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Dnipro State Agrarian and Economic University, Serhiy Yefremov st., 25, Dnipro, 49600, Ukraine.
Tel.: +38-095-188-97-61.
E-mail:
kovalovstas359@gmail.com

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Variability of yield and ear productivity traits of soft winter wheat in the Northern Subzone of the Ukrainian Steppe

S. R. Kovalov
Dnipro State Agrarian and Economic University, Dnipro, Ukraine

Abstract. This study was aimed at analyzing promising varieties of soft winter wheat for the selection of high-quality breeding material under the conditions of the Northern Subzone of the Ukrainian Steppe. The research has been conducted during 2022–2024 in the experimental field of the Scientific and Educational Center for Practical Training of the Dnipro State Agrarian and Economic University. The study material consisted of 12 varieties of soft winter wheat (Bohynia, Vezha, Dyvo, Ihrysta, Komertsiina, KSV 34, Podolianka, Peremoha, Palitra, Spivanka, Oleksiivka, and Yuzovska). The productivity parameters were determined along with the ecological plasticity and stability of the varieties and the duration of the vegetation period. The varieties were compared with the national standard, Podolianka. Therefore, the most productive varieties on average over the years of research in terms of the number of grains per spike and the number of spikelets per spike were Vezha, Palitra, Komertsiina, Spivanka, and Peremoha. In terms of grain weight per spike and spike weight, the varieties Spivanka, Yuzovska, KSV 34, and Bohynia were distinguished. Over the years, the varieties Spivanka, Oleksiivka, Dyvo, and Yuzovska exceeded the standard in thousand-grain weight, while the varieties Komertsiina and Peremoha showed lower weights. Regarding yield, the varieties Spivanka, Vezha, Yuzovska, and Palitra outperformed the standard. In terms of ecological plasticity, the most stable and adaptable varieties were Ihrysta, Peremoha, Komertsiina, Palitra, and Podolianka. By contrast, the most intensive and less stable varieties were Spivanka, Vezha, and Dyvo. The obtained data enabled the assessment of the stability of spike productivity elements and facilitated the identification of high-performing varieties for further use in breeding programs.

Keywords: *Triticum aestivum* L.; variety; vegetation period; variation of morphological parameters; adaptability; ecological plasticity; stability.

Introduction

Soft winter wheat (*Triticum aestivum* L.) is the main and most widespread cereal crop in the world, covering thousands of kilometers across Europe, Asia, and North America, with a total cultivation area exceeding 220 million hectares. It has an average grain yield of 5.5–6.0 t/ha and serves as the most important grain-based food product for humanity, providing over 20% of the human dietary needs for calories, proteins, B-group vitamins, and essential minerals (Hongjie et al., 2019; Dong et al., 2020; Bentley, 2022; Hera-symchuk et al., 2022). The variety is one of the key factors determining the efficiency of modern agriculture. The contribution of the variety to grain yield formation is estimated at 30 to 70%. To date, the most cost-effective and efficient method for increasing the overall wheat yield remains the development and implementation of new high-yielding, plastic, and disease-resistant varieties (Murashko et al., 2021).

Climate is the most important factor in realizing yield potential. Considering the aggressive changes in climate and biotic factors, the continuous search for and analysis of varieties as source material for breeding (Arora, 2019; Lee et al., 2024; Soukat et al., 2024; Zhang et al., 2024) is essential for addressing the challenges of increasing grain yield and quality, where the adaptability of a variety to different environmental conditions plays a key role (Protsyk & Beze, 2022). Due to its wide adaptability, soft winter wheat is cultivated across a broad range of ecological conditions. However, the insufficient plasticity and stability of varieties do not allow the full realization of genotype productivity potential under uncontrolled environmental conditions (Demydov et al., 2019; Dolgopolova et al., 2024).

To address this, the modern breeding process includes a strategy for developing new highly adaptable varieties with an agro-ecological focus, combining high genetic potential for grain productivity and quality with an optimal response to weather conditions (Harkness et al., 2020; Razaei et al., 2024). It also aims to create adaptive varieties with fundamentally new characteristics capable of ensuring high and stable yields under varying environmental conditions. When selecting initial material, priority should be given to traits with the least variation (Dawson et al., 2011). Studies by various authors have shown that quantitative traits such as thousand-grain weight, grain weight per spike, number of spikelets per spike, and number of grains per spike are genotype-dependent and exhibit significant variation. Therefore, success in practical breeding depends on the proper evaluation and diversity of the genetic resources used. In particular, the thousand-grain weight and the number of spikelets per spike are less variable and are therefore the most effective indicators for selection in the early stages of the breeding process (Rangare et al., 2010; Tester et al., 2010; Bulavka et al., 2018; Bazalii et al., 2018). The complexity of breeding is associated with the polygenic nature of economically valuable traits and their varying levels of interaction with abiotic factors (Bondareva et al., 2021).

The objective of this study was identifying potentially valuable soft winter wheat varieties for breeding based on the level of expression of quantitative morphometric and economically significant traits. Therefore, studying the variability and variation of spike productivity and yield traits under the vegetative growing conditions of the Northern Subzone of the Steppe of Ukraine is a relevant task for further breeding work.

Materials and methods

The experiments have been conducted at the Educational and Research Center of the Dnipro State Agrarian and Economic University (48°50’ N, 35°25’ E) in the crop rotation fields of the Department of Breeding and Seed Production, located on the left bank of the Dnipro River and near the Samara River. The soil cover of the plots consists of regular low-humus, medium-depth chernozems with a full profile, dominated by regular low-humus full-profile chernozems (about 70%) and slightly eroded soils (about 25%). Most of the full-profile chernozems (68%) contain 3.0 to 3.5% humus in the 0–30 cm layer. The arable soil layer contains 0.18–0.23% total nitrogen, 100–150 mg/kg available phosphorus (P_2O_5), and 200–300 mg/kg exchangeable potassium (K_2O).

The reaction of the soil solution of the humus horizon is close to neutral (pH 6.75–7.29). Absorbed alkalis were mainly represented by calcium and magnesium. Primary and pre-sowing tillage, as well as sowing, were carried out using standard practices for the Steppe zone of Ukraine with a SN-16 (Mounted Seeder-16) seeder. The seeding rate was 5 million seeds per hectare, and the preceding crops were black fallow and peas. The plot size was 10 m², with three replicates in the experiment arranged in a systematic sequence.

The climate in the area is moderately continental. Summers are hot and dry, with frequent thunderstorms and strong southeastern and eastern winds that cause droughts. Winters are mild and have little snow, with frequent thaws and ice formation. The average January temperature ranges from –4.5 °C in the southwest to –6.5 °C in the southeast, while the average July temperature is +22.5 °C and +21.5 °C, respectively. The frost-free period ranges 187 days in the north to 228 days in the south. The period with temperatures above +10 °C spans 178 days. Annual precipitation is 450–490 mm in the north and 400–430 mm in the south, with the majority falling during the warm season. Snow cover (10–15 cm) forms every year (except in the extreme southern part of the right bank), establishing in December and melting in early March. Adverse climatic phenomena include thaws, frosts with strong winds, dry winds, and dust storms. Dnipropetrovsk Oblast is located within an arid, very warm agroclimatic zone. The most significant factor limiting high and stable grain yields in this zone is the lack of productive moisture reserves in the soil.

The weather conditions during the research years varied significantly. In 2021–2022, the average daily temperature in autumn was within the norm, as well as in winter, with the exception of February, where the average daily temperature was 1.4 °C, against the norm of –2.8 °C. In spring and summer, the average monthly temperatures were also within the norm, except for June and August, where temperatures exceeded the norm by 1.7–2.5 °C. Throughout the year, precipitation was below normal, with the exception of December, April, and August, where precipitation exceeded the norm by 0.8–20 mm. In 2022–2023, the weather conditions were marked by a warm autumn-winter period, with average daily temperatures exceeding the norm by 1.0–3.8 °C, particularly in December, where the temperature was 8.3 °C above the norm. This period was also noted with considerable moisture accumulation, with monthly precipitation exceeding the norm by 1–14 mm. In the spring-summer period, the average daily temperatures were 0.3–2.5 °C above the norm, with sufficient moisture exceeding the norm by 1–15 mm. Notably, there was an exceptionally high amount of torrential rainfall in the first and third decades of June, totaling 30.3 mm and 24.3 mm, compared with the norm of 15 and 19 mm, respectively. The 2023–2024 growing season was characterized by a very warm autumn-winter period, with average daily temperatures consistently exceeding the norm by 2.5–5.5 °C and moisture accumulation within the norm. Following the spring onset of vegetation, frosts of –0 to –2 °C were observed in some areas during the first and second decades of May. Subsequently, extremely hot and dry weather followed, with the average daily temperatures exceeding the norm by 2.5–5.2 °C. The maximum temperatures were recorded in June and July, reaching 22.9–26.8 °C on average, with the hottest days reaching 32–37 °C. This period was characterized by consistently insufficient moisture, except for the first decade of June, when precipitation exceeded the norm, measuring 34 mm compared with the normal amount of 19 mm. Thus, the weather conditions in 2022–2023 can be characterized as favorable, except for the heavy rains in June, while 2024 was unfavorable due to frosts in May, high temperatures, and drought during the spring-summer period.

The initial material in the study included 12 varieties of soft winter wheat of Ukrainian selection from institutions such as the Donetsk State Agricultural Research Station (Dyvo, Vezha, Peremoha, Yuzovska, Ihrysta, Bohynia, Oleksiivka), the Institute of Plant Physiology and Genetics of the National Academy of Sciences of Ukraine (Podolianka), the Dnipro State Agrarian and Economic University (Spivanka, Komertsiina, KSV 34), and the Selection and Genetics Institute (Palitra). The varieties belonged to the following subspecies: Lutescens Al. – Podolianka, KSV 34; Erythrospermum Körn. – Dyvo, Veza, Peremoha, Yuzovska, Ihrysta, Bohynia, Oleksiivka, Spivanka, Komertsiina, and Palitra. During the 2022–2024 vegetation periods, the morpho-biological characteristics of the varieties were determined using specialized research methods: field, structural analysis, and statistical methods. The field experiments were conducted according to the generally accepted methodology (*Methodology for Conducting Qualification Expertise of Plant Varieties for Suitability for Distribution in Ukraine*, 2016). The following observations and studies have been carried out in accordance with the methodological recommendations: the vegetation period (from mass germination to full grain maturity), analysis of productivity structure (number of grains per spike, spike length, thousand-grain weight, grain weight per spike, spike weight, number of spikelets per spike). Thirty randomly selected plants from each variety with appropriate morphological characteristics have been taken for analysis. The grain yield per plot was converted to t/ha, and the data for each sample were averaged across three repetitions.

The results were mathematically processed using the analysis of variance (ANOVA). The variability of the mean difference was assessed using the Student's t-test. The data were statistically analyzed using ANOVA in the Statistica 10 software (StatSoft Inc., USA) and are presented in the tables as x ± SD (mean ± standard deviation). The differences between samples were evaluated using the Tukey's HSD test, with the differences considered significant at $P < 0.05$ (with the Bonferroni correction applied).

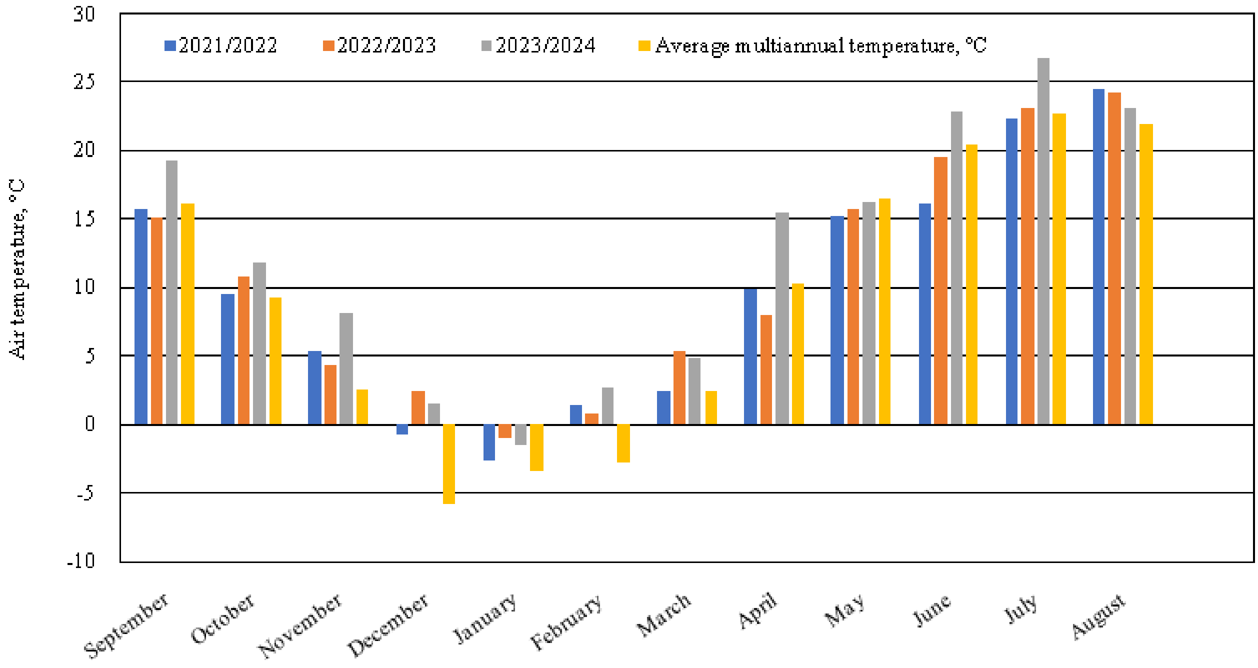

Fig. 1. Average daily air temperature during the vegetation period of 2022–2024 based on the data from the Dnipro Meteorological Station

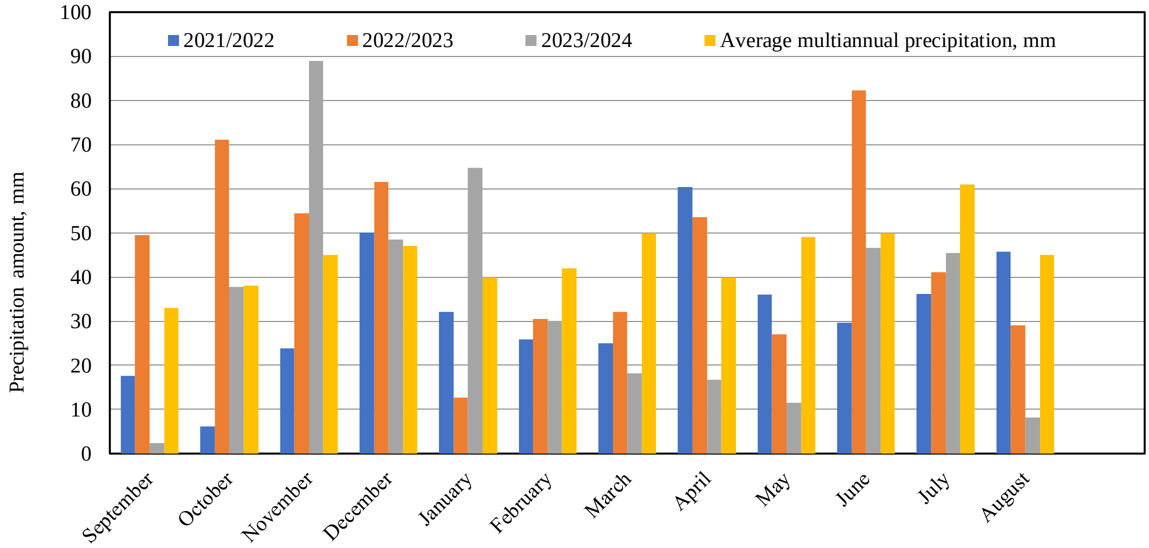

Fig. 2. Precipitation during the vegetation period of 2022–2024 based on the data from the Dnipro Meteorological Station

To quantitatively assess the yield stability of varieties under the influence of climatic factors, the regression coefficient (bi) of yield on the environmental conditions index – coefficient of ecological plasticity – was used, according to the methodology (Eberhart & Russell, 1966). The higher the numerical value of plasticity ($b_i > 1$), the greater the variety's response to changes in yield levels. The amplitude of yield fluctuations was characterized by the mean square deviation relative to regression – stability coefficient (S^2d_i), and the lower the value ($S^2d_i < 1$), the more stable the yields of a specific variety.

Results

During the 2022 vegetation period, the varieties Oleksiivka, Spivanka, and Bohynia exceeded the standard in spike length (9.4–9.5 cm against 9.2 cm). According to the number of spikelets per spike, the varieties Peremoha, Komertsiina, Dyvo, and Vezha outperformed (18.1–19.2 compared with 17.6), while in the number of grains per spike, the varieties KSV 34, Komertsiina, and Spivanka showed higher values (27.8–29.3 compared with 26.3). In 2023, the varieties Oleksiivka, Spivanka, and Komertsiina stood out for spike length (9.4–9.7 compared with 9.3 cm). According to the number of spikelets per spike, the varieties Peremoha, Ihrysta, Komertsiina, Vezha, and Dyvo were notable (18.6–20.7 compared with 18.3), while most varieties were stable and comparable to the standard number of grains per spike (32.2–33.2 compared with 33.7). However, Bohynia exceeded the standard with 34.4 grains, compared with 33.7 and Dyvo showed lower value (27.6 compared with 33.7). In 2024, the varieties Oleksiivka, Spivanka, and Bohynia again stood out in spike length (9.3–9.8 compared with 9.1 cm). According to the number of spikelets per spike, the varieties Palitra, Dyvo, and Peremoha showed higher values (17.2–17.8 compared with 16.4), while by the number of grains per spike, the varieties Spivanka, Veza, Palitra, Komertsiina, and Dyvo outperformed the standard (Table 1).

Table 1
Components of spike productivity in the soft winter-wheat varieties during the vegetation period of 2022–2024 (x ± SD, n = 20)

Variety	Spike length, cm			Number in spike, pcs					
				grains			spikelets		
	2022	2023	2024	2022	2023	2024	2022	2023	2024
Podolianka	9.2 ± 0.9^{a}	9.3 ± 1.0^{a}	9.1 ± 0.9^{a}	26.3 ± 2.6^{b}	33.7 ± 2.8^{a}	26.9 ± 2.0^{ab}	17.6 ± 2.6^{a}	18.3 ± 3.8^{ab}	16.4 ± 1.5^{b}
Spivanka	9.4 ± 0.7^{a}	9.6 ± 0.8^{a}	9.3 ± 0.6^{a}	28.2 ± 2.2^{a}	31.9 ± 4.6^{a}	27.3 ± 1.9^{ab}	17.2 ± 1.1^{a}	17.9 ± 1.4^{ab}	15.2 ± 1.3^{b}
Vezha	9.3 ± 0.7^{a}	8.9 ± 0.7^{a}	8.8 ± 0.6^{ab}	28.4 ± 2.3^{a}	33.1 ± 3.7^{a}	28.3 ± 2.2^{a}	18.1 ± 4.1^{a}	18.9 ± 4.3^{a}	16.2 ± 1.4^{b}
Yuzovska	8.1 ± 0.8^{b}	8.2 ± 0.8^{b}	8.3 ± 0.7^{b}	27.0 ± 2.3^{abc}	33.1 ± 3.5^{a}	27.9 ± 2.3^{a}	14.5 ± 1.5^{b}	15.1 ± 2.4^{b}	16.1 ± 1.7^{b}
Palitra	9.1 ± 0.8^{a}	9.3 ± 0.6^{a}	9.0 ± 0.7^{a}	27.5 ± 1.2^{ab}	32.3 ± 3.9^{a}	26.8 ± 2.6^{ab}	17.4 ± 4.0^{a}	17.9 ± 4.9^{ab}	17.2 ± 2.0^{a}
Bohynia	9.4 ± 1.0^{a}	9.3 ± 1.0^{a}	9.8 ± 0.4^{c}	26.2 ± 2.2^{bc}	34.4 ± 3.7^{a}	25.3 ± 1.8^{b}	16.4 ± 1.7^{ab}	17.1 ± 2.4^{b}	15.9 ± 1.5^{b}
Komertsiina	9.2 ± 0.6^{a}	9.7 ± 0.5^{a}	8.8 ± 0.8^{ab}	29.3 ± 3.6^{a}	31.1 ± 3.9^{ab}	27.2 ± 2.2^{ab}	18.8 ± 2.0^{a}	19.7 ± 2.1^{a}	16.4 ± 1.6^{b}
Dyvo	9.2 ± 0.7^{a}	9.1 ± 0.7^{a}	8.9 ± 0.7^{ab}	26.5 ± 2.2^{b}	27.6 ± 3.5^{b}	28.8 ± 1.8^{a}	18.5 ± 2.7^{a}	19.1 ± 3.0^{a}	17.5 ± 1.5^{a}
Ihrysta	9.1 ± 0.5^{a}	9.2 ± 2.5^{a}	8.9 ± 0.5^{ab}	25.3 ± 1.8^{b}	33.2 ± 0.6^{a}	25.2 ± 1.3^{b}	17.3 ± 2.5^{a}	18.6 ± 5.0^{ab}	16.5 ± 1.7^{b}
Oleksiivka	9.5 ± 0.7^{a}	9.4 ± 0.9^{a}	9.8 ± 0.7^{a}	27.4 ± 2.1^{ab}	32.8 ± 4.1^{a}	26.4 ± 2.1^{ab}	16.3 ± 2.3^{ab}	17.2 ± 1.3^{ab}	15.9 ± 1.0^{b}
Peremoha	9.1 ± 1.2^{a}	9.1 ± 0.9^{a}	9.3 ± 1.0^{a}	24.5 ± 3.3^{c}	31.3 ± 1.9^{a}	25.5 ± 3.1^{b}	16.2 ± 1.0^{ab}	20.7 ± 2.4^{a}	17.8 ± 1.2^{a}
KSV 34	9.1 ± 0.9^{a}	8.7 ± 1.1^{b}	8.9 ± 0.8^{ab}	27.8 ± 3.3^{ab}	32.2 ± 2.3^{a}	26.8 ± 2.5^{ab}	14.7 ± 0.8^{b}	16.1 ± 2.3^{b}	14.4 ± 1.0^{c}

Note: lowercase letters indicate statistical differences from the standard at $P < 0.05$ according to the Tukey's HSD test with the Bonferroni correction.

In 2022, higher grain weight per main spike and spike weight – compared with the standard – were observed in the varieties Yuzovska, Ihrysta, Bohynia, and Spivanka (1.15–1.25 and 1.68–1.76, compared with 1.14 and 1.65 g, respectively). Lower values have been found in Peremoha, Palitra (1.04–1.05 and 1.41–1.54 compared with 1.14 and 1.65 g), and Dyvo in spike weight (1.52 compared with 1.65 g). The varieties Spivanka and Yuzovska had a higher thousand-grain weight (42.4–42.8 compared with 42.3 g), while Bohynia and Peremoha had lower values (39.8 compared with 42.3 g). In 2023, higher grain weight per main spike was recorded in Yuzovska, Palitra, and Spivanka (1.42–1.53 compared with 1.42 g). Only KSV 34 exceeded the standard in spike weight (1.98 compared with 1.91 g). For thousand-grain weight, Spivanka, Veza, Yuzovska, Dyvo, and Oleksiivka were superior (43.2–44.6 compared with 43.0 g), while Bohynia and Peremoha had lower weights (40.4 and 41.0 compared with 43.0 g). In 2024, the varieties Spivanka and Yuzovska either exceeded or matched the standard for grain weight per spike (1.14–1.15 compared with 1.14 g). Higher spike weight was observed in Spivanka, Yuzovska, Dyvo, and Oleksiivka (1.55–1.74 compared with 1.54 g). According to thousand-grain weight, Yuzovska and Oleksiivka were superior (41.7–41.8 compared with 41.1 g, Table 2).

The yield of the studied varieties directly depended on the genotype and weather conditions during the years of research. In 2022, the yield ranged 5.9 to 7.0 t/ha. In 2023, under conditions of excessive moisture, the yield was the highest, measuring 6.8–8.2 t/ha; while in the dry 2024, it was the lowest over the study period, accounting for 4.9–5.9 t/ha. The average yield across the years of research was 6.4 t/ha, which is close to the standard variety Podolianka, which amounted to 6.5 t/ha (Table 3).

Table 2
Yield structure of the soft winter-wheat varieties during the vegetation period of 2022–2024 (x ± SD, n = 20)

Variety	Grain weight per spike, g			Spike weight, g			Thousand-grain weight, g		
	2022	2023	2024	2022	2023	2024	2022	2023	2024
Podolianka	1.14 ± 0.13^{b}	1.42 ± 0.20^{a}	1.14 ± 0.13^{a}	1.65 ± 0.22^{a}	1.91 ± 0.29^{a}	1.54 ± 0.18^{ab}	42.3 ± 1.72^{a}	43.0 ± 1.53^{b}	41.1 ± 0.93^{a}
Spivanka	1.15 ± 0.18^{b}	1.53 ± 0.14^{a}	1.15 ± 0.18^{a}	1.68 ± 0.18^{a}	1.89 ± 0.18^{a}	1.66 ± 0.18^{ab}	42.4 ± 0.84^{a}	44.6 ± 0.76^{a}	40.9 ± 0.96^{a}
Vezha	1.13 ± 0.13^{b}	1.37 ± 0.14^{a}	1.03 ± 0.16^{a}	1.68 ± 0.16^{a}	1.74 ± 0.16^{b}	1.45 ± 0.22^{b}	41.5 ± 0.75^{a}	44.5 ± 0.85^{a}	38.9 ± 1.49^{b}
Yuzovska	1.25 ± 0.09^{a}	1.48 ± 0.14^{a}	1.14 ± 0.13^{a}	1.74 ± 0.16^{a}	1.88 ± 0.19^{a}	1.74 ± 0.16^{a}	42.8 ± 0.93^{a}	43.7 ± 0.66^{b}	41.7 ± 1.20^{a}
Palitra	1.04 ± 0.12^{c}	1.42 ± 0.08^{a}	1.07 ± 0.09^{a}	1.41 ± 0.15^{b}	1.79 ± 0.15^{a}	1.45 ± 0.13^{b}	40.1 ± 0.80^{b}	42.8 ± 0.68^{b}	39.3 ± 0.81^{b}
Bohynia	1.23 ± 0.12^{a}	1.36 ± 0.12^{c}	1.04 ± 0.14^{a}	1.76 ± 0.23^{a}	1.80 ± 0.23^{a}	1.43 ± 0.32^{b}	39.8 ± 3.15^{b}	40.4 ± 1.35^{c}	38.5 ± 1.15^{b}
Komertsiina	1.14 ± 0.15^{b}	1.19 ± 0.18^{b}	1.02 ± 0.16^{a}	1.64 ± 0.17^{a}	1.64 ± 0.18^{b}	1.45 ± 0.19^{b}	41.4 ± 1.42^{a}	42.3 ± 0.58^{b}	40.3 ± 1.16^{a}
Dyvo	1.15 ± 0.10^{b}	1.21 ± 0.12^{b}	1.12 ± 0.10^{a}	1.52 ± 0.14^{ab}	1.61 ± 0.11^{b}	1.55 ± 0.12^{ab}	41.5 ± 1,51^{a}	43.2 ± 1.17^{b}	39.7 ± 0.97^{b}
Ihrysta	1.18 ± 0.13^{b}	1.17 ± 0.08^{b}	1.10 ± 0.18^{a}	1.68 ± 0.15^{a}	1.58 ± 0.16^{b}	1.51 ± 0.23^{ab}	40.5 ± 1.68^{b}	41.7 ± 0.87^{c}	38.4 ± 1.70^{b}
Oleksiivka	1.14 ± 0.10^{b}	1.24 ± 0.13^{b}	1.06 ± 0.10^{a}	1.55 ± 0.20^{ab}	1.73 ± 0.34^{b}	1.61 ± 0.17^{ab}	42.7 ± 0.83^{a}	44.5 ± 0.76^{a}	41.8 ± 1.06^{a}
Peremoha	1.05 ± 0.09^{c}	1.21 ± 0.11^{b}	1.05 ± 0.09^{a}	1.54 ± 0.12^{ab}	1.56 ± 0.14^{b}	1.54 ± 0.12^{ab}	39.8 ± 0.47^{b}	41.0 ± 0.79^{c}	39.3 ± 1.10^{b}
KSV 34	1.14 ± 0.12^{b}	1.40 ± 0.14^{a}	1.02 ± 0.13^{a}	1.60 ± 0.22^{ab}	1,98 ± 0.30^{a}	1.54 ± 0.22^{ab}	41.8 ± 1.06^{a}	42.8 ± 0.57^{b}	39.8 ± 1.07^{b}

Note: lowercase letters indicate statistical differences from the standard at P < 0.05 according to the Tukey's HSD test with the Bonferroni correction; no differences were found in grain weight per spike in 2024.

In 2022, the varieties Vezha (7.3 t/ha), Yuzovska (7.0 t/ha), Spivanka (6.9 t/ha), and Bohynia (6.9 t/ha) had higher yields, while Peremoha (6.3 t/ha) had a lower yield. In 2023, the low-yielding varieties were Ihrysta (6.3 t/ha), Komertsiina (6.8 t/ha), and Peremoha (6.3 t/ha), while Vezha (7.6 t/ha), Yuzovska (7.6 t/ha), Palitra (7.6 t/ha), and Spivanka (8.2 t/ha) had higher yields. In 2024, the lowest yields were recorded in Dyvo (4.9 t/ha), Oleksiivka (4.9 t/ha), and KSV 34 (5.0 t/ha). Higher yields were observed for Palitra, Peremoha (5.7 t/ha), and Spivanka (5.8 t/ha), while the other varieties were close to the standard. Low variability in yield was found in the varieties Ihrysta and Peremoha (4.3% and 5.7%), while higher variability was recorded in Dyvo (19.3%), Vezha (18.6%), Oleksiivka (18.4%), and KSV 34 (19.1%). High plasticity and stability over the years were observed in the varieties Ihrysta, Peremoha, Komertsiyna, Palitra, and the standard Podolianka (A = 0.25–0.94 and B = 0.2–1.4). The most intensive and less stable varieties were Yuzovska, Dyvo, Vezha, and Spivanka (A = 1.25–1.35 and B = 2.58–3.01).

The duration of the vegetation period varied depending on the weather conditions of the research year and showed significant differences. In 2022, the shortest duration was 281 days; in 2023, it accounted for 273 days; and in 2024, it was 253 days, with an average of 282, 277.1, and 255.2 days, respectively (Table 4). Depending on the variety, no significant differences were observed, indicating that the initial material for the study was well-selected, with high yield potential and an optimal vegetation duration for the Northern Subzone of the Steppe. Only the variety Komertsiina was earlier-maturing than the standard Podolianka in 2023 and 2024 (273 and 253 days compared with 278 and 257 days, respectively), as were the varieties Dyvo and Palitra in 2024 (253 and 254 days, compared with 257 days, respectively).

Table 3
Yield of soft winter wheat during the vegetation period of 2022–2024 (x ± SD, n = 3)

Variety	Yield, t/ha			A	B
	2022	2023	2024		
Podolianka	6.6 ± 0.36^{b}	7.3 ± 0.38^{b}	5.6 ± 0.15^{a}	0.94	1.44
Spivanka	6.9 ± 0.15^{ab}	8.2 ± 0.21^{a}	5.8 ± 0.09^{a}	1.29	2.75
Vezha	7.3 ± 0.17^{a}	7.6 ± 0.13^{b}	5.3 ± 0.21^{b}	1.35	3.01
Yuzovska	7.0 ± 0.10^{a}	7.6 ± 0.12^{b}	5.4 ± 0.21^{b}	1.25	2.58
Palitra	6.4 ± 0.12^{b}	7.6 ± 0.13^{b}	5.7 ± 0.10^{a}	0.88	1.28
Bohynia	6.9 ± 0.10^{ab}	7.2 ± 0.10^{b}	5.3 ± 0.12^{b}	1.11	2.03
Komertsiina	6.6 ± 0.31^{b}	6.8 ± 0.17^{bc}	5.5 ± 0.10^{a}	0.76	0.95
Dyvo	6.7 ± 0.20^{ab}	7.2 ± 0.10^{b}	4.9 ± 0.12^{c}	1.32	2.87
Ihrysta	6.4 ± 0.38^{b}	6.3 ± 0.21^{c}	5.9 ± 0.06^{a}	0.25	0.11
Oleksiivka	6.5 ± 0.11^{b}	7.1 ± 0.21^{b}	4.9 ± 0.15^{c}	1.25	2.58
Peremoha	6.3 ± 0.06^{b}	6.3 ± 0.10^{c}	5.7 ± 0.12^{a}	0.36	0.21
KSV 34	6.5 ± 0.15^{b}	7.3 ± 0.28^{b}	5.0 ± 0.17^{c}	1.20	2.42

Note: lowercase letters indicate statistical differences from the standard at P < 0.05 according to the Tukey's HSD test with the Bonferroni correction; the letter A denotes the coefficient of ecological plasticity – b_i (the higher the numerical value of plasticity, the greater the variety's response to changes in yield levels), and the letter B denotes the coefficient of stability – S^2d_i (the lower the numerical value, the more stable the yields of a specific variety, but less suitable for intensive cultivation technology).

Table 4
Duration of the vegetation period 2022–2024

Variety	Duration of the vegetation period, days			Average
	2022	2023	2024	
Podolianka	282	278	257	272.3^{a}
Spivanka	282	278	257	270.6^{a}
Vezha	282	279	255	272.0^{a}
Yuzovska	281	277	254	271.3^{a}
Palitra	282	277	255	270.6^{a}
Bohynia	282	277	256	271.3^{a}
Komertsiina	281	273	253	272,0^{a}
Dyvo	282	277	253	271.7^{a}
Ihrysta	282	277	257	271.3^{a}
Oleksiivka	283	277	254	271.0^{a}
Peremoha	282	277	255	269.0^{a}
KSV 34	283	278	256	272.3^{a}

Note: lowercase letters indicate statistical differences from the standard at P < 0.05 according to the Tukey's HSD test with the Bonferroni correction; no differences were found in duration of the vegetation period in average by years.

Discussion

According to foreign researchers, in the context of increasingly rapid climate change, there is a constant need to select new forms of initial material for wheat breeding, as emphasized by Harkness et al. (2020). Hongjie et al. (2019) stress that increasing grain yield remains a constant goal in wheat breeding; however, the annual growth rate of global wheat yield is estimated at around 1.0%, which does not meet the growing demand for wheat (Holman et al., 2024). The development of new varieties is one of the most important factors in increasing wheat production, but breeding goals depend on local conditions and must meet the needs of consumers, processors, and farmers. Dawson et al. (2011) and Bazalii et al. (2018) add that producers interested in on-farm breeding often seek more diverse varieties because they want these varieties to develop specific adaptations to their conditions and because genetic heterogeneity can buffer crops' responses to unpredictable environmental conditions (Tack et al., 2015; Spanic et al., 2024). The agronomic advantages of diversity include improved disease resistance and reduced disease severity, as well as greater buffering capacity in heterogeneous populations. In heterogeneous populations, phenotypic stability can arise due to genetic diversity, which allows flexible expression of trait components, leading to greater stability of complex traits such as yield and quality. Preserving genetic diversity within varieties not only facilitates the development of well-adapted varieties but is also important for maintaining the adaptive potential of these varieties (Demidov et al., 2023; Muhamad et al., 2024).

Therefore, Pradeep et al. (2024) and Baranwal et al. (2024) note that one of the primary tasks in selecting initial material is the analysis of varieties based on spike productivity, which is crucial for the quantitative assessment of yield. It is also important for analyzing technological elements and environmental factors that contributed to the variation of productivity elements and the formation of grain weight per spike and thousand-grain weight at the spike level. Gherban & Sala (2024) emphasize that productivity elements exhibit varying degrees of variability depending on the interaction between genotype and environmental factors. Grain weight per spike and thousand-grain weight have a proportional correlation with each other and are influenced by annual conditions (Bergkamp et al., 2018; Kovalyshyna & Havryliuk, 2024). This is supported by the findings that in the well-watered 2023, the average yield for many varieties was 7.2 t/ha or higher, exceeding the typical yields for the Northern Subzone of the Steppe zone of Ukraine in 2022 (6.6 t/ha) and significantly surpassing the drought-affected 2024, with an average yield of 5.4 t/ha and a CV of 5.6–7.6%. Grain weight per plant and thousand-grain weight decreased proportionally, with a CV of 2.9–6.9%. Conversely, the number of spikelets per spike showed minimal variation across years, as also noted in the study by Lozinskiy et al. (2021). Although Ebrahimnejad & Rameeh (2015), Guo et al. (2018), and Manukyan et al. (2019) point out that spike length can strongly correlate with weather conditions, in this case, the varieties did not exhibit significant changes over the years, with an average spike length of 9.1–9.2 cm and a CV of 4.9–10.2%.

Taking into account all the above, the author believes that the research aimed at analyzing and selecting the best initial material for further identification and implementation in topcross breeding is highly relevant. The main objective is producing progeny with a complex of traits such as grain weight per spike, spike weight, thousand-grain weight, and adaptive properties to ensure high productivity.

Conclusion

The varieties Spivanka, Vezha, Yuzovska, Palitra, KSV 34, Bohynia, and Dyvo were identified as the best and most promising based on yield structure indicators as a result of a three-year study of soft winter wheat varieties in the Northern Subzone of the Steppe of Ukraine. These varieties demonstrated either higher yields, compared with the standard variety Podolianka, or greater stability and plasticity over the years. The best-performing varieties based on the studied parameters are recommended for further use as initial material in breeding programs aimed at increasing productivity and improving the quality of soft winter wheat grain.

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