UDC: 631.527:581.19 DOI: 10.30835/2413-7510.2023.283648

CHARACTERISTICS OF WINTER SPELT WHEAT (TRITICUM SPELTA L.) BREEDING LINES IN THE EASTERN FOREST-STEPPE OF UKRAINE

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Winter spelt lines derived from crossing spelt with bread wheat were characterized by major economically valuable traits. Promising lines as sources of valuable traits for further improvement of spelt are highlighted.

Key words: *spelt, winter bread wheat, performance constituentss, yield, grain quality*

Introduction. Spelt wheat (*Triticum spelta* L.) is an ancestral wheat species. It was grown as early as in the 7^{th} – 8^{th} millennia BC [1]. The crop was widespread in ancient times, but later its cultivation almost ceased due to low yields, hullness and spike brittleness [2, 3 ,4]. However, in recent decades, scientists and consumers have got more and more interested in spelt due to its valuable properties. Spelt is resistant to bio- and abiotic factors and, therefore, is able to yield stably without chemicals; hence, it can be an alternative to bread wheat as a source of organic or healthy food. Ukraine is among the top ten global leaders in terms of organic cereal area, with 11.4% of the world's certified areas allocated to spelt [5, 6]. In some cases, the nutritional properties of spelt even allow it to replace the traditionally dominating bread wheat [7, 8].

Literature Review and Research Objectives. Spelt grain, in comparison with bread wheat, has a high energy value, contains more beta-carotene, retinol, and fats; it is characterized by more extensible but less elastic gluten [9, 10]. Gluten proteins, which are especially abundant in this cereal, contain essential amino acids that cannot be obtained from animal foods. The content of lysine (limiting amino acid) is 7.7% higher than in bread wheat flour [6]. All nutrients are detected not only in bran, but also throughout kernels, so the nutritional value is preserved in bread even from finely milled flour [6]. The floury endosperm of spelt, due to its high protein content and amylography-confirmed high viscosity, is beneficial for the manufacture of cakes and confectionery [11, 12, 13]. It was shown [6, 8] that bread from *T. spelta* flour had a larger specific loaf volume than wheat bread and was correctly shaped; the crumb was creamy, with a pleasant taste and aroma; however the crumb was granular and coarse compared to bread wheat [14, 15]. Biomedical tests demonstrated that spelt products had antioxidant activity and hepatoprotective effects. They can be recommended for both traditional and preventive nutrition for people suffering from metabolic disorders and obesity. Swiss scientists found that all spelt food products (bread, pasta, grits) help strengthen the immune system due to specific soluble carbohydrates in grain - mucopolysaccharides [9]. Spelt gluten contains fewer celiac disease (and other types of wheat intolerance in susceptible people)-inducing gluten components than bread wheat [16– 18].

Six winter spelt varieties have been registered in Ukraine: Zoria Ukrainy (2012), Yevropa (2015), Vyshyvanka Bilotserkivska, Evrika (2020) (UA), Attergauer Dinkel (2019) (AUT) and Mv Martongold (2022) (HUN) [19]. Thus, interest in this wheat species is increasing, and more and more producers are interested in its cultivation. Hence, it is expedient to improve spelt breeding to increase yields and adapt varieties to current growing and processing technologies. Genetic similarity with bread wheat is the basis for using the latter as a source of valuable traits in spelt breeding.

We conducted a series of crossings between spelt and bread wheat accessions of different origins, from which several promising offsprings were selected. NSS 1/02 *T. spelta* var.

duhamelianum line (Serbia) / Oktava *T. aestivum* variety (Ukraine) was the most effective combination.

Our purpose was to characterize winter spelt lines selected from this combination by major economically valuable features.

Materials and Methods. Winter spelt (*T. spelta*) lines derived from crossing NSS 1/02 *T. spelta* var. duhamelianum line (Serbia) with Oktava *T. aestivum* variety (Ukraine) at the National Center for Plant Genetic Resources of Ukraine of the Plant Production Institute named after V.Y. Yuriev (PPI) of NAAS were chosen to investigate. Plants were grown on the PPI's experimental farm *Elitne* in the Kharkiv Region. Basic and pre-sowing tillage was conventional for the Forest-Steppe of Ukraine. The climate is temperate continental, mild, with sufficient precipitation. The lines were sown within the optimal timeframe in preliminary and competitive trials; in 10 m^2 plots in four replications. For structural analysis, plants were taken from an area of 0.25 m^2 and 20 spikes were analyzed in detail for the following morphological parameters: plant height, total and productive tillering, length of the main spike, and spike density per 1 m^2. The following performance constituents were analyzed: number of spikelets in the main spike, kernel number per spike, kernel weight per spike, and thousand-kernel weight. During the growing period, the main developmental phase onsets were noted. After harvesting, the following grain quality indicators were determined: protein content, gluten content, and SDS sedimentation index. Studying the spelt lines, we used the following varieties as the check ones: Yevropa winter spelt variety bred by the All-Ukrainian Research Institute of Breeding in cooperation with Uman National University of Horticulture, Podolianka and Bunchuk winter bread wheat varieties (national standards), Harmonika and Doskonala varieties bred in the PPI.

Results and Discussion. In our experiments, the spelt lines were the most winter hardy accessions among the winter bread wheat varieties and lines of the competitive and preliminary trials (Table 1). The 2019 had best weather for spelt overwintering: all spelt plots completed the winter period well and had high overwintering scores. In 2020, Yevropa spelt (check variety) had an overwintering score of 6 points which was inferior to the winter hardiness of the bread wheat varieties and spelt accessions under investigation. In addition to high winter hardiness, spelt was noticeable for high resistance to powdery mildew and tan spot (8-9 points) and medium resistance to Septoria (5-6.4 points). In the spring, the spelt lines started regrowing more slowly than winter bread wheat.

The registered spelt varieties are considered to ripe later compared to winter bread wheat. In our experiments, earing occurred between May 23 and May 31, depending on the weather. The spelt lines started earing 4 days later than Harmonika bread wheat, 2 days later than Bunchuk and Doskonala varieties and simultaneously with Yevropa spelt and Podolianka bread wheat (Table 1).

Spelt plants are usually tall. On average across the 4 study years, the spelt lines were as tall as or slightly shorter than Yevropa (check variety) (Table 1).

2022 turned out to be the most favorable year for the realization of the genetic potential in terms of the plant height: plants were 140-150 cm tall. 2021 was drier and the height of spelt lines was similar to that of the mid-tall bread wheat varieties, Podolianka and Doskonala. 1145-16 *T. spelta* line attracted attention because it was shorter than the other spelt lines. It was 32.5 cm taller than the short-stemmed bread wheat varieties, Bunchuk and Harmonika, and 10.6 cm taller than the mid-tall varieties, Podolianka and Doskonala. At the same time, our observations evidenced that spelt stems were quite strong and resistant to lodging, despite their length.

The number of productive stems per unit area is an important element of the yield structure. Ukrainian and foreign scientists showed [4, 20] that the density of productive stems and tillering coefficient in spelt wheat were 2–3 times higher than those in bread wheat. Our accessions had no advantages over bread wheat. The density of productive stems in bread wheat ranged from 360 stems/m^2 in Doskonala to 433 stems/m^2 in Bunchuk, with the mean of 403 stems/m^2 for bread wheat (Table 2). Yevropa (check spelt variety) had almost 2 times fewer productive stems than bread wheat (160 stems/m^2). However, our spelt lines were superior to Yevropa, as their density of productive stems exceeded that in the check spelt variety by 84

stems/m^2. The tillering coefficient in the bread wheat varied from 2.04 in Podolianka to 2.30 in Harmonika. 1139-16, 1140-16, 1145-16 spelt lines (tillering coefficient = 1.69, 1.80, 1.79, respectively) on average exceeded Yevropa (1.31) in this indicator. 1140-16 and 1145-16 lines showed a significant advantage over the check variety in 2020.

Table 1.

Economically valuable traits of winter spelt and bread wheat (mean for 2019–2022)

Wheat species	Line/variety	Winter hardiness, score	Spring regrowth intensity score	Earing, days + to Harmonika	Resistance, score		Yield, t/ha	Kernel, score	Grain plumpness, score
					pyrenophora	leaf septoria			
Winter *T. spelta*	1139-16	8.0	5.8	+4	8.0	6.4	6.71	7.0	6.4
	1140-16	8.3	6.1	+4	9.0	5.0	7.25	7.0	5.3
	1145-16	8.3	5.6	+4	8.0	6.0	6.52	7.0	5.9
	Yevropa	7.6	5.9	+4	8.0	5.5	6.43	7.0	5.9
Mean		8.1	5.9	-	8.3	5.7	6.73	7.0	5.9
Winter *T. aestivum*	Podolianka	8.0	7.2	+4	6.0	4.9	6.88	6.4	7.0
	Bunchuk	8.0	7.0	+2	7.7	6.5	7.12	5.6	6.0
	Harmonika	7.8	7.3	0	7.6	5.3	6.74	6.7	6.4
	Doskonala	8.0	7.5	+2	7.9	5.3	6.64	7.0	6.9
Mean		7.9	7.3	-	7.3	5.5	6.85	6.4	6.6
$LSD_{0.05}$					0.9	1.3	1.41		

Table 2.

Height and productive tillering of winter spelt and bread wheat plants (mean for 2019–2022)

Wheat species	Line/variety	Plant height, cm	Plant density, plants/m^2	Productive spike density, spikes/m^2	Productive tillering coefficient
Winter *T. spelta*	1139-16	128.12	123.00	218.00	1.69
	1140-16	127.50	141.50	252.50	1.80
	1145-16	124.37	146.00	262.00	1.79
	Yevropa	128.12	119.00	160.50	1.31
	Mean	127.02	132.40	223.20	1.64
Winter *T. aestivum*	Podolianka	110.62	191.00	409.50	2.04
	Bunchuk	95.37	191.50	410.50	2.08
	Harmonika	88.37	186.00	433.00	2.30
	Doskonala	116.87	169.00	360.00	2.11
	Mean	102.81	184.40	403.30	2.13
$LSD_{0.05}$		6.29	63.39	142.33	0.56

Spikes in spelt lines were white, loose, and awnless. All the spelt lines under investigation had longer spikes than the check bread wheat varieties (on average 3.4 cm longer), whereas the check varieties had spikes of similar length (mean length = 8.2 cm). The mean spike length in Yevropa was 12.19 cm, amounting to 14 cm in favorable years (Table 3). The longest spikes were recorded for 1145-16 *T. spelta* line (11.2 cm); 1139-16 and 1140-16 lines had spikes of equal lengths that were 1 cm shorter than those in the check variety.

As to the spikelet number in the main spike, the spelt lines were inferior to both Yevropa and the bread wheat varieties (Table 3). In bread wheat, the spikelet number averaged 17.03 spikelets/spike; in spelt accessions – 16.51 spikelets/spike. In 2021, a year with favorable weather

for winter cereals, the spikelet number in Yevropa spelt variety, 1140-16 *T. spelta* line and Bunchuk variety averaged 19 spikelets per spike.

Table 3.

Constituents the main spike performance in winter spelt and bread wheat (mean for 2019–2022)

Wheat species	Line, variety	Spike length, cm	Spikelet number per spike	Kernel number per spike	Spike density, spikes/10 cm	Kernel weight per spike, g	Thousand kernel weight, g
Winter *T. spelta*	1139-16	10.47	15.74	28.32	15.13	1.37±0.2	49.97±1.5
	1140-16	10.92	16.34	28.39	15.12	1.36±0.1	50.44±3.7
	1145-16	11.17	16.00	29.70	14.40±0.5	1.37±0.1	47.31±3.4
	Yevropa	12.19	17.97	29.83	14.84±0.5	1.46±0.1	49.79±1.5
Mean		11.18	16.51	29.06	14.87±0.7	1.39±0.1	49.37±2.5
Winter *T. aestivum*	Podolianka	8.30	17.06	32.54	20.65±0.3	1.37±0.1	42.86±1.2
	Bunchuk	7.86	17.35	38.21	22.08±0.3	1.36±0.2	36.76±1.1
	Harmonika	8.14	17.23	37.05	21.23±0.3	1.47±0.1	40.99±1.7
	Doskonala	8.31	16.48	33.98	19.91±0.5	1.46±0.1	43.64±1.2
Mean		8.15	17.03	35.44	20.96±0.4	1.41±0.1	41.06±1.3
$LSD_{0.05}$		0.51	0.97	4.39	0.84	0.25	4.44

In terms of spike density, the spelt lines we re significantly inferior to the bread wheat varieties. Bunchuk (22.08 spikelets/spike) was the spike density leader in our study; it had short spikes (7.86 cm) with an increased number of spikelets (17.35) (Table 3). Harmonika was close to Bunchuk in this trait. They were followed by Podolianka, Doskonala, 1139-16 *T. spelta* line, 1140-16 *T. spelta* line, Yevropa, and 1145-16 *T. spelta* line in order of decreasing spike density.

The kernel number per spike is an important element of the yield. The highest values of this trait were recorded for the intensive winter bread wheat varieties, Bunchuk and Harmonika: on average across 4 years, they formed 37.63 kernels per spike, while Podolianka and Doskonala - 33.26. The spelt lines had fewer kernels per spike: from 28.32 in 1139-16 line to 29.70 in 1145-16 line, which was similar to this indicator in Yevropa (29.83). Spelt kernels are elongated, plump and resembled Doskonala and Podolianka kernels. By the kernel weight from the main spike, the spelt lines were slightly inferior to Yevropa, Harmonika and Doskonala, but equal to Bunchuk and Podolianka.

The thousand kernel weight is both an element of the plant performance and an indicator of wheat grain quality. In the spelt lines, it ranged 47.31 g to 50.44 g. Of the studied lines, the largest weight of thousand kernels (50.44 g) was recorded for 1140-16 *T. spelta* line, which was significantly higher than in all the check varieties.

It is believed that the negative characteristics of spelt are its low yield and difficult threshing. In our experiment, the grain yield was determined with glumes removed. This became possible due to facilitated threshing of the lines, although their morphology was typical for spelt. All the spelt lines on average outperformed the bread wheat check varieties by 0.50 t/ha. The spelt lines yielded best in 2022: by 0.95 t/ha more than in previous years. 1140-16 *T. spelta* line was the most productive: it yielded by 0.82 t/ha more than Yevropa (check spelt variety) and by 0.40 t/ha more than the check winter bread wheat varieties. Of the winter bread wheat varieties, Harmonika was the leader in terms of yield, producing on average 6.92 t/ha over 4 years. Yevropa yielded worse than both the bread wheat varieties and spelt lines.

It is known that spelt wheat is characterized by high contents of protein and gluten in grain. Our lines were similar to Yevropa in terms of protein content, but superior to the bread wheat varieties. The protein content varied from 13.90% to 16.68% in different years (Table 4). The highest protein content was detected in 1145-16 *T. spelta* line (up to 16.28% in 2020). The

gluten content was also higher than that in the check bread wheat varieties, with the mean of 30.78%. In terms of the SDS sedimentation index, the spelt lines were significantly inferior to the bread wheat varieties; their SDS sedimentation index did not exceed 50%, indicating low strength of flour (weak flour).

Table 4.

Grain quality of winter spelt and bread wheat varieties (mean for 2019–2022)

Wheat species	Line/variety	Content, %		SDS sedimentation index
		protein	gluten	
Winter *T. spelta*	1139-16	14.49	30.04	48
	1140-16	14.71	31.06	49
	1145-16	15.01	31.02	50
	Yevropa	14.60	31.00	49
Mean		14.70	30.78	49
Winter *T. aestivum*	Podolianka	14.32	28.42	70
	Bunchuk	13.44	26.54	86
	Harmonika	13.90	30.61	66
	Doskonala	13.25	27.50	80
Mean		13.73	28.26	76

Hybridization between spelt and bread wheat is an effective way to increase spelt yields, as evidenced by our experience. However, it is very easy to lose the unique dietary and medicinal properties of spelt grain. Therefore, when breeding this crop, one should select offspring of hybrids with due account for biochemical composition of grain.

Conclusions. 1140-16 *T. spelta* line significantly outperformed the check spelt variety in terms of tillering coefficient (1.80), thousand kernel weight (50.44 g), spikelet number per spike (16.34), spikelet density (15.12) and yield (7.25 t/ha); 1145-16 *T. spelta* line was distinguished by reduced plant height (124.37 cm), higher productive tillering (1.79), spike length (11.17 pieces), kernel number in the main spike (29.70) and increased protein content (15.01%), which gives grounds to single out these spelt lines as promising ones for further breeding.

The “NSS 1/02 *T. spelta* var. duhamelianum line (Serbia) / Oktava *T. aestivum* variety (Ukraine)” crossing combination was proven to be promising for breeding improvement of winter spelt in terms of yield, winter hardiness and grain quality in the Eastern Forest-Steppe of Ukraine.

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ХАРАКТЕРИСТИКА СЕЛЕКЦІЙНИХ ЛІНІЙ ПШЕНИЦІ СПЕЛЬТИ ОЗИМОЇ (TRITICUM SPELTA L.) В УМОВАХ СХІДНОГО ЛІСОСТЕПУ УКРАЇНИ

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Мета і задачі досліджень. Метою нашої роботи було дати характеристику лініям спельти озимої, відібраним від схрещування спельти з пшеницею м'якою за основними господарсько-цінними показниками.

Матеріали та методи. Матеріалом дослідження обрано лінії спельти озимої (T. spelta), отримані шляхом схрещування T. spelta лінія NSS 1/02 var. duhamelianum (Сербія) / T. aestivum сорт Октава (Україна) у Національному центрі генетичних ресурсів рослин України Інституту рослинництва імені В.Я. Юр'єва (ІР) НААН України. Рослини вирощували на полях дослідного господарства Елітне ІР НААН України в Харківській області впродовж 2019 – 2022 рр. Зразки висівали в оптимальні строки в попередньому та конкурсному сортовипробуванню, на ділянках 10 м^2 в чотириразовій повторності. Матеріал досліджували за морфологічними показниками, елементами продуктивності та якості зерна. Для проведення структурного аналізу брали рослини з площі 0,25 м^2, детально аналізували 20 колосів. При дослідженні ліній спельти як стандарти використовували: сорт спельти озимої Європа; сорти пшениці м'якої озимої: національні стандарти – Подолянка, Бунчук, сорти селекції ІР НААН – Гармоніка, Досконала.

Результати і обговорення. Лінії спельти характеризуються високою зимостійкістю, стійкістю до збудників борошнистої роси, піренофорозу (8 – 9 балів), мають середній рівень стійкості до септоріозу (5 – 6,4 бали). Починають відновлення весняної вегетації повільніше ніж пшениця м'яка озима. Виколошуються одночасно зі спельтою Європа та пшеницею м'якою Подолянка. Висота рослин ліній спельти була на рівні або дещо нижче стандарту сорту Європа. Наші спостереження показують, що соломина рослини спельти досить міцна та стійка до вилягання, попри її довжину. Коефіцієнт кущення ліній спельти варіював від 1,69 до 1,80 і в середньому перевищував стандарт Європа (1,31), але поступався сортам пшениці озимої. За морфологією колос ліній спельти білий, нещільний, безостий. За довжиною колоса, кількістю колосків у головному колосі, лінії спельти поступалися і сорту Європа і сортам пшениці м'якої. Зерно у спельти видовжене, добре виповнене, подібне до зерна сортів пшениці Досконала та Подолянка. За масою зерна з головного колоса лінії спельти трохи поступилися стандарту Європа, сортам Гармоніка та Досконала і були на рівні стандартів Бунчук і Подолянка. Відмічена висока маса 1000 зерен, яка становила від 47,31 г до 50,44 г. За врожайністю лінії спельти перевершили у середньому стандарти пшениці на 0,50 т/га. Найбільш урожайною була лінія T.spelta 1140-16, яка перевищувала стандарт спельти Європа на 0,82 т/га та стандартні сорти пшениці м'якої озимої на 0,40 т/га, що стало можливим завдяки полегшеному вимолоту зразків. За показниками якості – вмісту білка в зерні, вмісту клейковини у борошні ліній спельти були на рівні стандарту пшениці спельта сорту Європа і перевищували звичайну м'яку пшеницю, а за показником седиментації поступалися сортам пшениці.

Висновки. Комбінація схрещування T.spelta лінія NSS 1/02 var. duhamelianum (Сербія) / T. aestivum сорт Октава (Україна) є перспективною для селекційного покращення озимої

спельти за урожайністю, зимостійкістю та якістю зерна в умовах східного лісостепу України.

Ключові слова: *спельта, пшениця м'яка озима, елементи продуктивності, врожайність, якість зерна.*

CHARACTERISTICS OF WINTER SPELT WHEAT (TRITICUM SPELTA L.) BREEDING LINES IN THE EASTERN FOREST-STEPPE OF UKRAINE

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Purpose and Objectives. The aim of our work was to characterize winter spelt lines selected from spelt/bread wheat hybrid combinations by major economically valuable parameters.

Materials and Methods. Winter spelt (*T. spelta*) lines derived from crossing NSS 1/02 *T. spelta* var. duhamelianum line (Serbia) with Oktava *T. aestivum* variety (Ukraine) at the National Center for Plant Genetic Resources of Ukraine of the Plant Production Institute named after V.Y. Yuriev (PPI) of NAAS of Ukraine were studied. Plants were grown on the experimental farm *Elite* of the PPI NAAS of Ukraine (Kharkiv Region) in 2019–2022. The accessions were sown in plots of 10 m^2 of preliminary and competitive trials in four replications within the optimal timeframe. Plants were analyzed for morphological parameters, performance constituents and grain quality. For structural analysis, plants were taken from an area of 0.25 m^2 and 20 spikes were analyzed in detail. Studying the spelt lines, we took the following accessions as the check varieties: Yevropa winter spelt variety; Podolianka and Bunchuk winter bread wheat varieties (national standards), Harmonika and Doskonala bred at the PPI NAAS.

Results and Discussion. The spelt lines were characterized by high winter hardiness, high resistance to powdery mildew and tan rot pathogens (8–9 points), and medium resistance to Septoria (5–6.4 points). They started spring growth more slowly than winter bread wheat. They came into ear simultaneously with Yevropa spelt and Podolianka bread wheat. Plants of the spelt lines were as tall as or slightly shorter than Yevropa plants (check variety). Our observations showed that spelt stems were quite strong and resistant to lodging, despite their length. The tillering coefficient of the spelt lines ranged 1.69 to 1.80, with the mean exceeding Yevropa's value (1.31), but was lower in comparison with the winter bread wheat varieties. Spikes of the spelt lines were white, loose and awnless. In terms of the spike length and the number of spikelets in the main spike, the spelt lines were inferior to both Yevropa and bread wheat varieties. Spelt kernels were elongated, plump and resembled Doskonala and Podolianka kernels. As to the kernel weight from the main spike, the spelt lines were slightly inferior to Yevropa, Harmonika and Doskonala, but not inferior to Bunchuk and Podolianka (national standards). The thousand kernel weight was high, ranging 47.31 g to 50.44 g. In terms of yield, the spelt lines outperformed the check bread wheat varieties on average by 0.50 t/ha. 1140-16 *T. spelta* line was most productive, yielding by 0.82 t/ha more than Yevropa and by 0.40 t/ha more than the check winter bread wheat varieties, which was possible due to easy threshing of the accessions. As to quality indicators (protein content in grain, gluten content in flour), the spelt lines were similar to Yevropa and bested the bread wheat varieties, but their sedimentation index was worse than that in the bread wheat varieties.

Conclusions. The "NSS 1/02 *T. spelta* var. duhamelianum line (Serbia) / Oktava *T. aestivum* variety (Ukraine)" turned out to be a promising combination for breeding improvement of winter spelt in terms of yield, winter hardiness and grain quality in the Eastern Forest-Steppe of Ukraine.

Key words: *spelt, winter bread wheat, performance constituents, yield, grain quality*.