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# Breeding and genetic improvement of soft winter wheat with the use of spelt wheat

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**Abstract.** In the process of carrying out studies as a result of hybridization of soft wheat with spelt wheat, a number of new forms that differ in morphobiological and economically valuable features were obtained. The aim of the research was to expand the genetic diversity of soft wheat by hybridization with spelt wheat, analysis of the heterotic effect in hybrids in order to systematize the samples and obtain valuable original forms for the breeding process of creating high-yielding varieties.

As a result of research the breeding technology of creating high-yielding forms of soft winter wheat by cross-species hybridization of *Triticum aestivum* L. × *Triticum spelta* L. has been improved. It has been determined that the plant height and ear length in hybrids are inherited by type of intermediate inheritance or negative dominance, the number of grains in the ear - by type of intermediate inheritance or positive dominance; ear grain weight - by type of superdominance or positive dominance. In $F_2$ hybrids there is a dihybrid cleavage into forms with speltoid, squarehead and typical ear with a quantitative predominance of speltoid plants, which indicates the control of the 'ear shape' indication by two non-allelic genes. The ear shape of the soft wheat original varieties in relation to speltoid varieties turned out to be a recessive trait, but at the same time it was dominant to a squarehead form. Regardless of the genotypes of soft wheat included in the combination of crossbreeding with spelt wheat, red color ear indication was determined by a monogenic type of inheritance. Varieties of soft winter wheat Artaplot, Umanska Tsarivna and Freya have been created, which are included in the State Registry of Plant Varieties Suitable for Distribution in Ukraine and recommended for cultivation in Polissia.

**Key words:** intraspecific hybridization, inheritance of characteristics, ear morphotype, grain quality, productivity, variety.

## INTRODUCTION

The main directions in wheat breeding are the creation of high-yielding varieties with excellent grain quality (Guzman et al., 2016). However, in recent years there has been a tendency to yield increase along with a marked decline in grain quality (Rybalka, 2011). That is why a number of scientific institutions are currently conducting breeding work to create high-yielding and high-quality wheat varieties resistant to adverse environmental factors.

World practice has shown that an effective method of breeding is the crossing of geographically distant forms, but the success of breeding work depends on the successful selection of hybridization components, namely the initial material (Rybalka, 2011; Xie et al., 2015). To create new varieties of wheat that would meet the requirements of modern agricultural production, it is advisable to use genetically distant forms (Peleg et al., 2011; Polyanetska, 2012). At the same time wild, semi-wild and forgotten forms are often the donors of high content of protein, gluten, lysine and resistance to diseases and pests.

In particular, spelt wheat is used as a donor of valuable characteristics as it is a donor of high protein content and contains almost all the nutrients in a harmonious and balanced state that a human body needs. The researches of domestic and foreign breeders have shown a positive effect of hybridization of soft and spelt wheat, in particular a significant expansion of existing genetic diversity and getting new forms of wheat that combine high protein and gluten content of spelled and high productivity of wheat (Polyanetska, 2012; Guzman et al., 2016). However, according to Rybalka (2011) it is undesirable to carry out such crossings as it leads to spelt quality deterioration and soft wheat inheritance of complicated grain threshing and ear fragility.

Breeders in a number of countries around the world are improving the quality of wheat by hybridizing it with spelt. In this direction, some progress has been made in Switzerland, Austria and Serbia, where spelt varieties Bauländer, Schwabenkorn, Frankenkorn (Austria), Nirvana (Serbia), Altgold Rotkorn (Sweden) have been created (Dvorak et al., 2012). In Ukraine, extensive research in this area has been conducted at Uman National University of Horticulture, Ukrainian Scientific Institute of Plant Breeding and the Plant Production Institute named after V. Ya. Yuriev.

We conducted a number of studies on the hybridization of soft wheat and spelt wheat, which made it possible to form a collection of samples from the resulting variety of breeding materials unique in morphological, biological and biochemical characteristics. They are a source of valuable genetic plasma to improve existing and create new varieties of wheat.

**The aim** of our research was to expand the genetic diversity of soft wheat by hybridization with spelt wheat, to analyse the heterosis effect in hybrids to systematize the created samples and obtain valuable original forms by involving them in the breeding process to create high-yielding varieties.

## MATERIALS AND METHODS

Research on the breeding and genetic improvement of soft winter wheat with the use of spelt wheat began in 2006 under the direction of Dr. F. M. Parii in the research field of the Department of Genetics, Plant Breeding and Biotechnology of Uman

National University of Horticulture, located in Uman, Cherkasy region, the zone of the Right Bank Forest-Steppe of Ukraine, the subzone of unstable moisture.

As an initial material for hybridization regionalized varieties of soft wheat Favorytka, Smuglianka, Podolianka, Zolotokolosa, Harus, Bila Tserkva semi-dwarf, Myrhad, Kryzhynka, Farandol, Yermak, Selianka, Panna, Krasnodarska 99 and spelt wheat Zoria Ukrainy were involved. Hybridization was performed by manual emasculation of flowers and subsequent controlled pollination by the restricted method. Emasculated spikelets of the female parent together with the male parent were placed under a parchment insulator.

To determine the nature of the quantitative trait inheritance by the dominance degree (hp), the formula of Griffing (1950) and the gradation of Beyl & Atkins (1965) were used:

$$hp = (F_1 – MP)/(P_{max} – MP), \quad (1)$$

where hp – dominance assessment; $F_1$ – arithmetic mean of first generation hybrids; $P_{max}$ – arithmetic mean of the male parent with the highest manifestation of the trait; MP – arithmetic mean of two parent forms.

The created material ranking due to the dominance degree was performed according to the following gradation: 1) $hp <–1$ – negative superdominance (negative heterosis, or depression); 2) $–1 \leq hp <–0.5$ – negative dominance; 3) $–0.5 \leq hp \leq 0.5$ – intermediate inheritance; 4) $0.5 < hp \leq 1$ – positive dominance; 5) $hp > 1$ – positive superdominance (positive heterosis).

The share of original and hypothetical heterosis was calculated by the formulas of Daskalev et al (1967):

$$\text{true heterosis: } X = (F_1 – P_{max}) \times 100 / P_{max}, \quad (2)$$

where $F_1$ – the value of the hybrid trait; $P_{max}$ – the highest trait value of one of the parents.

$$\text{hypothetical heterosis: } X = F_1 \times 100 / MP, \quad (3)$$

where $F_1$ – the value of the hybrid trait; MP – arithmetic mean of the two initial forms.

Correspondence of cleavage in $F_2$ hybrid combinations was theoretically expected using $\chi 2$ (Dospekhov, 1985).

Testing of the created materials was carried out during 2013–2020 under the conditions of Uman National University of Horticulture. All accounting and observation were carried out in accordance with the ‘State qualification methodology of plant varieties expertise on definition of suitability for distribution in Ukraine (grains, grouts, and leguminous species)’ (2012). Soft winter wheat Podolyanka variety was the standard. A systematic method of plots placement was used in the research. The numbers were arranged in blocks with a plant density of 400 thousand pcs per ha under four-time repetition.

Plant height was measured in the field before harvesting. Biometric indicators (ear length and plant height) were determined on 50 plants selected from each plot in two non-contiguous replicates. Wheat sample grouping by plant height was performed according to the method of Dorofeev et al. (1987). Quality indicators (gluten and protein content in grain, flour strength) were determined by infrared spectroscopy using the

Infratec™ Nova instrument (FOSS Analytical, Sweden). After accounting and measurements, grain was threshed and yield was determined.

The reliability of research, the degree of features variation and the significance of differences between indicators of laboratory tests (protein and gluten content) were determined at the level of significance of $P \leq 0.01$, for field studies - $P \leq 0.05$, for hybridological analysis - $P \leq 0.001$ using statistical analysis program (SAS) v. 9.1.3. The variation coefficient (Cv, %), standard deviation (S) and experimental error (Sx) were determined by the method of E. R. Ehrmantraut et al. (2000) and the use of MS Excel program.

Formal and qualification examination of the created varieties was carried out in 19 branches of the Ukrainian Institute for Plant Variety Examination of different regions and geographical zones of Ukraine (Steppe, Forest-Steppe, Polissia): Artaplot variety during 2016–2018, Umanska Tsarivna variety - 2018–2020, Freia variety - 2019–2021.

## RESULTS AND DISCUSSIONS

Spelt wheat is a hexaploid species of wheat with a similar to soft wheat genomic composition ($A^uBD$), so their hybridization is relatively easy, although there are some issues related to the morphological structure of plants (spelt is tall, while varieties for hybridization are mostly short and semi-dwarf) and flowering period.

In the spelt study a pollinator is usually used. However, there was a small proportion of cross combinations with positive progeny transgressions, where spelt was the female parent. In most cross-breeding combinations where soft wheat was used as the female parent, an average level of cross-compatibility was observed (25.3–35.4% of seed formation). In cross-breeding combinations where spelt wheat was the female parent, a low level of seed formation was recorded - 7.8–19.5%, indicating low cross-compatibility of spelt wheat.

**Dominance degree and analysis of heterosis effect of breeding-valuable features.** Seeds obtained as a result of hybridization were sown in a breeding nursery for splitting and grouping analysis of mixed materials due to phenotype. In some other variants, backcrossing was carried out to enrich the forms with economically valuable genes. $F_1$ progeny were evaluated for the equal decline of economically valuable features and heterosis display. Complex analysis of the inheritance patterns of a particular feature makes it possible to conduct targeted breeding in subsequent generations (Kochmarskij et al., 2012). However, heterosis amount of first-generation of wheat hybrids can vary widely, and its level does not always predict the emergence of valuable transgressive forms in fissile generations, as the first hybrid generation may have interallelic gene interactions that are not inherited by subsequent generations. Therefore, this indicator should be analyzed in a complex according to all criteria, which provides greater efficiency of breeding (Prasad et al., 1998).

In the result of the study it was found that that five of 16 singled out forms have inherited plant height by intermediate type, four hybrids showed negative dominance, two - depression (Table 1). Three crossbreeding combinations showed positive dominance and one - positive dominance of the tall-growing parent form.

**Table 1.** Degree of dominance and level of heterosis according to the main economically valuable indicators of soft winter wheat samples obtained by interspecific hybridization with spelt wheat

| Trait | Degree of dominance and level of heterosis | Sample and combination of crossing | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 255 (Krasnodarska 99 × Zoria Ukrainy) | 268 (Farandol × Zoria Ukrainy) | 270 (Zoria Ukrainy × Farandol) | 278 (Panna × Zoria Ukrainy) | 302 (Zoria Ukrainy × Panna) | 305 (Yermak × Zoria Ukrainy) | 308 (Selianka × Zoria Ukrainy) | 313 (Smuhlianka × Zoria Ukrainy) | 340 (Zolotokolosa × Zoria Ukrainy) | 348 (Zoria Ukrainy × Zolotokolosa) | 358 (Kopylivchanka × Zoria Ukrainy) | 364 (Harus × Zoria Ukrainy) | 365 (Kryzhynka × Zoria Ukrainy) | 370 (Favorytka × Zoria Ukrainy) | 375 (Podolianka × Zoria Ukrainy) |
| Plant height | Degree of dominance, (hp) | 0.75 | -0.74 | 0.61 | 0.29 | 0.57 | -1.42 | -0.72 | -0.38 | -0.33 | 0.33 | -1.71 | -0.63 | -0.87 | 1.17 | -0.38 |
| | The nature of inheritance | PPD | PNI | PPD | II | PPD | D | PNI | II | II | II | D | PNI | PNI | PS | I I |
| | True heterosis, % | -4.6 | -31.3 | -7.0 | -11.6 | -7.00 | -33.6 | -36.0 | -20.9 | -18.6 | -18.6 | -44.1 | -36.0 | -33.6 | 2.30 | -20.9 |
| | Hypothetical heterosis, % | 112.6 | 88.6 | 109.5 | 103.9 | 107.8 | 83.7 | 86.7 | 95.1 | 96.2 | 96.2 | 76.5 | 87.6 | 86.6 | 113.5 | 95.1 |
| Ear length | Degree of dominance, (hp) | -0.86 | -0.90 | 0.05 | -0.60 | 0.28 | -0.72 | -0.68 | -0.89 | -0.54 | 0.34 | -0.64 | -0.91 | -0.63 | -0.29 | -0.27 |
| | The nature of inheritance | PNI | PNI | II | PNI | II | PNI | PNI | PNI | PNI | II | PNI | PNI | PNI | II | II |
| | True heterosis, % | -33.5 | -38.0 | -19.0 | -30.4 | -13.9 | -31.6 | -33.5 | -33.5 | -29.7 | -12.7 | -31.6 | -39.9 | -31.0 | -25.3 | -24.6 |
| | Hypothetical heterosis, % | 81.1 | 77.5 | 101.2 | 85.9 | 106.3 | 83.7 | 83.0 | 80.8 | 87.1 | 108.2 | 84.7 | 76.0 | 85.2 | 92.9 | 93.3 |
| Grain number in the ear | Degree of dominance, (hp) | 1.0 | -0.50 | 1.50 | 2.20 | 0.60 | 0.71 | 2.50 | 0.33 | 0.43 | -0.43 | 0.50 | -0.20 | 1.00 | 1.33 | 0.50 |
| | The nature of inheritance | PPD | PNI | PS | PS | PPD | PPD | PS | II | II | II | II | II | PPD | PS | II |
| | True heterosis, % | 0.00 | -6.25 | 2.08 | 6.12 | -2.04 | -1.96 | 6.25 | -4.00 | -4.00 | -9.80 | -2.08 | -6,12 | 0.00 | 2.00 | -3.85 |
| | Hypothetical heterosis, % | 106.4 | 97.8 | 106.5 | 111.8 | 103.2 | 105.3 | 110.9 | 102.1 | 102.1 | 96.8 | 102.2 | 98.9 | 106.4 | 108.5 | 104.2 |
| Grain weight o f the ear | Degree of dominance, (hp) | 1.87 | 2.54 | -0.53 | 2.53 | -0.12 | 0.62 | 0.00 | 0.75 | 1.38 | 0.10 | 1.67 | 1.33 | 0.19 | 1.36 | 0.94 |
| | The nature of inheritance | PS | PS | PNI | PS | II | PPD | II | PPD | PS | II | PS | PS | II | PS | PPD |
| | True heterosis, % | 10.1 | 6.1 | -16.9 | 14.0 | -10.2 | -3.3 | -7.3 | -2.6 | 4.1 | -9.8 | 5.9 | 2.7 | -7.9 | 3.7 | -0.5 |
| | Hypothetical heterosis, % | 124.6 | 110.4 | 93.4 | 125.4 | 98.8 | 106.0 | 100.0 | 108.7 | 116.8 | 101.2 | 116. | 112.0 | 102.1 | 115.5 | 110. |

Note: * PS – heterosis (positive superdominance); PPD – partial positive dominance; II intermediate inheritance; PNI– partial negative inheritance; D – depression (negative dominance).

In general, from the $F_1$ population, plants of sample 358 (78 cm) were characterized by the lowest stem obtained with the use of soft winter wheat variety Kopylivchanka, and the highest - samples created by hybridization of Krasnodarska 99 × Zoria Ukrainy (112 cm) and Favorytka × Zoria Ukrainy (118 cm).

Negative dominance was observed in most singled out forms. Only five hybrids had intermediate inheritance. The use of spelt wheat as the female parent provided ear elongation in first-generation hybrids. Exactly such hybrids were characterized by the longest ear (12.8–13.8 cm) and trait intermediate inheritance (hp = 0.05–0.34). It should be noted that these hybrids, despite the ear elongation, had significant inferior to spelt in this indicator. Therefore, in all other selected samples there was a negative value of original heterosis at the level of - 12.7–19.0%. The number of grains in the ear in most progeny is inherited by intermediate inheritance type and partial positive dominance, while the grain weight of the ear - by type of over dominance.

**The inheritance of breeding and valuable traits.** $F_1$ hybrids were monotypic in ear morphological structure and were characterized by a speltoid shape, glume red color and awnlessness, which indicate the dominance of the speltoid inheritance. Seeds of $F_1$ hybrids were sown by the spaced planting in a breeding nursery. After the end of the growing season in $F_2$ hybrids, the phenotypic manifestation of ear morphology was assessed. In the $F_2$ progeny, 412 plants out of 546 had traits of spelt wheat, 85 - of soft wheat and 49 - of squarehead wheat (Table 2).

**Table 2.** Hybridological analysis of $F_2$ progeny segregation by phenotype

| Trait | Ear phenotype | Segregation | | | | |
|---|---|---|---|---|---|---|
| | | actual | expected | ratio | $\chi$ 2 actual | $\chi$ 2 theo |
| Ear form | spelt | 412 | 410 | 12 : 3 : 1 | 4.19* | 5.99 |
| | soft wheat | 85 | 99 | | | |
| | squarehead | 49 | 37 | | | |
| Awn availability | awnedness | 428 | 410 | 3 : 1 | 3.17* | 3.84 |
| | awnless | 118 | 136 | | | |
| Ear color | red | 424 | 410 | 3 : 1 | 1.92* | 3.84 |
| | white | 122 | 136 | | | |

Note: * – the value of $\chi$ 2 is significant at the level $P \leq 0.001$.

Thus, in $F_2$ there was a quantitative advantage of plants with speltoid ear shape over plants with of squarehead and natural shape. The typical ear shape in comparison with the speltoid shape was recessive, but at the same time it was dominant relative to the squarehead shape. The peculiarity of hybrid segregation is the dominance of the trait 'squarehead ear', which was not among the parent forms. In subsequent generations, the segregation of forms with a compact ear type (short, ultra-dense ear) was also observed.

According to a number of studies, the Q gene located in the long arm of chromosome 5A is essential in the formation of speltoid shape of wheatear. It belongs to the family of transcription factors APETALA-2, which control the flower development (de Faris et al., 2003). The change of only one pair of nucleotides in the alleles of the Q gene led to the emergence of an ear with an elastic stem and spikelets that easily peel (recessive allele) instead of long, brittle stem, which has a difficult threshing ear (dominant allele), which was fundamental in wheat cultivation (Gil-Humanes et al., 2009). The q-5D and q-5B genes are thought to be involved in inhibition of speltoid trait. The influence of regulatory genes is not excluded, because even a single mutation in their sequence can lead to significant changes in the phenotype (Kosuge et al., 2012).

The squarehead trait may have a different genetic nature. Polysomy, aberrations or gene mutations can cause it. The latter can be monogenic recessive, monogenic dominant and dominant with a recessive epistasis manifestation (Kosuge et al., 2012). The formation of plants with a squarehead ear shape among hybrid progeny is due to the dominant gene C and a number of recessive genes expressed in the Q gene presence. Ear density is also regulated by extension genes $L_1$, $L_2$. In the presence of recessive alleles of all these genes (genotype $ccl_1l_1l_2l_2$), hexaploid wheat develops a short, dense clavate ear of 'squarhead' type. In the absence of ear extension genes, common wheat forms short and dense ear and becomes square-headed or clavate-shaped (Simonov et al., 2016).

Populations of $F_2$ hybrids were studied on the basis of awnedness of ear. Soft wheat awnedness is a recessive trait that is not seen in $F_1$ hybrids and is found in the second generation, regardless of the morphological structure of the ear. In our studies, the cleavage into awnless and awned forms was 410 : 136 ($\chi 2 = 3.17$), which is significantly consistent with the monogenic cleavage of 3 : 1. A number of studies have found that the genes of almost all wheat chromosomes can affect the display of the 'awnedness-awnlessness' trait. In addition, modifier genes, genotypic environment, and regulatory genes affect too (Sichkar et al., 2016). However, most scientists believe that awnlessness is controlled by a single dominant $B_1$ gene of chromosome 5AL. Awnlessness in $F_1$ hybrids inherited from spelt and segregation of awned forms among $F_2$ hybrids confirm the dominance of awnlessness over awnedness (Morhun & Oksom, 2011; Mukhordova, 2015).

Genetic analysis of the hybrid segregation obtained by crossing varieties with red and white ears and conducted by a number of scientists indicates the monogenic nature of this trait inheritance. Dominant allele concentration in the genome determines the intensity of coloration (Filipchenko, 1979; Nilsson-Ehle, 1909; Khlestkina et al., 2016). However, when crossing some red-eared varieties with white-eared ones Nilsson-Ehle (1909) found splitting both 3 : 1 and 15 : 1 with different red color gradations. Now three genes have been identified that determine the red color of the ear: Rg1, localized on chromosome 1BS, $Rg_2$ – on chromosome 1DS, $Rg_3$ – on chromosome 1AC (Khlestkina et al., 2009; Khlestkina et al., 2016).

Our researches have shown that when crossing soft wheat with spelt, the red color of the ear in $F_2$ hybrids has a constant tendency of permanent dominance over its white color. The experiment revealed 424 red-eared and 122 white-eared plants, which significantly corresponded to the ratio of 3 : 1 ($\chi^2 = 1.92$). Thus, regardless of the genotypes of soft wheat varieties included in the combination of crossbreeding with spelt, the trait of the red color of the ear showed a dominant monogenic nature of inheritance.

Subsequent generations of hybrids *Triticum aestivum* L. × *Triticum spelta* L. showed further cleavage by ear morphology and except spelt, squarehead and typical forms, intermediate forms were observed between soft and spelt wheat and densely spiked samples. In order to systematize obtained progeny, we proposed a classification according to the morphological structure of the ear, due to which all the obtained material is divided into six morphotypes: spelt, speltoid, a form with a typical soft wheat ear, squarehead, subcompactoid and compactoid (Diordiieva et al., 2018).

The most valuable from a practical point of view are speltoid forms with a typical soft wheat ear and squarehead forms, because they have a well-grained ear with easy grain threshing, which provides high crop yields. Spelt is not characterized by high ear grain content, and, as a result, it has lower productivity. However, the main hindrance to its manufacturing application is the complicated grain threshing (about 60%), which complicates the process of their mechanized harvesting. Forms with a long low-density ear have a number of advantages, in particular rapid ear drying after the rain, which reduces the susceptibility of plants to disease and the formation of large grains with excellent technological properties. In such forms, high pollen fertility and yield have been observed.

**Analysis of hybrids of *Triticum aestivum* L. × *Triticum spelta* L. in terms of productivity and quality of grain.** In order to identify donors of certain economic and valuable traits, the created samples were analyzed according to the level of their display. The research analyzes newly created wheat samples and previously created stable forms that are stored in the genetic collection of the Department of Genetics, Plant Breeding, and Biotechnology. All created materials, taking into account the general plant habits and morphological structure of the ear, were divided into soft wheat, spelt and intermediate (spelt-like) forms. The group of soft wheat included samples with a medium-dense or dense ear (16–28 spikelets per 10 cm of ear) with a typical glume and easy grain threshing. The group of spelt wheat combines forms with a long low-density ear (< 16 spikelets per 10 cm of ear), coarse glume and complicated grain threshing. Spelt-like group include samples that occupied an intermediate position between the parental forms in terms of the morphological structure of the ear. The range of variability on the basis of 'plant height' trait was 52–129 cm. Created samples, according to the classification of Dorofeev (1987) were divided into tall (over 120 cm), medium (105–119 cm), short (85–104) cm), semi-dwarfs (60–84 cm) and dwarfs (< 60 cm). Low-growing and semi-dwarf groups of wheat turned out to be the most numerous and productive.

As a result of research among the progeny of $F_{4–5}$, a significant increase in productivity and quality of grain was recorded in samples 255 and 340, which had a yield of 6.65–6.67 t $ha^{-1}$, protein content of 13.9–14.4%, gluten - 30.4–30.5% (Table 3).

Among the progeny of $F_{5–10}$, samples 1809, 3872, 4075, 6274 and 6750 were singled out, which during the whole research period were characterized by a combination of high productivity (5.97–7.28 t $ha^{-1}$) with high protein (15.5–18.0%) and gluten (36.8–39.2%) content in grain and high flour strength (365–387 alveograph units).

**Table 3.** Economically valuable indicators of soft winter wheat collection samples created by hybridization *Triticum* aestivum L. × *Triticum* spelta L. (Ukraine, Cherkasy region, 2013–2020)

| Breeding material | Plant height, cm | Ear lenth, cm | Thousand grain weight, g | Flour strength (W), a.u. | Gluten content in grain, % | Protein content in grain, % | Productivity, t ha$^{-1}$ |
|---|---|---|---|---|---|---|---|
| | $F_{4–5}$ (average for 2019–2020) | | | | | | |
| Podolianka (st) | 88 | 9.5 | 50.5 | 295 | 29.3 | 13.4 | 6.21 |
| 255 | 88 | 10.1** | 51.2 | 310 | 30.4*** | 14.4*** | 6.65** |
| 278 | 95** | 10.2** | 48.1 | 328** | 31.2*** | 14.8*** | 6.35 |
| 340 | 90 | 10.4** | 51.3 | 308 | 30.5*** | 13.9*** | 6.67** |
| 348 | 115** | 12.5** | 46.7 | 352** | 36.2*** | 16.9*** | 5.62 |
| 365 | 87 | 10.4** | 46.8 | 338** | 34.1*** | 15.6*** | 5.51 |
| 375 | 98* | 11.3** | 48.2 | 335** | 32.2*** | 15.2*** | 5.75 |
| *LSD** | 4* | 0.4* | 1.8* | 15* | 0.2* | 0.1* | 0.25* |
| $x \pm S_x$ | 95.2 ± 8 | 10.5 ± 0.7 | 46.2 ± 1.5 | 342 ± 18 | 33.2 ± 1.6 | 15.3 ± 0.8 | 5.87 ± 0.24 |
| *Cv*, % | 30.1 | 14.5 | 17.1 | 12.5 | 27.6 | 13.8 | 6.11 |
| $S_x$, % | 4.2 | 3.78 | 1.6 | 3.8 | 2.5 | 2.5 | 3.51 |
| | $F_{5–10}$ (average for 2013–2018) | | | | | | |
| Podolianka (st) | 86 | 9.7 | 52.5 | 302 | 29.5 | 13.7 | 6.77 |
| 1692 | 100** | 8.6 | 55.3** | 312 | 30.2*** | 14.1*** | 7.03** |
| 1686 | 78 | 8.8 | 50.2 | 325** | 31.8*** | 15.3*** | 6.41 |
| 1675 | 61 | 9.6 | 48.8 | 335** | 33.5*** | 16.2*** | 5.81 |
| 1678 | 59 | 8.7 | 46.9 | 330** | 32.3*** | 16.1*** | 6.31 |
| 1809 | 79 | 14.1** | 45.6 | 387** | 39.2*** | 18.0*** | 5.97 |
| 3872 | 93** | 10.7** | 50.7 | 368** | 36.8*** | 15.8*** | 7.03** |
| 4075 | 94** | 10.2** | 50.2 | 365** | 36.8*** | 15.9*** | 7.08** |
| 6274 | 95** | 11.8** | 51.8 | 372** | 37.1*** | 15.5*** | 7.12** |
| 6750 | 98** | 10.1** | 51.7 | 375** | 37.2*** | 16.0*** | 7.28** |
| *LSD** | 3* | 0.3* | 1.7* | 18* | 0.2* | 0.1* | 0.22* |
| $x \pm S_x$ | 79.0 ± 9 | 8.8 ± 0.6 | 50.1 ± 1.7 | 347 ± 21 | 32.3 ± 1.8 | 15.3 ± 0.8 | 6.27 ± 0.32 |
| *Cv*, % | 31.1 | 13.7 | 17.1 | 18.5 | 28.6 | 14.2 | 5.09 |
| $S_x$, % | 5.4 | 3.4 | 1.6 | 4.1 | 2.5 | 2.5 | 2.41 |

Note: * – significance of differences between indicators of laboratory tests (protein and gluten content) were determined at the level of significance of $P \leq 0.01$, for other indicators – $P \leq 0.05$; ** – the difference is significant at the level $P \leq 0.05$; *** – the difference is significant at the level $P \leq 0.01$.

**The results of winter wheat breeding.** As a result of a number of studies on interspecific hybridization, individual and kin selection and sample analysis, high-yielding genotypes 1809, 6274 and 3872 were identified, which were transferred to the Ukrainian Institute of Plant Variety Examination under the names Artaplot, Umanska Tsarivna and Freia.

Formal and qualification examination was conducted in 19 branches of the Ukrainian Institute for Plant Variety Examination, located in different regions and geographical zones (Steppe, Forest-Steppe, Polissia) of Ukraine. During the approbation period, Artaplot, Umanska Tsarivna and Freia exceeded the average yield of varieties that passed the State Registration in the previous five years in Polissia and were characterized by high grain quality indicators (Table 4).

**Table 4.** Field research results of indicators of economic suitability of soft winter wheat varieties Artaplot, Umanska Tsarivna, Freia

| Trait | Value | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Artaplot (2016–2018) | | Umanska Tsarivna (2018–2020) | | | Freia (2019–2021) | | |
| | F* | P* | S* | F* | P* | S* | F* | P* |
| Average all varieties yield that have passed the State registration for the previous five years, t ha$^{-1}$ | 6.38 | 5.66 | 5.28 | 6.71 | 5.87 | 5.19 | 6.69 | 5.99 |
| Variety yield at standard humidity (14%), t ha$^{-1}$ | 6.15 | 6.19 | 4.79 | 6.59 | 5.87 | 4.87 | 6.29 | 6.52 |
| ± to average yield | -0.23 | +0.53 | -0.49 | -0.12 | 0.0 | -0.32 | -0.40 | +0.53 |
| Growing season duration, days | 285 | 290 | 268 | 259 | 273 | 273 | 260 | 283 |
| Plant height, cm | 849 | 86 | 86 | 93 | 98 | 104 | 101 | 108 |
| Thousand grain weight, g | 43.7 | 45.2 | 40.4 | 44.1 | 40.5 | 45.2 | 46.0 | 42.1 |
| Protein content, % | 14.8 | 14.3 | 14.5 | 14.0 | 13.3 | 14.4 | 14.7 | 14.1 |
| Gluten content, % | 31.2 | 30.6 | 28.8 | 28.1 | 26.7 | 29.2 | 30.3 | 27.7 |
| Flour strength, a.u. | 280 | 285 | 253 | 244 | 182 | 214 | 237 | 131 |
| Bread volume from 100 g of flour, mL | 900 | 880 | 840 | 970 | 900 | 970 | 940 | 860 |
| Immunity to, score: lodging | 9 | 9 | 9 | 7 | 6 | 9 | 6 | 6 |
| shedding | 9 | 9 | 8 | 9 | 9 | 9 | 8 | 9 |
| drought | 8 | 9 | 7 | 7 | 7 | 5 | 7 | 7 |
| powdery mildew | 8 | 8 | 8 | 7 | 7 | 7 | 8 | 8 |
| brown rust | 8 | 8 | 9 | 9 | 8 | 7 | 7 | 8 |
| fusarium head blight | 7 | 8 | 9 | 8 | 6 | 9 | 8 | 6 |
| frit fly | 9 | 9 | 8 | 9 | 8 | 7 | 9 | 9 |
| corn bug | 9 | 9 | 8 | 8 | 9 | 9 | 9 | 9 |
| Winter resistance, score | 8 | 8 | 8 | 7 | 8 | 9 | 9 | 9 |
| Freezing resistance (according to Plant Production Institute named after V. Ya. Yuriev) | 7.2 | | 6.7 | | | 6.5 | | |

Note: *S – Steppe; F – Forest steppe; P – Polissia.

According to the results of the qualification expertise, the varieties Artaplot (in 2018), Umanska Tsarivna (in 2020) and Freia (in 2021) are included in the State Registry of Plant Varieties Suitable for Distribution in Ukraine (2021) and recommended for cultivation in Polissia.

## CONCLUSIONS

1 Breeding technologies for creating highly productive forms of soft winter wheat by interspecific hybridization of *Triticum aestivum* L. × *Triticum spelta* L. have been improved.

2 Studies have shown that plant height and ear length in hybrids of *Triticum aestivum* L. × *Triticum spelta* L. are inherited by the type of intermediate inheritance or partial negative inheritance; the grain number in the ear - by type of intermediate inheritance or partial positive dominance; grain weight of the ear - by type of superdominance or partial positive dominance.

3 In $F_2$ hybrids there is a dihybrid cleavage into forms with speltoid, squarehead and normal ears, with a quantitative predominance of speltoid plants, which indicates the control of the trait 'ear shape' by two non-allelic genes. The ear shape of the soft wheat original varieties in relation to speltoid wheat varieties turned out to be recessive, but at the same time it was dominant to the squarehead form. Regardless of the genotypes of soft wheat included in the combination of crossbreeding with spelt wheat, red color ear indication was determined by a monogenic type of inheritance.

4 Varieties of soft winter wheat Artaplot, Umanska Tsarivna and Freia were created, which is included in the State Registry of Plant Varieties Suitable for Distribution in Ukraine and recommended for cultivation in Polesia.

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