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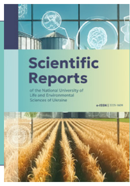

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Analysis of soft winter wheat hybrids for main morphological and productive traits of the ear

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Abstract. The study aimed to calculate the general combining ability of winter bread wheat varieties as maternal and paternal components for the main morphological and productive traits of the ear, to determine the level of variability of these traits and to identify promising genotypes for use in breeding programmes. In the study, F_1 hybrids of soft winter wheat obtained by crossing six varieties according to the full diaphyletic scheme were studied. The hybrids were evaluated based on the main indicators of ear productivity: length of the ear rod, weight of the ear, number of ears and grains in the ear, and weight of grains. To determine the general combining ability (GCA) of hybrids, a methodology was used that involves the evaluation of each variety as a mother and father component. Moreover, the index of phenotypic dominance of traits was determined to assess the inheritance of productivity and its structural elements. Significant variability in F_1 hybrids in terms of ear productivity was found. The highest rates of GCA as a maternal component were observed in the varieties Katrusia Poliska and Svitanok Myronivskyi, and as a paternal component in Myronivska 808, Nezabudka, and Svitanok Myronivskyi. For most hybrids, partial or complete dominance of individual traits was observed, indicating the influence of dominant genes on their formation. The calculation of the index of phenotypic dominance shows that for most hybrids, the index ranged from 0 to 1, which confirms partial dominance with the advantage of the best parental forms. The highest values of ear weight dominance were found in the following

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combinations: Katrusia Poliska × Nezabudka, Myronivska 808 × Vodohrai, Katrusia Poliska × Myronivska 808. The results of the study indicate that the use of different varieties of soft winter wheat for crosses can provide promising hybrids with improved ear productivity. Observations of the inheritance of productive traits confirmed that partial and complete dominance are typical for most hybrids

Keywords: combinational ability; degree of phenotypic dominance; hybrid combination; parental components; inheritance; spikelet structure

Introduction

Ear traits are central in wheat yield formation, as their morphology and productivity determine the main elements of the yield structure. In the context of an unstable climate, declining natural soil fertility and growing demand for high-quality grain, the study of intraspecific variability and breeding potential of new hybrids is of particular importance. Indicators related to the structure of the ear, the amount and weight of grain are critical for assessing the adaptability of varieties, their plasticity and efficiency under different agricultural-environmental stresses. Therefore, a systematic analysis of these traits is a reasonable approach to the selection of breeding material aimed at increasing crop productivity.

According to the State Statistics Service of Ukraine, the area under wheat in Ukraine was growing until 2021, when it reached 7095 thousand hectares. However, after the outbreak of hostilities in the country, there was a significant reduction in these areas, and as of 2023, they amounted to only 4665 thousand hectares (State Statistics Service of Ukraine, n.d.). Given this, one of the ways to increase grain production is to develop new high-yielding winter wheat varieties.

The development of winter wheat varieties with high productive potential and universal use is an important area of breeding. In this regard, one of the most urgent problems is to determine the morphological and physiological parameters most closely related to the high level of winter wheat productivity. Studies have shown that important parameters that affect productivity are such characteristics as the length of the ear rod, the number of ears and grains in the ear, and the weight of grain per ear. H.S. Koliucha *et al.* (2016) analysed the use of representatives of the genus *Aegilops* as a source of resistance traits to major foliar diseases and grain quality for breeding soft winter wheat. The study emphasises the importance of wild relatives of cultivated cereals in the formation of immunity against pathogens, in the context of increasing biotic stress, which determines the research relevance for breeding programmes aimed at improving the resistance of varieties.

V.D. Tromsyuk & V.D. Bugayov (2021) in the research on winter triticale emphasised the importance of preliminary evaluation of parental forms in the development of high-yielding varieties, by studying the manifestation of heterosis and the nature of inheritance of the main productivity traits. The use of diallel analysis identified hybrid combinations with high performance for such traits as productive bushiness, number of grains per ear and grain weight per plant.

I. Havryliuk & H. Kovalyshyna (2024) evaluated soft winter wheat varieties by yield structure and grain quality indicators. The authors analysed the elements of productivity (number of ears, grains, weight of 1000 grains) that determine the yield potential of the variety. The study highlighted the importance of a comprehensive assessment of the morphological and qualitative traits of the ear to develop high-performance forms with improved baking properties. M.M. Kamara *et al.* (2022) investigated the genetic potential and models of inheritance of physiological, agronomic and quality traits of bread wheat under conditions of normal moisture and water deficit. The authors noted a significant influence of genotype on the manifestation of traits such as ear length, number of grains and total productivity. The study determined that under stressful conditions, the heritability of some trait changes, which requires a differentiated approach to breeding in a changing climate.

In modern research on soft winter wheat breeding, the development of high-yielding varieties adapted to changing climate conditions are prioritised. One of the most important areas is the study of morphological and productive traits of the ear, which have the greatest impact on yield formation. Scientists K. Din *et al.* (2021) demonstrated the importance of such indicators as the length of the ear rod, the number of ears per ear, the number of grains per ear, and the weight of grains, which directly correlate with the level of productivity. V.T. Kolyuchyi *et al.* (2007) and N.M. Bunyak (2023) emphasised the importance of morphological and physiological traits as indicators of wheat productivity potential. They emphasised that to develop high-yielding wheat varieties, it is necessary to consider not only general agronomic characteristics, but also a deep understanding of the heritability of these traits. They also noted that the development of new varieties requires an integrated approach that includes the use of adaptive resources, such as resistance to adverse environmental factors.

O.O. Filitska (2022) highlighted the prospects for improving wheat genotypes by increasing the potential and actual productivity of the ear, by studying the characteristics of the ear rod and the number of ears per ear. The study emphasised the importance of studying the physiology of the ear, as this organ has the greatest impact on yield formation. Furthermore, the length of the spikelet and the number of spikelets in the ear significantly affect the grain weight, which is an important criterion for breeding work. The search for genetic features of inheritance of these traits is an important part of modern breeding. S. El Hanafi *et al.* (2022) determined that the assessment of the general combining ability of F_1 hybrids improves the accuracy of the determination of the prospects of crosses to obtain varieties with high productivity.

Thus, numerous studies confirm the importance of an in-depth study of morphological and productive traits of winter durum wheat ears. This can be used to develop new varieties with high productivity levels, which is highly relevant for ensuring food security in the face of global climate change and geopolitical challenges.

The study aimed to investigate the general combining ability of F_1 winter wheat hybrids in terms of yield structure, in particular, ear length, ear weight, number of ears per ear, number of grains per ear and weight of grains per ear. The study assessed the genetic features of inheritance of these traits in hybrid combinations, analysing phenotypic dominance for increasing productivity and breeding improvement of winter soft wheat varieties.

Materials and Methods

The study of F_1 winter soft wheat hybrids was conducted in the 2023/24 growing season in two locations: on the breeding fields of the National Research Centre "Institute of Agriculture of the National Academy of Agrarian Sciences of Ukraine" and the Production Unit "Agronomic Research Station" of the National University of Life and Environmental Sciences of Ukraine. The study complied with the standards set out in the Convention on Biological Diversity (1992). The crosses were conducted between 6 winter wheat varieties (Nezabudka, Myronivska 808, Svitanok Myronivskyi, Sonata Odesa, Vodohrai and Katrusia Poliska) in a full diallel scheme on the breeding fields of the National Research Centre "Institute of Agriculture of NAAS of Ukraine" (Table 1).

Table 1. *Crossing of soft winter wheat varieties according to the full diaphyletic scheme*

	Nezabudka	Mironovskaya 808	Svitanok Myronivskyi	Sonata Odesa	Vodohrai	Katrusia Poliska
Nezabudka	–	+	+	+	+	+
Mironovskaya 808	+	–	+	+	+	+

***Table 1.** Continued*

	Nezabudka	Mironovskaya 808	Svitanok Myronivskyi	Sonata Odesa	Vodohrai	Katrusia Poliska
Svitanok Myronivskyi	+	+	–	+	+	+
Sonata Odesa	+	+	+	–	+	+
Vodohrai	+	+	+	+	–	+
Katrusia Poliska	+	+	+	+	+	–

Source: compiled by the authors based on research

To evaluate F_1 hybrids of soft winter wheat by the main indicators of ear productivity, the method of determining the general combining ability (GCA) was used. The hybrids were evaluated by the following parameters: length of the ear rod (cm), weight of the ear (g), number of ears per ear (pcs.), number of grains per ear (pcs.) and weight of grains per ear (g). The index of phenotypic dominance of traits (*h*) was used to determine the inheritance of productivity and its structural elements in the first generation of winter bread wheat hybrids. The dominance index was determined by the formula (Griffing, 1950):

$$h = \frac{F_1 - P_{min}}{P_{max} - P_{min}}, \quad (1)$$

F_1 – average value of the trait in the hybrid generation; P_{max} – average value of the trait in the parental form with the higher index; P_{min} – average value of the trait in the parental form with the lower index. This approach, based on modern genetic evaluation methods (Spriazhka & Zhemoida, 2022), can accurately determine the potential of hybrids to express productivity traits under different growing conditions and justify their use in the breeding process. The results were interpreted as follows (Beil & Atkins, 1965):

$h = 0$ – absence of dominance (AD) – additive effect of genes;

$0 < h < 1$ – partial dominance (PD);

$h = 1$ – complete dominance (CD);

$h > 1$ – superdominance (SD);

$h < 0$ – negative dominance (ND) – hybrid inferior to parents.

Each variety was evaluated for its general combining ability as a mother and father component. Observations and records were made following generally accepted methods (Tkachyk, 2016).

Results and Discussion

The degree of phenotypic dominance of traits. The distribution of F_1 winter wheat hybrids by the degree of phenotypic dominance (*h*) indicates the predominance of superdominance for most of the studied traits, which indicates a significant effect of heterosis (Fig. 1). The largest number of hybrids with the manifestation of dominance was observed for ear weight (15 hybrids) and grain weight per ear (12 hybrids), which indicates the important role of dominant alleles in the control of productive traits and their high breeding value. A similar trend was observed for the length of the ear spike, where 11 hybrid combinations demonstrated superdominance.

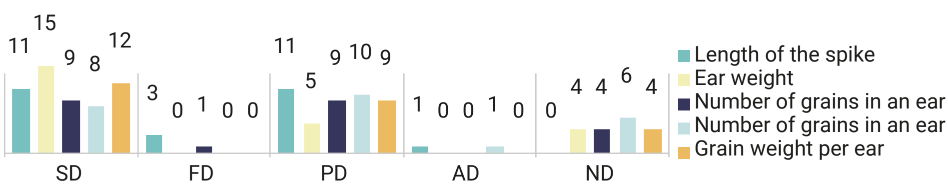

***Figure 1.** Distribution of first-generation winter soft wheat hybrids by h*

Note: SD – superdominance; FD – full dominance; PD – partial dominance; AD – absence of dominance – additive gene action; ND – negative dominance

Source: compiled by the author based on research

Partial dominance, characterised by a relatively weak expression of dominant alleles, was common among hybrids for ear length (11 cases), number of ears per ear (9), weight per ear (9) and number of grains per ear (10). This indicates the intermediate nature of the inheritance of these traits, which can complicate the selection process in the early stages. Complete dominance of traits was less common. The analysis detected in three F_1 hybrids for the length of the spikelet and some cases, for the number of spikelets per ear. The absence of dominance was recorded only in 2 hybrid combinations.

Negative dominance, in which hybrid combinations are inferior to both parental forms, was recorded in four to six hybrids, depending on the trait. Most of these cases were observed for the number of grains per ear (6 hybrids) and ear weight (4 hybrids). According to K. Din *et al.* (2021), who conducted a line × tester combining ability analysis in hybrid populations of winter bread wheat to assess genetic differences, inheritance of valuable economic traits, and determine heritability traits, the analysis determined that most of the studied traits are controlled by dominant genes. The obtained values of the degree of dominance indicated the predominance of non-additive gene action, therefore, the authors concluded that the selection of promising populations should be postponed until the next segregating generations to achieve greater breeding efficiency.

Thus, based on the weight of the ear, the trait was observed to be superdominant in most hybrids; based on the length of the ear and the number of spikelets in the ear, the trait was superdominant and partially dominant; based on the number of grains in the ear, the trait was mostly partially dominant; and based on the weight of the grains in the ear, the trait was superdominant. D.E. Qulmamatova *et al.* (2022), determining the genetic potential of spring durum wheat (*Triticum aestivum* L.) populations of first and subsequent generations of hybrids for yield traits, also found that the number of grains and grain weight per ear are inherited by the type of gene action, superdominance in F_1 hybrids.

In the study of the degree of phenotypic dominance (*h*) in hybrid combinations of soft winter wheat, significant variability in the inheritance of the studied traits was observed (Table 2). The highest values of superdominance (*h* > 1) were found for ear weight in the following combinations: Katrusya Poliska × Nezabudka (*h* = 17.6, Fig. 2), Mironivska 808 × Vodograi (*h* = 7.5) and Katrusya Poliska × Mironivska 808 (*h* = 5.8). This indicates a high potential for heterosis and the possibility of using these hybrids in breeding to increase productivity.

Table 2. *The degree of phenotypic dominance in F_1 hybrids*

Hybrid combination	The degree of phenotypic dominance (*h*) by				
	the length of the spikelet	ear weight	number of spikelets in an ear	number of grains in an ear	weight of grains per ear
Nezabudka × Mironovskaya 808	**2.5***	0.6	1.2	0.2	0.2
Nezabudka × Svitanok Mironovskiy	0.0	0.1	0.3	0.4	-0.3
Nezabudka × Sonata Odesa	0.3	0.2	0.3	0.0	0.1
Mironovskaya 808 × Nezabudka	1.0	**1.2***	**1.0***	0.6	**1.1***
Mironovskaya 808 × Svitanok Mironovskiy	**3.7***	-0.1	0.5	-1.4	-0.2
Mironovskaya 808 × Sonata Odesa	0.3	0.6	-1.6	0.4	0.4
Mironovskaya 808 × Vodohrai	**1.0***	**7.5***	**1.2***	-0.4	0.3
Mironovskaya 808 × Katrusia Poliska	**1.3***	-0.3	-0.6	-1.5	-0.8
Svitanok Myronivskyi × Nezabudka	0.7	0.9	**1.0***	**4.7***	0.9
Svitanok Myronivskyi × Sonata Odesa	0.7	**2.0***	**4.0***	**1.3***	**2.0***

***Table 2.** Continued*

Hybrid combination	The degree of phenotypic dominance (*h*) by				
	The length of the spikelet	ear weight	Number of spikelets in an ear	number of grains in an ear	weight of grains per ear
Svitanok Myronivskyi × Katrusia Poliska	0.6	**1.5***	**1.3***	0.4	**2.6***
Sonata Odesa × Nezabudka	**1.1***	**2.9***	0.9	0.1	0.5
Sonata Odesa × Mironovskaya 808	**1.3***	**1.9***	**3.5***	0.7	**1.7***
Sonata Odesa × Svitanok Myronivskyi	0.7	**1.2***	**1.1***	**1.6***	**1.8***
Sonata Odesa × Vodohrai	0.4	**1.4***	-0.8	0.4	0.6
Sonata Odesa × Katrusia Poliska	0.9	0.5	0.3	-0.2	0.6
Vodograi × Nezabudka (defect)	0.5	**2.1***	0.6	**23.3***	**1.5***
Vodohrai × Mironovskaya 808	**1.9***	**2.3***	0.7	0.1	**1.2***
Vodohrai × Svitanok Mironovskiy	**2.2***	**1.6***	**2.4***	**1.1***	0.5
Vodohrai × Sonata Odesa	0.3	-0.7	-0.7	0.2	**2.2***
Vodohrai × Katryna Poliska	**1.4***	1.7	0.6	**1.8***	**1.2***
Katrina Poliska × Nezabudka	**2.0***	17.6	**1.2***	**2.0***	**3.2***
Katrusia Poliska × Mironovskaya 808	**1.0***	5.8	0.8	-0.6	**3.8***
Katrusia Poliska × Svitanok Myronivskyi	**2.8***	1.1	**2.8***	**4.8***	**1.8***
Katrusia Poliska × Sonada Odesa	0.4	-5.3	**2.0***	-0.1	-2.3

Note: * – the values of indicators indicating the dominance of the trait in the hybrid combination are highlighted
Source: compiled by the authors based on research

***Figure 2.** Hybrid combination Katrusia Poliska × Nezabudka*
Note: ♀ – Katrusia Poliska, ♂ – Nezabudka, F_1 – a hybrid between the two
Source: compiled by the authors based on research

***Figure 3.** Hybrid combination Katrusia Poliska × Svitanok Myronivskyi*
Note: ♀ – Katrusia Poliska, ♂ – Svitanok Myronivskyi, F_1 – a hybrid between the two
Source: compiled by the authors based on research

In terms of spikelet length, the highest *h* values were found in the hybrids Myronivska 808 × Svitanok Myronivskyi (3.7) and Katrusia Poliska × Svitanok Myronivskyi (2.8) (Fig. 3). At the same time, in some hybrids, such as Nezabudka × Svitanok Myronivskyi (0.0), there was no dominance effect.

In terms of the number of spikelets per ear, a wide amplitude of variation in phenotypic dominance was observed: the highest level was observed in Svitanok Myronivskyi × Sonata Odeska (4.0) and Sonata Odeska × Myronivska 808 (3.5), indicating a high heterosis effect. However, there are negative *h* values in some combinations, such as Myronivska 808 × Sonata Odesa (-1.6) and Sonata Odesa × Vodohrai (-0.8).

In terms of the number of grains per ear, the hybrid combination Vodohrai × Nezabudka had a high dominance value (23.3). High values were also found in the combinations Katrusia Poliska × Svitanok Mironivskyi (4.8) and Svitanok Mironivskyi × Nezabudka (4.7, Fig. 4), which indicates a positive effect of dominant genes in these combinations. At the same time, in some combinations, in particular Myronivska 808 × Katrusia Poliska (-1.5) and Myronivska 808 × Svitanok Myronivskyi (-1.4), the effect of negative dominance of the trait was observed, which indicates their kinship and limits their effectiveness in breeding programmes.

Figure 4. *Hybrid combination Svitanok Myronivskyi × Nezabudka*
Note: ♀ – Svitanok Myronivskyi, ♂ – Nezabudka, F_1 – a hybrid between the two
Source: compiled by the authors based on research

The weight of grains per ear also varied widely. The maximum values of *h* were observed in the hybrid combinations Katrusia Poliska × Myronivska 808 (3.8) and Katrusia Poliska × Nezabudka (3.2, Fig. 2), indicating a significant heterotic effect. At the same time, in some combinations, such as Katrusia Poliska × Sonata Odesa (-2.3, Fig. 5) and Myronivska 808 × Katrusia Poliska (-0.8), a negative dominance value was observed. The dominance of most of the studied traits was observed in hybrid combinations: Svitanok Myronivskyi x Sonata Odesa (Fig. 6), Sonata Odesa x Myronivska 808, Sonata Odesa × Svitanok Myronivskyi (Fig. 7), Vodohrai × Svitanok Myronivskyi (Fig. 8), Katrusia Poliska × Nezabudka (Fig. 2), Katrusia Poliska × Svitanok Myronivskyi (Fig. 3). In the hybrid combination Svitanok Myronivskyi × Sonata Odeska, the dominance was observed for the following traits: ear weight (*h* = 2.0), number of spikelets per ear (*h* = 4.0), number of grains per ear (*h* = 1.3), weight of grains per ear (*h* = 2.0).

Figure 5. *Hybrid combination Katrusia Poliska × Svitanok Myronivskyi*
Note: ♀ – Katrusia Poliska, ♂ – Svitanok Myronivskyi, F_1 – a hybrid between the two
Source: compiled by the authors based on research

Figure 6. *Hybrid combination Svitanok Myronivskyi × Sonata Odesa*
Note: ♀ – Katrusia Poliska, ♂ – Svitanok Myronivskyi, F_1 – a hybrid between the two
Source: compiled by the authors based on research

Figure 7. *Hybrid combination Sonata Odesa × Svitanok Myronivskyi*
Note: ♀ – Katrusia Poliska, ♂ – Svitanok Myronivskyi, F_1 – a hybrid between the two
Source: compiled by the authors based on research

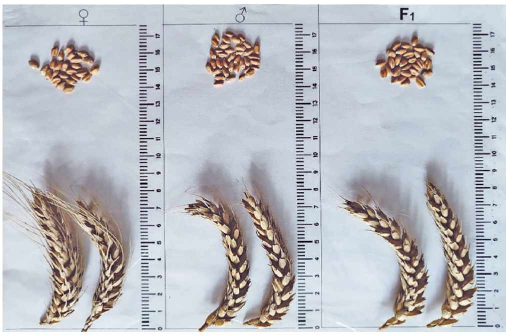

Figure 8. *Hybrid combination Vodohrai x Svitanok Myronivskyi*
Note: ♀ – Vodohrai, ♂ – Svitanok Myronivskyi, F_1 – a hybrid between the two
Source: compiled by the authors based on research

In the hybrid combination Sonata Odessa x Svitanok Myronivsky, superdominance was noted for the following traits: ear weight (h = 1.2), number of spikelets per ear (h = 1.1), number of grains per ear (h = 1.6), and grain weight per ear (h = 1.8). In the hybrid combination of Vodogray × Svitank Myronivsky, superdominance was observed in the following traits: length of the rachis (h = 2.2), ear weight (h = 1.6), number of spikelets per ear (h = 2.4), number of grains per ear (h = 1.1).

High rates of phenotypic dominance of ear length were also noted by M. Mohammadi *et al.* (2021), as a result of a study of hybrid combinations between durum wheat and Emmer wheat (*Triticum turgidu*m ssp. *dicoccum*), where significant genetic variability and the presence of overdominance in several valuable agricultural traits, including ear length, were found. Incorporating the dominant type of inheritance of this trait, the authors recommend selective breeding in the next generations, when the manifestation of heterosis is partially stabilised, which will contribute to more efficient consolidation of valuable genotypes.

Similar results were obtained by H. Ustynova *et al.* (2024), who studied the inheritance of ear length in winter bread wheat hybrids with the participation of early and medium early, medium early and medium late varieties. In most combinations, the inheritance of this trait was of the positive dominance type. The authors found a significant level of heterosis for spike length in F_1 and frequent manifestation of positive transgressions in the second generation of F_2 (26 out of 40 combinations in 2019-2020), which indicates the active formation of new recombinations and confirms the feasibility of selection for this trait in subsequent generations.

S. Khomenko *et al.* (2021) noted that most F_1 wheat hybrids showed the phenomenon of overdominance and partial dominance for traits such as ear length and number of grains per ear. The authors highlighted the importance of selecting a trait system that ensure genetic progress and improve yield potential in breeding programmes. They determined that most wheat hybrids (64.3%) are characterised by superdominance and partial dominance for the following traits: ear length and number of grains per ear. According to their research, it is advisable to select for these traits in future generations to create new promising wheat lines.

M.M. Kamara *et al.* (2022) highlighted the high potential for improving wheat genotypes by increasing the number of grains per ear, which is an important aspect for increasing productivity, especially under water stress. The authors noted that by optimising parameters such as the number of grains per ear, the overall yield could be significantly increased. The study, which included the evaluation of different wheat genotypes under normal and drought conditions, showed that water deficit significantly reduced chlorophyll content, photosynthetic efficiency, grain moisture and other agronomic traits, including the number of grains per ear. However, a significant positive correlation was also observed between physiological parameters such as chlorophyll content, relative plant water content and grain yield under water deficit conditions. Thus, optimisation of traits such as the number of grains per ear is one of the factors in wheat breeding to increase its yield under climate change.

D.E. Qulmamatova *et al*. (2022) argued that ear traits are inherited by dominance from the best parental component. The study, which included the analysis of the genetic potential of winter bread wheat populations, determined that F_1 hybrids obtained by crossing six varieties demonstrate inheritance of spikelet structure traits by type of dominance. The analysis of the spikelet structure in F_1 hybrids showed that the number of grains in the spikelet and grain weight are inherited by the type of superdominance, which means the predominant influence of one of the parental components, which shows higher performance in these characteristics. The highest values for the number of grains and grain weight were observed in hybrids obtained in combinations with high-yielding parental components, which confirms the possibility of using such populations for further breeding to improve these traits.

Similar patterns of trait inheritance were established in the studies of I.A. Khorsun (2012) and S.S. Yurchuk (2024), based on the analysis of hybrid populations of soybean and winter rape to determine the degree of heterosis and type of trait dominance. The authors emphasised that in the presence of a high degree of dominance of a certain valuable economic trait, selection can be effective in the first generations. This opened prospects for the development of crossbreeding programmes with predictable transmission of valuable traits to offspring, which is a relevant approach for wheat breeding, for the characteristics of the ear structure.

General combining ability. The papers by M.M. Kamara *et al*. (2021) and T. Begna (2021) highlighted the importance of combinational ability for optimising wheat crossing schemes, as it can be used for new hybrid combinations with high productivity and resistance to adverse conditions. The researchers noted that to create adapted varieties, it is important not only to select maternal and paternal forms but also to correctly predict the inheritance of the main productive traits in hybrids.

Table 3 shows the results of the evaluation of the general combining ability (GCA) of winter soft wheat varieties as parent components in terms of ear structure in two different locations. The data indicate variability of GCA depending on the variety and growing conditions (locations).

Table 3. *General combining ability of soft winter wheat varieties as a mother component in terms of ear structure*

Varieties	Length of the spikelet		Spike weight		Number of spikelets in an ear		Number of grains in an ear		Grain weight from the ear	
	I	II	I	II	I	II	I	II	I	II
Nezabudka	-0.50	-0.57	-0.48	-0.67	-2.18	-2.60	-8.63	-8.37	-0.38	-0.45
Mironovskaya 808	-0.27	-0.24	-0.13	-0.39	-0.30	-1.02	-4.89	-6.26	-0.17	-0.41
Svitanok Myronivskyi	0.04	-0.10	-0.05	0.49	0.30	0.80	1.09	**8.75***	-0.05	**0.48***
Sonata Odesa	**0.41***	0.47	0.22	0.09	0.98	0.30	5.17	-0.63	**0.24***	-0.01
Vodohrai	0.02	-0.35	0.01	-0.16	-0.54	-0.16	1.01	-0.07	0.15	-0.02
Katrusia Poliska	0.29	**0.79***	**0.42***	**0.64***	**1.74***	**2.67***	**6.25***	6.59	0.20	**0.43***

***Table 3.** Continued*

Varieties	Length of the spikelet		Spike weight		Number of spikelets in an ear		Number of grains in an ear		Grain weight from the ear	
	I	II	I	II	I	II	I	II	I	II
s^2	0.12	0.27	0.10	0.26	1.84	3.14	33.28	45.89	0.06	0.16
n	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
s	0.34	0.52	0.31	0.50	1.36	1.77	5.77	6.77	0.24	0.40
SE	0.14	0.21	0.13	0.21	0.55	0.72	2.36	2.77	0.10	0.16
$LSD_{0.05}$	0.34	0.52	0.31	0.51	1.36	1.77	5.77	6.78	0.24	0.40

Note: research locations are marked as I (breeding fields of the National Research Centre "Institute of Agriculture of the National Academy of Agrarian Sciences of Ukraine") and II (Agronomic Research Station of the National University of Life and Environmental Sciences of Ukraine); * – highlighted values of indicators are significantly higher than the average

Source: compiled by the authors based on research

In the breeding fields of the National Research Centre "Institute of Agriculture of NAAS of Ukraine" (location I), the variety Sonata Odesa was identified, which had significantly high values of the GCA for the length of the ear rod (0.41) and the weight of grain per ear (0.24). However, these values did not exceed the threshold of reliability in the second location and therefore cannot be considered stable. Similarly, Katrusia Poliska demonstrated a high level of GCA for the number of grains per ear (6.25), but the value was also not significantly higher than the average in the second location, indicating limited stability of the effect across locations. In the second location of the SE "Agronomic Experimental Station" of the National University of Life and Environmental Sciences of Ukraine (location II), significantly high values of the GCA for the trait number of grains per ear (8.75) and grain weight per ear (0.48) were found in Svitanok Myronivskyi, but the values did not exceed the threshold of reliability in the first location. In addition, Katrusia Poliska showed significantly high effects of GCA for ear length (0.79) and grain weight per ear (0.43) only in the same location.

At the same time, negative values of the GCA were recorded for the varieties Nezabudka, Myronivska 808 and Vodograi, which did not show significantly positive values of the GCA for any of the studied traits in both locations. This indicates a low potential for their use as mother components in breeding programmes. Significantly high values of the GCA in both locations were noted only for the variety Katrusia Poliska in terms of ear weight and number of spikelets per ear. Thus, according to the results of the GCA, among the studied varieties, Katrusia Poliska as a maternal component can be a universal donor of high spike weight and number of spikelets per spikelet. The varieties Svitanok Myronivskyi and Sonata Odeska require additional research under other conditions to establish their value as a maternal component for improving spike structure, and the varieties Nezabudka, Myronivska 808 and Vodograi are not advisable to use for such purposes.

According to the results of the analysis of the GCA of soft winter wheat varieties as the parental component (Table 4), significant differences between varieties and locations were also noted. At the location of the Agronomic Research Station of the National University of Life and Environmental Sciences of Ukraine, the varieties Nezabudka and Sonata Odessa were noted as parental components with a high statistically significant GCA rating for ear weight (0.38) and grain weight (0.15), respectively (Table 4). At the breeding fields of the National Scientific Centre "Institute of Agriculture of the National Academy of Agrarian Sciences of Ukraine", the varieties Mironivska 808 for ear weight (0.17) and Katrusya Poliska for grain weight per ear (0.11) were noted. Among the studied varieties, as a parental component, a reliably high level of GCA was noted in two locations for Myronivska 808 in terms of spike length (I 1.06, II 0.54) and number of spikelets in the spike (I 0.94, II 4.83), Svitanok Myronivsky in terms of the number of grains in the spike (I 4.99, II 4.83).

Table 4. *General combinability of soft winter wheat varieties as parental components based on ear structure indicators*

Varieties	Length of the spikelet		Spike weight		Number of spikelets in an ear		Number of grains in an ear		Grain weight from the ear	
	I	II	I	II	I	II	I	II	I	II
Nezabudka	0.11	0.06	-0.24	**0.38***	-1.04	-1.00	0.87	0.03	-0.12	0.06
Mironovskaya 808	**1.06***	**0.54***	**0.17***	0.22	**0.94***	**1.28***	0.39	0.17	0.04	0.09
Svitanok Myronivskyi	-1.04	-0.87	-0.04	-0.40	0.48	0.56	**4.99***	**4.83***	-0.12	-0.17
Sonata Odesa	0.09	-0.05	-0.08	-0.17	-0.90	-0.58	-4.23	-2.53	0.08	**0.15***
Vodohrai	-0.64	-0.05	0.10	-0.09	0.12	0.05	-0.41	-0.63	0.00	-0.08
Katrusia Poliska	0.41	0.36	0.10	0.07	0.40	-0.32	-1.61	-1.83	**0.11***	-0.05
s^2	0.56	0.24	0.02	0.08	0.64	0.68	9.29	6.70	0.01	0.01
n	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
s	0.75	0.49	0.15	0.28	0.80	0.82	3.05	2.59	0.10	0.12
SE	0.31	0.20	0.06	0.12	0.33	0.34	1.24	1.06	0.04	0.05
$HIP_{0.05}$	0.75	0.49	0.15	0.28	0.80	0.82	3.05	2.59	0.10	0.12

Note: research locations are marked as I (selection fields of the National Scientific Centre's Institute of Agriculture of the National Academy of Agrarian Sciences of Ukraine) and II (Agronomic Research Station of the National University of Life and Environmental Sciences of Ukraine); * highlighted values are significantly higher than average

Source: compiled by the authors based on research

Thus, for the varieties Nezabudka, Sonata Odeska and Katrusia Poliska, as a parental component, mathematically justified consistently high values of the GCA for the studied traits were not found, so they need further study in other locations. It is not advisable to use the variety Vodograi as a parental component to improve the spike structure. The variety Myronivska 808 as a parental component can serve as a universal donor to improve the spikelet length and number of spikelets per ear, and the variety Svitanok Myronivskyi as a parental component can improve the number of grains per ear.

The results of the analysis of variance indicate significant differences between varieties in terms of combinational ability, as evidenced by the values of standard deviation (s) and standard error (SE), especially in terms of the number of grains per ear. L.A. Zhivotkov *et al*. (1989) stated that due to the complexity of inheritance and the presence of high modification variability of the number of grains per ear, it is difficult to select and evaluate breeding material for this trait. This is confirmed by the results of the research, as the highest variability was found for the number of grains per ear (Tables 3 and 4). This also indicates significant genetic differences between the studied varieties and their different breeding potential in hybridisation schemes. Hence, there is a need for a more detailed study of Svitanok Myronivskyi as a parental component as a donor to improve the number of grains per ear, due to the high variability of the trait. S. Khomenko *et al.* (2021) noted the prospects of intraspecific crosses. Determining the parameters of plant productivity, the nature of their inheritance, and the combinational ability of varieties is an urgent task both in creating new varieties and in predicting the breeding and genetic effects of crosses.

Thus, the analysis confirms the expediency and necessity of an in-depth study of the combinational ability of varieties at the early stages of the breeding process. The identified differences between varieties in terms of spikelet structure indicate the potential for effective selection of parental components in hybridisation schemes. This also creates the preconditions for improving the efficiency of breeding by optimising the combination of genotypes with high overall combinational ability.

Conclusions

The study of the degree of phenotypic dominance (*h*) in hybrid combinations of soft winter wheat based on such indicators as spike length, spike weight and grain weight per spike revealed the manifestation of superdominance. This suggests that selection based on these traits may be highly effective in creating new lines. The highest values of superdominance in ear weight were found in the following hybrids: Katrusya Poliska × Nezabudka (*h* = 17.6), Mironivska 808 × Vodograi (*h* = 7.5), Katrusya Poliska × Mironivska 808 (*h* = 5.8). These hybrid combinations should be included in further breeding research and used in breeding programmes to increase the productivity of soft winter wheat.

High, statistically significant, positive effects of the overall general ability for various parameters (length of the ear rod, ear weight, number of ears and grains in the ear, weight of grain per ear) were observed in the following varieties of soft winter wheat:

- by the number of grains in the ear: Svitanok Myronivskyi (♂);
- high GCA for the complex of traits was noted in the varieties: Katrusia Poliska (♀), by ear weight and number of spikelets per ear, Myronivska 808 (♂), by ear length and number of spikelets per ear.

These varieties are recommended for use in breeding soft winter wheat as maternal and paternal components to increase crop productivity by improving such indicators as the number of grains per ear, ear weight, number of spikelets per ear and ear length.

In the context of the results obtained, a promising area for further research is an in-depth analysis of the heritability of traits in subsequent generations (F_{2-n}) using the recommended hybrid combinations. The stability of heterosis in different soil and climatic conditions and under variable agrophysical conditions should be prioritised. It is also advisable to conduct molecular genetic studies to identify markers associated with the manifestation of superdominance and high combinational ability, which will improve the accuracy of parental form selection and accelerate the development of new productive winter bread varieties.

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Conflict of Interest

None.

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Аналіз гібридів пшениці м’якої озимої за основними морфологічними та продуктивними ознаками колоса

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Анотація. Мета дослідження полягала у розрахунку загальної комбінаційної здатності сортів пшениці м’якої озимої у ролі материнського та батьківського компонентів за основними морфологічними та продуктивними ознаками колоса, встановленні рівня варіабельності цих показників та визначенні перспективних генотипів для використання в селекційних програмах. У ході дослідження вивчено гібриди F_1 пшениці м’якої озимої, отримані за допомогою схрещувань шести сортів за повною діалельною схемою. Оцінку гібридів здійснено за основними показниками продуктивності колоса: довжина колосового стрижня, маса колоса, число колосків і зерен у колосі, маса зерен. Для визначення загальної комбінаційної здатності (ЗКЗ) гібридів використано методику, що передбачає оцінку кожного сорту як материнського та батьківського компонентів. Також проведено визначення індексу фенотипового домінування ознак для оцінки успадкування продуктивності та її структурних елементів. Встановлено значну варіативність у гібридах F_1 за показниками продуктивності колоса. Найвищі показники ЗКЗ у ролі материнського компонента мали сорти Катруся Поліська, Світанок Миронівський, а у ролі батьківського – Миронівська 808, Незабудка, Світанок Миронівський. Для більшості гібридів спостерігали часткове або повне домінування окремих ознак, що вказує на вплив домінантних генів на їх формування. Розрахунок індексу фенотипового домінування свідчить, що для більшості гібридів індекс варіював від 0 до 1, що підтвердило часткове домінування з перевагою кращих батьківських форм. Найвищі значення наддомінування за масою колоса встановлено в таких комбінаціях: Катруся Поліська × Незабудка, Миронівська 808 × Водограй, Катруся Поліська × Миронівська 808. Результати дослідження свідчать, що використання різних сортів пшениці м’якої озимої для схрещувань дозволяє отримати перспективні гібриди з покращеними показниками продуктивності колоса. Спостереження за успадкуванням продуктивних ознак підтвердило, що часткове і повне домінування є характерними для більшості гібридів

Ключові слова: комбінаційна здатність; ступінь фенотипового домінування; гібридна комбінація; батьківські компоненти; успадкування; структура колоса