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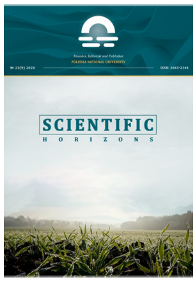

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Creation of source material by attracting different varieties of common winter wheat in breeding for adaptability, productivity, and grain quality

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Abstract. The relevance of the subject matter lies in the constant pursuit to improve and improve varieties of common winter wheat by using various genetic resources and breeding methods to achieve better adaptability, higher productivity, and superior grain quality. The purpose of the study was to expand the genetic diversity of common winter wheat, which combines high productivity and adaptability for further breeding in the context of food security. The research uses generally accepted methods and their modifications, which ensured high objectivity of the results obtained. Phenology,

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morphological studies, and evaluation of breeding material based on economically valuable characteristics were carried out according to the methodology for conducting an expert examination of plant varieties. It was found that the involvement of the Ferrugineum 1239 sample before crossing allows forming a hybrid material with increased resistance against adverse abiotic environmental factors, which was observed on crops of breeding numbers 0284/18/1, 0135/18, 0209/18/1, etc. It was proved that consideration of the nature of inheritance and preservation of features of ear productivity elements at the level of the best parent components in combination with high quantitative features of the number of grains from the main ear, the weight of grains from the main ear, the weight of 1,000 grains in hybrid populations of the first generation, the above combinations of crosses *Triticum aestivum* var. *erythrospermum* with *Triticum aestivum* var. *barbarossa*, *Triticum aestivum* var. *erythrospermum* with *Triticum aestivum* var. *ferrugineum* can be valuable in the selection of common winter wheat. The practical value of the study lies in the fact that the findings expand information about the use of erythrospermum and lutescens and other varieties of common wheat in breeding for the productivity and quality of common winter wheat: *Triticum aestivum* var. *barbarossa* and *Triticum aestivum* var. *ferrugineum*. As a result of the research, the best samples (F_4) were transferred to the Nosivka Breeding and Research Station for further breeding work

Keywords: common winter wheat; varieties; *erithrospermum* Körn.; *lutescens* Alef.; *ferrugineum* Alef.; *barbarossa* Alef.; selection; new hybrid forms; evaluation

INTRODUCTION

Research and development of new varieties of common winter wheat with high adaptability to changing climatic conditions, high productivity, and superior grain quality is an extremely urgent task to ensure a stable harvest, increase productivity, and meet the needs of the population in food resources. The study of common wheat obliges producers to grow varieties that meet modern requirements – characterised by high environmental stability, productivity, and grain quality (Filip *et al.*, 2023). In turn, such issues require the breeder to work hard and responsibly to form the appropriate source material for further breeding (Suchowilska *et al.*, 2020). According to Kumar *et al.* (2022), climate change leads to a loss of biodiversity, and therefore, overexploitation and selection by individual traits have led to a decrease in the genetic diversity of common wheat. However, most breeders are aware of possible problems and work to create varieties (lines) of common wheat that are resistant to climate and adverse biotic environmental factors, using the types and diversity of wheat endowed with a complex of important genes (Pour-Aboughadareh *et al.*, 2021).

Varieties of common wheat have a number of genetic characteristics, which gives, first of all, geneticists and breeders valuable information for forming the source material and building a variety model. Chinese researchers Yang *et al.* (2023) suggest that the morphological features and physiological features of common wheat varieties have been honed over time, in particular, about 5.5 million years ago as a result of spontaneous crossing of two wild cereals – *Triticum urartu* Tumanian ex Gandilyan (2n=14) and *Aegilops* (not yet identified, but close to *Aegilops speltoides*, 2n=14), which separated from a common ancestor about 7 million years ago, formed the wild spelt, or wild emmer (*Triticum dicoccoides* (Körn. ex Asch. & Graebner) Schweinf., 2n=28), as the closest but not a direct carrier of subgenome B. Other researchers (Dvorak *et al.*, 2012) add that less than 1 million years ago wild spelt (*Triticum dicoccoides* gave rise to fertile tetraploid wheat *Triticum turgidum* (2n=28), that is, an allotetraploid in the nucleus of which the A and B genomes function.

According to Laugherotte *et al.* (2022), approximately 8-10 thousand years ago as a result of natural hybridisation of *Triticum turgidum* with *Aegilops tauschii* (DD, 2n=14) common allohexaploid wheat was formed (*Triticum aestivum* L., 2n=42), which gave rise to the emergence of modern genotypes. Therefore, common wheat, which has 42 chromosomes and about 17 billion base pairs, is the result of a combination of three diploid genomes – AABBDD and consists of 90-96 thousand genes evenly distributed over 6 sets of chromosomes of genomes A, B, and D, where the A – haploid genome close to *Triticum urartu*, B – haploid genome *Aegilops*, close to *Aegilops speltoides*, and the D – haploid genome of a species close to *Aegilops tauschii*, in this case, the latter is the result of hybridisation between *Triticum urartu* and *Aegilops speltoides* (Haider, 2013).

According to the paper (Mirzaghaderi & Mason, 2019), the D genome of allohexaploid common wheat is the least diverse of the three wheat genomes and is undoubtedly less diverse than that of the diploid progenitor genome *Aegilops tauschii* (2n=DD), which is important when selecting varieties of common wheat as a starting material. According to Li *et al.* (2022), the donor subgenome in common wheat is a separate and most likely extinct diploid species that has separated from the carrier ancestor of the B genome, to which the existing species *Aegilops speltoides* belongs. Modern research indicates the importance of *Aegilops* muticum as a donor of common wheat subgenomes B and D (Avni *et al.*, 2021; Li *et al.*, 2022). Therefore, the process of introgression – from wild emmer wheat to domesticated emmer wheat or bread wheat – has become an important mechanism in increasing genetic diversity during the evolution of common wheat (Zhou *et al*., 2020). In this regard, a wide variety of common wheat biotypes has been created since the domestication of wheat by unconscious selection based on adaptive characteristics, and over time – by empirical selection, which is characterised by a unique biopotential both in terms of grain yield and quality, and tolerance to adverse biotic and abiotic environmental stresses (He *et al*., 2019).

However, the biological potential of common wheat varieties is not fully used in breeding, in particular, during the period of global climate change. For example, in Ukraine's grain sector, common winter wheat is sown on an area of 6-8 million hectares, summer wheat – 160-400 thousand hectares, represented by a number of varieties (in particular, as of 2023, more than 721 varieties of common wheat are registered in the State register of plant varieties (State register of plant varieties, 2023), of which only awned (*erythrospermum*) and awnless (*lutescens*) varieties dominate. It remains relevant to introduce new genes into modern wheat varieties to reduce the negative impact of pathogens, and according to Singh *et al*. (2022), among 200 of which, 50 cause significant economic damage (about 20% of wheat crops are lost annually).

The purpose of the study was to develop new genotypes of common winter wheat, combining high adaptability, productivity, and grain quality for further breeding in the context of food security.

MATERIALS AND METHODS

The study was conducted during 2016-2021 at the Nosivka Breeding and Research Station of the V.M. Remeslo Myronivka Institute of Wheat the National Academy of Agrarian Sciences of Ukraine (NAAS of Ukraine) (southern part of Polissia of Ukraine) and the Institute of Horticulture of the NAAS of Ukraine (Northern Forest-Steppe of Ukraine). Based on the designed model of the variety, a programme was developed in which the ways of breeding new raw material of common wheat were consistently substantiated. In 2016-2017, breeding work began with a nursery of source material, which consisted of a collection nursery represented by varieties from different countries of the world, which are sources and donors of economically valuable traits and biological properties. The total set of source materials was formed at the expense of the author's own line database and samples provided by the National Centre for Plant Genetic Resources of Ukraine of the V.Y. Yuriev Institute of Plant Production of NAAS of Ukraine. Agricultural techniques for growing winter wheat are generally accepted for the Polissia and Forest-Steppe zones of Ukraine. Seeds intended for sowing in nurseries of the source material were placed in parchment bags, on which the plot number, the number or mass of grains, and the name of the nursery were indicated. Sowing of the source material (collections, hybrids of different generations) was carried out manually. During 2018-2022, the hybrid nursery included first- to fourth-generation (F_{1-4}). Hybrid seeds were sown separately, one ear – on one or two rows, the number of which depended on the number of selected ears from each combination, the number of parent forms and standard plots. The collection of common winter wheat source material was evaluated for productivity, lodging resistance, and disease resistance for further creation of new forms with a complex of valuable economic characteristics according to the methods of plant variety expertise (Tkachyk *et al*., 2016).

The best varieties (lines) of common winter wheat for crossing were sown manually in autumn with an area of 2 m^2 each, with a row spacing of up to 20 cm. Selection of parent pairs for paired (simple) crosses and hybridisation was carried out in 2018 (Table 1, Fig. 1).

Table 1. *Parent forms of common winter wheat of species erythrospermum (Erithrospermum Körn.) and lutescens (Lutescens Al.) used in crossing with common wheat varieties barbarossa (Barbarossa Al.) and ferrugineum (Ferrugineum Al.)*

No.	Name of parent forms	Origin
1.	PKB Rodika	Romania
2.	L59-95 (UA0108016)*	Donska n/k × [(Maris Madler × Pony) × Donska n/k]
3.	Kyivopolka (UA0123746)	(Chisinau intensive × (Polisska 87 × Kiyanka)
4.	Svyatdonivka (UA0123749)	00239 × Donska n/k

Note:* *– number in the national catalogue assigned by the National Centre for Plant Genetic Resources of Ukraine*
Source: *developed by the authors*

1 2 3 4 5 6 7 8

Figure 1. *Parent components (varieties, lines) involved in hybridisation: 1. Triticum aestivum L. var. ferrugineum (Ferrugineum 1239); 2. Triticum aestivum L. var. barbarossa; 3. Kyivopolka*; 4. PKB Rodika**; 5. L 59-95; 6. Svyatdonivka*; 7. Priaspa**; 8. KS 14***

Note: ** species erithrospermum; ** species lutescens*

Source: *photographed by the authors*

The main method that was used to increase hereditary variability in populations is hybridisation. Crossing was carried out according to the scheme: simple paired. Crossing was carried out by pollination of neutered TVEL spikelets by the Norman Borlaug Global Rust Initiative (2020). Phenological observations were carried out mainly for the following phases of plant development: germination, tillering, earing, maturation (waxy, full ripeness). Field germination and plant survival were determined. Resistance to lodging was evaluated on a 5-point scale according to the method of examination of plant varieties (Tkachuk *et al.*, 2016).

The mass of seeds for sowing was considered in the section of plots and repetitions. Hybrid populations F_2 (grain F_3), which received a positive rating in F_1, were sown in two ecological points (southern part of Polissia and the Northern Forest-Steppe) to make better use of the spectrum of genetic variation for the selection of elite plants of the corresponding agroecotypes. Generation F_1-F_4 sown in a hybrid nursery, and next to F_1-F_2, parental forms were sown manually along the edges – after 20-30 numbers. Working with split generations consisted of selecting biotypes that correspond to the purpose of the work. The protein and gluten content were determined by infrared spectrometry (Chen *et al.*, 2017). Harvesting was carried out manually during the full ripeness phase.

The degree of dominance was calculated by the equation:

$$hp = \frac{F1-Mp}{Pmax-Mp}$$

where: *hp* – degree of dominance; *F*1 – indicator of the trait of a particular hybrid; *Mp* – average value of parent forms; Pmax – maximum value of one of the parent components.

The data was grouped according to classification by G.M. Beil, R.E. Atkins (according to Zymogliad *et al.,* 2021): partial negative dominance $-1\leqslant hp<-0.5$, partial positive dominance $+0.5<hp \leqslant+1$, positive over-dominance $hp>+1$, intermediate inheritance $-0.5\leqslant hp\leqslant0.5$, negative over-dominance (depression) $hp<-1$. The reliability of the difference between the average values of indicators in parent forms and hybrids of the first generation was determined using variance analysis. The degree of excess of the trait level in first-generation hybrids over their parents was determined by true heterosis $\dot{H}bt$, which allows identifying the highest level of manifestation of the trait of first-generation hybrids in comparison with the best parent form and assessing the breeding value and probability of forming transgressive forms in a hybrid combination.

When determining the true heterosis, the equaiton was used:

$$Hbt = \frac{F1-BP}{BP} \text{x } 100\ (\%)$$

where Hbt – true heterosis; F1 – value of the trait in the first-generation hybrid; BP – value of the trait in the best of the parent components.

Significant values were values that exceeded the indicators of the best parent component by more than 5%. Trait inheritance Rate (N^2) was determined by variations of parent components and hybrids:

$$\dot{H}^2 = \frac{\sigma_G^2}{\sigma_P^2},$$

where σ_G^2 – variation genetic; σ_P^2 – variations of parent components.

Inheritance rate (h^2) was determined using regression coefficients between the values of traits of parent components and hybrid generations by the equaiton:

$$h^2 = b_{БГ}\ ,$$

where h^2 – inheritance rate in a narrow sense; $b_{БГ}$ – regression coefficient between the trait in parent components and hybrids.

The dependence of indicators in hybrids on the average value of indicators of traits in parent components was determined by the equaiton:

$$y = f(\dot{x}) + \varepsilon$$

where *y* – amount of change in the indicator; *f*(x) – current factor; ε – random error describing the effect of factors not considered in the experiment. The regression coefficient was considered the average inheritance coefficient.

The reliability of the results was evaluated using the MS Excel programme.

RESULTS

As noted by Moskalets *et al.* (2020; 2022) the breeding process can be divided into three consecutive stages: development of a model of the future variety and determination of ways to implement it; selection of initial forms and creation of synthetic material for selection; development of the variety as a stable biological system.

In the process of crossing hexaploid wheat of the common variety erythrospermum (*Triticum aestivum* var. *erythrospermum Körn.*) with common wheat varieties barbarossa (*Triticum aestivum* L. var. *barbarossa* (Alef.) Mansf.) and ferrugineum (*Triticum aestivum* L. var. *ferrugineum* Al.), which also belongs to the group of hexaploid wheat (2n=42), fertile hybrids are formed. Crossing increases the number of genetic recombinations. For first-generation hybrids (F_1) grain binding is noted, that is, there is a normal course of chromosome conjugation in meiosis, and viable gametes are formed, the fusion of which gives a viable grain.

Hexaploid variety of common wheat *Triticum aestivum* L. var. *barbarossa* (Alef.) Mansf. is known as a source of signs of grain quality. First generation hybrids (F_1) *Triticum aestivum* var. *erythrospermum* Körn. × *Triticum aestivum* L. var. *barbarossa* (Alef.) Mansf. were mostly low-growing – up to 105 cm tall, while they were marked by a strong stem, a spinous red spike with tomentous spikelet scales and an oval or egg-shaped red powdery grain. In F_2-F_3 for generations, plants that were similar in phenotype were isolated with different frequency *Triticum aestivum* var. *erythrospermum* Körn., but combined the signs *Triticum aestivum* L. var. *barbarossa* (Alef.) Mansf. (Fig. 2).

1 2 3

Figure 2. *Main ear of the best breeding numbers F_4: 1. 0135/18 (Kyivopolka × Triticum aestivum L. var. ferrugineum (Alef.) Velican.; 2. 0284/18 (analogue × Triticum aestivum L. var. ferrugineum (Alef.) Velican.; 3. 0133/18/3 (Kyivopolka × Triticum aestivum L. var. barbarossa (Alef.) Mansf.)*

Source: *photographed by the authors*

First generation hybrids (F_1) *Triticum aestivum* var. *erythrospermum* Körn. × *Triticum aestivum* L. var. *ferrugineum* Alef. were characterised as medium-sized – 105-120 cm and prone to lodging, with long (>25 cm), narrow (<1 cm) green leaves, spinous and red-yellow with a bronze sheen ear at full ripeness and red grain. Hybrids of the first generation of combinations of both erythrospermum × barbarossa and erythrospermum × ferrugineum were characterised by a low grain weight from the ear (<1.5 g) and a weight of 1,000 grains (<40 g), compared with the parent forms of the erythrospermum variety, which had indicators of more than 2 g and 50 g, respectively. In the second and third generations, plants with a higher grain weight from the main ear were selected, which exceeded the parent forms of barbarossa and ferrugineum, and amounted to more than 2 g. The minimum value of the inheritance coefficient used for successful selection in generations F2-3 was 0.50. For hybrids of combinations of Kyivopolka × *Triticum aestivum* L. var. *barbarossa* and *Triticum aestivum* L. var. *barbarossa* × PKB Rodika, the ratio of length inheritance coefficients was 0.81/0.71 and 0.55/0.46, respectively, the difference between which is insignificant, this indicates that the genotypic variability in these hybrids is due to additive effects of genes, and the selection by phenotype is close to the selection of the corresponding forms (Table 2).

Table 2. Morphological features and indicators of productivity elements of parent forms and hybrids (F_3)

Selection number	Name of the parent forms involved in crossing	Plant height, cm	Colour of the ear	Presence of awns/ tomentum of spikelet scales	Ear length, cm	Number of grains from the main ear, pcs.	Weight of grains from the main ear, pcs.	Weight of 1,000 grains, g
342/16	*Triticum aestivum* L.var. *ferrugineum*	101.5	light brown	yes/no	8.7	38.2	1.85	40.4
368/16	*Triticum aestivum* L. var. *barbarossa*	98.7	brown	yes/yes	9.5	41.5	1.92	45.3
103/18	L59-95**	85.8	straw yellow	yes/no	8.3	45.6	2.11	50.5
166/17	PKB Rodika*	92.5	white	no/no	10.5	49.5	2.20	48.6
159/16	Kyivopolka**	87.5	white	yes/no	10.7	52	1.95	51.3
158/16	Svyatdonivka**	79.5	white	yes/no	9.5	59	2.72	52.5
101/16	Analog**	88.3	straw yellow	yes/no	9.1	48.7	2.03	46.7
0208/18/2	*Triticum aestivum* L. var. *barbarossa* × PKB Rodika	121.5	brown	no/yes	11.2	54.5	2.36	47.2
0208/18/3	*Triticum aestivum* L. var. *barbarossa* × PKB Rodika	96.5	white	no/no	11.5	44.6	2.17	50.4
0207/18/1	*Triticum aestivum* L. var. *barbarossa* × Svyatdonivka	98.3	white	yes/yes	11.0	57	2.63	48.5
0209/18/1	*Triticum aestivum* L. var. *barbarossa* × *Triticum aestivum* L. var. *ferrugineum*	75.5	brown	yes/yes	8.5	48	2.42	48.4
0209/18/3	*Triticum aestivum* L. var. *barbarossa* × *Triticum aestivum* L. var. *ferrugineum*	103.6	brown	yes/yes	9.9	59	2.81	49.2
0212/18/1	*Triticum aestivum* L. var. *barbarossa* ×*Triticum aestivum* L. var. *ferrugineum*	91.4	brown	yes/yes	8.9	40	1.98	49
0212/18/2	*Triticum aestivum* L. var. *barbarossa* × *Triticum aestivum* L. var. *ferrugineum*	110.5	brown	yes/no	10.2	53	2.68	51.2
0137/18/1	L 59-95 × *Triticum aestivum* L. var. *barbarossa*	83.5	red-brown	yes/no	10.7	81	4.14	51.6
0133/18/1	Kyivopolka × *Triticum aestivum* L. var. *barbarossa*	107.5	brown-yellow	yes/no	11.3	56	2.7	50.2
0133/18/3	Kyivopolka × *Triticum aestivum* L. var. *barbarossa*	93.4	light brown	yes/no	10.1	74	3.82	53.2
0135/18	Kyivopolka × *Triticum aetsivum* L. var. *ferrugineum*	87.8	light brown	yes/no	11.2	44	2.24	52.8
0284/18/1	Analog** × *Triticum aestivum* L. var. *ferrugineum*	90.5	brown	yes/no	9.7	65	3.2	52.2

Note: **species lutescens; **species erythrospermum*
Source: *compiled by the authors*

When analysing the yield structure of hybrids in the first generation, the number and weight of grains in the main ear exceeded the parent components in most of the combinations under study. In combination L 59-95 × *Triticum aestivum* L. var. *barbarossa*, it was noted that the degree of phenotypic dominance (hp) in the inheritance of the trait the number of grains in the ear in the hybrid material was 16.0%, and the trait – the mass of grains from the ear – 21.3, which indicates a positive over-dominance. This fact is evidenced by indicators of the degree of phenotypic dominance and other combinations of Kievopolka × *Triticum aestivum* L. var. *barbarossa* – 4.4 and 94.5%, Analog × *Triticum aestivum* L. var. *ferrugineum* – 4.4 and 14.0%, respectively. According to the economically valuable trait, the weight of 1,000 seeds of the above-mentioned hybrids of the first generation significantly exceeded the parent components.

As a result of hybridological analysis of hybrids of the first generation when crossing samples *Triticum aestivum* L. var. *barbarossa* with semi-dwarf lines and varieties of common wheat of the erythrospermum variety, inheritance of traits of the number and weight of grain from the ear, the weight of 1,000 grains, and the length of the ear according to the type of positive super-dominance was noted. The inheritance of the number of grains in the main spikelet trait by the type of positive super-dominance was observed in many hybrids of the studied combinations. It was found that almost all samples overwintered well during 2018-2022 and were assigned to the first group, in which the condition of the ground part was only up to 20-25% damaged, and the winter hardiness score was not lower than 8 (Table 3).

***Table 3**. Ripeness group and indicators of resistance to adverse environmental factors of hybrids (F_3) compared to parent forms*

Selection number	Name of the parent forms involved in crossing	Ripeness group	Winter hardiness	Drought resistance	Resistance to shedding	Resistance to lodging
			score			
342/16	*Triticum aestivum* L. var. *ferrugineum*	mr*	9.0	9.0	8.7	7.0
368/16	*Triticum aestivum* L. var. *barbarossa*	mr	7.2	9.0	8.0	8.0
103/18	L59-95	me	8.5	8.5	9.0	8.7
166/17	PKB Rodika	mr	8.0	7.0	8.5	8.0
159/16	Kyivopolka	me	8.6	8.5	8.3	9.0
158/16	Svyatdonivka	mr	9.0	9.0	8.5	8.0
101/16	Analog	er	8.6	8.2	8.2	8.7
0208/18/2	*Triticum aestivum* L. var. *barbarossa* × PKB Rodika	mr	8.2	8.0	8.5	8.5
0208/18/3	*Triticum aestivum* L. var. *barbarossa* × PKB Rodika	mr	7.5	7.0	9.0	8.7
0207/18/1	*Triticum aestivum* L. var. *barbarossa* × Svyatdonovka	mr	8.7	8.5	8.5	8.0
0209/18/1	*Triticum aestivum* L. var. *barbarossa* × *Triticum aestivum* L. var. *ferrugineum*	mr	9.0	9.0	8.5	8.0
0209/18/3	*Triticum aestivum* L. var. *barbarossa* × *Triticum aestivum* L. var. *ferrugineum*	ml	9.0	9.0	8.5	7.2
0212/18/1	*Triticum aestivum* L. var. *barbarossa* × *Triticum aestivum* L. var. *ferrugineum*	mr	8.5	8.7	8.2	8.5
0212/18/2	*Triticum aestivum* L. var. *barbarossa* × *Triticum aestivum* L. var. *ferrugineum*	mr	8.0	8.5	8.8	7.7
0137/18/1	L 59-95 × *Triticum aestivum* L. var. *barbarossa*	me	8.5	9.0	8.5	7.5
0133/18/1	Kyivopolka × *Triticum aestivum* L. var. *barbarossa*	mr	8.5	9.0	8.0	7.5
0133/18/3	Kyivopolka × *Triticum aestivum* L. var. *barbarossa*	mr	8.5	8.5	8.3	8.0
0135/18	Kyivopolka × *Triticum aestivum* L. var. *ferrugineum*	mr	9.0	9.0	8.0	8.5
0284/18/1	Analog** × *Triticum aestivum* L. var. *ferrugineum*	er	9.0	9.0	8.5	8.5

***Note:** ml – middle-late; mr – middle-ripened; me – middle-early; er – early-ripened*
***Source:** compiled by the authors*

Breeding numbers 368/16 and 0208/18/3 were assigned to the second wintering group, as their leaf surface was damaged by more than 25%. But it is worth noting that sample 368/16 or *Triticum aestivum* L. var. *barbarossa* during April-June, was characterised as highly drought-resistant (9 points), which was also noted in hybrid plants of breeding numbers 0209/18/1, 0209/18/3, 0133/18/1 and 0137/18/1, which were created using the above number.

The Ferrugineum 1239 sample was characterised by high winter and drought resistance (9 points). The involvement of this sample in crossing significantly resulted in an increase in resistance against adverse abiotic environmental factors, which was observed on crops of breeding numbers 0284/18/1, 0135/18, 0209/18/1, etc. However, the Ferrugineum 1239 sample of common wheat of the ferruginem species showed an increased tendency to lodging. During 2018-2022, the average score of the sample's resistance to lodging was 7.0 points, which is lower compared to *Triticum aestivum* L. var. *barbarossa* and hybrids that are being created *Triticum aestivum* L. var. *ferrugineum* (Ferrugineum 1239) used.

The use in hybridisation of early-maturing common wheat varieties erythrospermum Analog and medium-early line L 59-95 with wheat varieties barbarossa and ferrugineum allowed obtaining, in comparison with the latter, earlier-maturing biotypes with high resistance to adverse abiotic environmental factors. These are the selection numbers 0284/18/1 (Analog × *Triticum aestivum* L. var. *ferrugineum*), 0137/18/1 (L 59-95 × *Triticum aestivum* L. var. *barbarossa*). In general, it is worth noting that the breeding numbers of new hybrids were characterised as resistant to shedding.

According to the State Standard of Ukraine DSTU 3768:2010 (2010), common wheat is classified into 4 classes, which are regulated by quality indicators, in particular, wheat of Class 1-3 is used in the domestic market for food needs (bakery and flour industry) and exports, and wheat of Class 4 – for food and non-food needs. According to Table 4, it can be seen that almost all samples – both source material and hybrids – belong to Class 1 of wheat quality in terms of the mass fraction of protein, in terms of dry matter, and the mass fraction of raw gluten.

Table 4*. Grain quality indicators of hybrids (F_3) compared to parent forms*

Selection number	Name of the parent forms involved in crossing	Mass fraction of protein, in terms of dry matter, %	Mass fraction of raw gluten, %
342/16	*Triticum aestivum* L. var. *ferrugineum*	14.7	29.5
368/16	*Triticum aestivum* L. var. *barbarossa*	16.5	31.3
103/18	L59-95	14.5	28.5
166/17	PKB Rodika	14.0	29.5
159/16	Kyivopolka	13.6	29.0
158/16	Svyatdonivka	13.5	28.2
101/16	Analog	14.8	30.5
0208/18/2	*Triticum aestivum* L. var. *barbarossa* × PKB Rodika	14.2	29.7
0208/18/3	*Triticum aestivum* L. var. *barbarossa* × PKB Rodika	16.4	31.8
0207/18/1	*Triticum aestivum* L. var. *barbarossa* × Svyatdonivka	14.7	30.7
0209/18/1	*Triticum aestivum* L. var. *barbarossa* ×*Triticum aestivum* L. var. *ferrugineum*	15.0	32.5
0209/18/3	*Triticum aestivum* L. var. *barbarossa* × *Triticum aestivum* L. var. *ferrugineum*	13.5	28.4
0212/18/1	*Triticum aestivum* L. var. *barbarossa* × *Triticum aestivum* L. var. *ferrugineum*	14.2	28.8
0212/18/2	*Triticum aestivum* L. var. *barbarossa* × *Triticum aestivum* L. var. *ferrugineum*	16.0	31.7
0137/18/1	L 59-95 × *Triticum aestivum* L. var. *barbarossa*	16.1	32.5
0133/18/1	Kyivopolka × *Triticum aestivum* L. var. *barbarossa*	14.6	29.5
0133/18/3	Kyivopolka × *Triticum aestivum* L. var. *barbarossa*	16.8	32.5
0135/18	Kyivopolka × *Triticum aestivum* L. var. *ferrugineum*	14.0	27.5
0284/18/1	Analog** × *Triticum aestivum* L. var. *ferrugineum*	14.0	28.5

Source: *compiled by the authors*

It was found that the grain of common wheat of the barbarossa variety is characterised by a high content of protein and gluten. The involvement of the above-mentioned wheat in hybridisation improved the grain quality of the hybrid material, in particular, samples with a protein content of at least 16% and raw gluten content of at least 30% were selected based on the selection results. These include the selection numbers 0208/18/3, 0212/18/20133/18/3, and 0137/18/1.

Based on the above results, there are objective possibilities when crossing different varieties of common wheat to create new forms with an increased potential for productivity and resistance to adverse environmental factors, since these properties are controlled by different genetic systems. The selected hybrids, which differ in the nature of the manifestation of traits and are characterised by a satisfactory combination of them with productivity, can be an excellent starting material for further breeding of common wheat for adaptability and productivity.

DISCUSSION

The use of the lutescens varieties in breeding combination with others, in particular erythrospermum, allows forming a valuable source material in terms of adaptability and quality. In particular, researchers at the V.Y. Yuriev Institute of Plant Industry of NAAS of Ukraine (Leonov *et al.*, 2020) determined that the lutescens wheat species are carriers of Vrn genes, in particular, the lutescens 540 variety with one dominant Vrn-A1 gene, the lutescens 516 variety with the dominant Vrn-A1 allele and is polymorphic to the VrnB1 gene, and the above-mentioned varieties are characterised by an increased content of carotenoids in flour, which is important in breeding for quality. Moreover, considerable attention in breeding is attracted by wheat of the albidum species, since along with lutescens, it serves as a donor of awnless trait, and was also characterised by high grain quality. As a result of its use in hybridisation, early-maturing awned and awnless varieties were created with high grain quality and average indicators of dough and bread. Also of great importance in the selection of common wheat are the species gostianum and velutinum, based on which the varieties Koral Odeskii and Ulyanivka, respectively, are created. The varieties milturum and caesium are the most common among the varieties of spring development type. In particular, the latter variety is common in the countries of Transcaucasia. Varieties of nigriaristatum, erythroleucone, alborubrum, and grekum are not very common. However, the Azerbaijan Research Institute conducts serious breeding studies with the latter variety, in particular, the early-maturing white-grain variety Gobustan has been created, which is characterised by high drought resistance, yield, and grain quality (Hasanova *et al.*, 2019). Also in Azerbaijan, work is carried out with a ferrugineum variety. In particular, in the conditions of the unsecured boghara of Nagorny Shirvan (780-810 m above sea level, Kobustan Zonal Experimental Station, the above-mentioned research institute), not only *lutescens*, *erythrosperm* common wheat (*Triticum aestivum* L.) varieties are studied, but also biotypes of the variety *ferrugineum* in which, according to the results of research, winter and frost resistance is high – at the level of 8-9 points and, accordingly, high resistance to fungal diseases, including yellow rust is high in epiphytic years – about 68%.

Local samples of *Triticum aestivum* L. ps. *barbarossa*: Azgr-9558, Azgr-9556, Azgr-9555, etc., and *Triticum aestivum* L. var. *ferrugineum* (Alef.) Mansf.: Azgr-9539, Azgr-9538, etc., are registered at the Institute of Genetic Resources of the National Academy of Sciences of Azerbaijan, which are widely used in drought tolerance breeding (2020).

The Scientific Centre for Agrobiotechnology of Armenia preserves a number of samples of common wheat, which are represented by varieties *Triticum aestivum* L. var. *Ferrugineum* Alef. collected in the Syunik region and *Triticum aestivum* L. var. *lutescenc* Alef. selected in the Kotayk region of the above-mentioned country and is a valuable source material for breeding for adaptability to adverse abiotic environmental factors (Agrobiotechnology Scientific Center Branch, 2020).

The European search catalogue of plant genetic resources also reports that the Georgia Bank of Plant Genetic Resources has a sample of *Triticum aestivum* L. var. *ferrugineum* Alef., collected at an altitude of 552 m, which is stored at the I. Lomuri Institute of Agriculture and is in demand among geneticists and breeders (EURISCO, 2023). Also in the above-mentioned country, as one of the Centres of wheat origin and the birthplace of numerous wheat varieties, many of which are endemic, the winter wheat variety Tsiteli doli (*Triticum aestivum* var. *ferrugineum*) was created, which is adapted to the conditions of heavy poor soils, drought and frost-resistant, and highly resistant to diseases. Breeders take this variety as a standard for grain yield and quality. Although when it is grown on non-irrigated land (which is the norm), the yield is somewhat reduced and there is a tendency to lodging, but the taste and baking qualities are better than when grown in irrigated fields. Bread baked from this flour has a characteristic taste, bluish colour, and retains its freshness for up to a week. Today, Akhaltsihis Tsiteli doli is grown only in 25-30 farms in Georgia, which grow it for their own needs and for bakeries (Slow Food Foundation for Biodiversity, 2023). Another variety is Vardzia, which belongs to the species *Triticum aestivum* var. *ferrugineum* (Alef.) Velican, created by the Institute of Agriculture of Georgia, by the method of induced mutagenesis from the population variety Hulugo, by the effect of a 0.01% solution of the chemical mutagen NMM (nitrosomethylurea) on seeds. The above-mentioned variety is characterised by high drought resistance and resistance to fungal diseases and has been allowed to spread in all regions of Georgia with common wheat breeding and crop production (Natsarishvili *et al.*, 2016).

It is worth noting that the search for genetic diversity of ancient wheat varieties for breeding is also carried out in other countries, in particular in Turkey (regions of Central and Central-Eastern Anatolia and Cappadocia), the dominant local species of common wheat (87.5%) with a wide variety of morphotypes have been identified: albirubrum, albidum, erythroleucum, delfium, ferrugineum, and erythrospermum. Biotypes of the above-mentioned species are carefully preserved in farm fields in Turkey, Afghanistan, Iran, etc., as part of the CIMMYT project to preserve ancient wheat species, multilocal testing them, as valuable genetic resources for solving breeding and crop production problems (Morgounov *et al.*, 2016).

In 2010-2013, an inventory of ancient wheat varieties that are still grown by ancient farmers was conducted on the territory of Uzbekistan, as a result of which it was found out that most of them belong to the species *ferrugineum*, *erythrospermum*, and *greacum*, it is important for the development of these varieties of source material to create varieties adapted to the conditions of the above-mentioned country (Baboev *et al.*, 2021). Similar studies were conducted by other researchers (Morgounov *et al.*, 2021) in many regions of Afghanistan, where the majority of local common wheat varieties were attributed to the species erythrospermum and greacum, accounting for more than 80%. And the territory of Kazakhstan, which is characterised by a variety of natural and climatic zones and extreme instability of meteorological conditions for years and seasons of the year, which requires the breeder to create genetically diverse varieties of winter wheat of the southern non-irrigated mountain agroecotype, represented by the following species: barbarossa, pyrotrix, lutescens, ferrugineum, erythrospermum, etc. It is worth noting that the involvement of biotypes of the barbarossa species in breeding allows obtaining varieties characterised by an average grain yield and winter hardiness, a high content of gluten (36.4 and 37.3%) and protein (15.8 and 18.2%), in particular, these are the well-known varieties Alatai and Karasai (Wheat of Kazakhstan, 2020).

In Ukraine, less attention is paid to the study of biotypes of the barbarossa and ferrugineum, in particular when using induced mutagenesis. In particular, at the Genetics, breeding and seed production of Bila Tserkva National Agrarian University from the seeds of mutant 42 (which was obtained by the action of DMS 0.025% concentration on seeds of the Ilyichivka variety) re-treated with ethylenimine 0.125% concentration, forms of dwarf (<65 cm) and semi-dwarf (>65-80 cm) types of development and varieties erythrospermum, suberitrospermum, and barbarossa were obtained, the latter biotypes were characterised by average productivity, inferior to the previous two (Khomenko & Fedorenko, 2011).

It is worth noting that the samples of *ferrugineum* are a standard of winter hardiness, such as the sample Ferrugineum 1239 (9 points) and resistance to the expression of hybrid necrosis and dwarfism and white-cap chlorosis genes in common varieties in Armenia (Alti-agach, Akhtamar, Armyanka, Karmir slfaat, Leninakan 3, Leninakan 216, etc.) (Sadoyan, 2017).

As noted by Yu. Kolupaev *et al.* (2023), over the past decades, Ukraine has experienced abnormally high air temperatures and droughts at different times of the year, including the autumn period, which leads to the establishment of stressful conditions for winter cereals, especially common wheat at the very beginning of ontogenesis. Therefore, selection to create sources and donors of valuable traits, including those that will determine the adaptability and quality of the new gene pool, will not lose its relevance.

Summarising the above, it can be stated that scientists are concerned about the impoverishment of the diversity of common wheat, so in many countries measures are being taken to create genetic banks to preserve biotypes belonging to varieties with valuable economic characteristics, in particular *erythrospermum, lutescens, ferrugineum, barbarossa,* etc., well-adapted to local conditions in order to attract them to the breeding process and obtain forms that are resistant to adverse environmental factors with high grain yield and quality.

CONCLUSIONS

A low level of variability in the main characteristics of productivity of the main ear (the length of the ear, the number of spikelets in the ear, the number of grains and the weight of grains from the ear) was established for crossing common wheat varieties erythrospermum with varieties barbarossa and ferrugineum, which indicates a high efficiency of selection for these characteristics.

It was found that when crossing common wheat varieties erythrospermum with common wheat varieties barbarossa and ferrugineum, the number of genetic recombinations increases, which, in turn, affects a significant number of forms with a complex of economically valuable traits. Hybrids of erythrospermum × barbarossa were characterised by the number of plants with a thickened stem, white and tomentous ear, red and not always naturist grain, medium ripeness, increased heat resistance, and hybrids of barbarossa × erythrospermum – vrown, mostly not tomentous ear, red and naturist grain, increased winter hardiness.

It was determined that hybrids of the ferrugineum × erythrospermum combinations were characterised by a tendency to lodging. In F_3, forms with a consistently high level of grain weight from the main ear and a weight of 1,000 grains are identified, compared to the mother form, which was common wheat of the variety *erythrospermum*. It is shown that the highest weight of 1,000 grains had hybrids selected from the population from crossing the variety erythrospermum (Kyivopolka, Analog) and ferrugineum, which was more than 50, with fluctuations in variability of about 4 g. This trend was also noted in hybrids of the combination of crossing another line of the erythrospermum variety with the line of the barbarosa variety, where the weight of 1,000 grains was also high and ranged from 48.6 to 49.5 g.

It was found that by the weight of grains from the main ear, the highest degree of heterosis (3.9-7.4%) was observed in combinations of L 59-95 × *Triticum aestivum* L. var. *barbarossa*, Kyivopolka × *Triticum aestivum* L. var. *barbarossa*, Analog × *Triticum aestivum* L. var. *ferrugineum*, *Triticum aestivum* L. var. *barbarossa* × *Triticum aestivum* L. var. *ferrugineum*. Studies of selected hybrids have shown that the weight of 1,000 grains for hybrids of erythrospermum × Barbarosa and erythrospermum × ferrugineum is the most stable feature, in contrast to the characteristics of the mass of grains and the number of grains from the main and side ears, the indicators of which vary to a much greater extent. It was found that a number of breeding numbers of combinations of common wheat varieties erythrospermum with barbarossa determined high genotypic effects and stability of their manifestation in terms of grain quality indicators (protein content, gluten).

For further breeding to create new varieties, a hybrid material of common winter wheat of the erythrospermum variety was prepared with the participation of related varieties of winter wheat barbarossa and ferrugineum with red and amber grain in combination with high grain quality (protein and gluten content), resistance to lodging and fungal pathogens, and productivity of the main ear.

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CONFLICT OF INTEREST

None.

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Створення вихідного матеріалу у результаті залучення різних різновидностей пшениці м'якої озимої в селекції на адаптивність, продуктивність і якість зерна

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Анотація. Актуальність даної теми полягає у постійному прагненні до вдосконалення і покращення сортів пшениці м'якої озимої шляхом використання різних генетичних ресурсів і селекційних методів для досягнення кращої адаптивності, вищої продуктивності і вишуканої якості зерна. Мета роботи полягала в розширенні генетичного різноманіття пшениці м'якої озимої, що поєднує в собі високу продуктивність і якість адаптивність для подальшої селекції у контексті продовольчої безпеки. У дослідженнях використані загальноприйняті методики та їх модифікації, що забезпечили високу об'єктивність одержаних результатів. Фенологію, морфологічні дослідження, оцінку селекційного матеріалу за господарсько-цінними ознаками проводили згідно методики проведення експертизи сортів рослин. З'ясовано, що залучення зразка Ferrugineum 1239 до схрещування дозволяє сформувати гібридний матеріал з підвищеною стійкістю проти несприятливих абіотичних чинників довкілля, що відмічено на посівах селекційних номерів 0284/18/1, 0135/18, 0209/18/1 та ін. Доведено, що з урахуванням характеру успадкування та збереження ознак елементів продуктивності колоса на рівні кращих батьківських компонентів у комплексі з високими кількісними ознаками кількості зерен з головного колоса, маси зерен з головного колосу, маси 1000 зерен у гібридних популяцій першого покоління вищезазначені комбінації схрещувань *Triticum aestivum* var. *erythrospermum* з *Triticum aestivum* var. *barbarossa*, *Triticum aestivum* var. *erythrospermum* з *Triticum aestivum* var. *Ferrugineum* можуть бути цінними в селекції пшениці м'якої озимої. Практична цінність роботи полягає в тому, що результати досліджень розширюють відомості про використання в селекції на продуктивність і якість пшениці м'якої озимої різновидностейерітроспермум і лютесценс інших різновидів пшениць м'якої: *Triticum aestivum* var. *barbarossa* і *Triticum aestivum*var. *ferrugineum*. В результаті досліджень кращі зразки (F_4) передані на Носівську селекційно-дослідну станцію для подальшої селекційної роботи

Ключові слова: пшениця м'яка озима; різновидності; *erithrospermum* Körn.; *lutescens* Alef.; *ferrugineum* Alef.; *barbarossa* Alef.; селекція; нові гібридні форми; оцінювання