check cultivar "Zhetisu " and "Pamyat' 47", respectively.



Note: A – number of kernels per spike, B – thousand kernels weight

Figure 3 – The binomial distributions of major yield-related traits of winter wheat collection in two regions.

The principal component analysis (PCA) for the yield components divided the accessions of winter wheat collection into two distinct principal components: PC1 and PC2, which explain 23.6 % and 14.9 % total variation, respectively. Also, there was a similar negative correlation between NKS and TKW at KRIAPI, with arrows pointing in different directions (Fig. 4). The same trend was noted using Pearson correlation analysis at KRIAPI (Fig. 2 A).



Note: accessions – point, directions of traits – blue color.

Figure 4 – Principal component analysis for the yield components in the winter wheat collection from Central Asia

The evaluation of yield components allowed the selection of accessions, which could play an important role in the future wheat breeding program in south and south-east Kazakhstan. In addition, the variation of the field data can be successfully used in further activities related to GWAS for grain yield and yield-related traits in winter wheat. The significant difference in soil and weather conditions of the two regions gave a variance in yield components between South-east and South Kazakhstan.

Conclusion

This study described the field assessments of the winter wheat collection from Central Asia consisting of 139 accessions. The collection was tested over the two years from 2020 to 2022 in the fields of the KRIAPI (south-east Kazakhstan) and KBS (south Kazakhstan). The field assessments showed that the collection is a potentially important genetic resource for winter wheat breeding projects, as it showed a wide range of variation in yield-related traits, including PH, SL, NKS, TKW, and YM2.

The average YM2 value of 107 and 134 accessions exceeded the check cultivars in Almaty (Zhetisu) and Turkestan (Pamyat 47) regions, respectively. The Pearson correlation index showed positive correlations between yield-related traits in the two studied regions. The ANOVA predicted a significant effect of environmental factors on the performance of winter wheat in the south and south-east of Kazakhstan. Obtained results will be used to select promising lines for winter wheat breeding projects in Kazakhstan and for further studies related to GWAS of yield and yield-related traits in bread wheat.

Conflict of interest

All authors are familiar with the article's text and declare that they have no conflict of interest.

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