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Variation and transgressive variability of the stem length in F1 and F2 soft spring wheat under conditions of forest-steppe of Ukraine

Serhii Vakhnyi [1*], Valerii Khakhula [1], Tetiana Lozinska [2], Yriy Fedoruk [1], Mykola Lozinskyi [3], Serhii Obrazhyy [4], Nataliya Fedoruk [5], Oleksandr Panchenko [4], Oleksandr Yakovenko [1]

[1] Department of Technologies in Plant Growing and Plant Protection, Bila Tserkva National Agrarian University, Bila Tserkva, UKRAINE
[2] Department of Forestry, Botany and Plant Physiology, Bila Tserkva National Agrarian University, Bila Tserkva, UKRAINE
[3] Department of Genetics, Breeding and Seed production, Bila Tserkva National Agrarian University, Bila Tserkva, UKRAINE
[4] Department of Agriculture, Agricultural Chemistry and Soil Science, Bila Tserkva National Agrarian University, Bila Tserkva, UKRAINE
[5] Department of Food Technologies and Technologies of Animal Products Processing, Bila Tserkva National Agrarian University, Bila Tserkva, UKRAINE
*Corresponding author: Vakhser@gmail.com

Abstract

The paper highlights the question of the stem length variability in F_1 and F_2 soft spring wheat and the detection of transgressive forms in the second generation of hybrids.
The complicated character of stem length determination in F_1 is defined, since in this process not only genes of additive type of action are involved, but also alleles of genes with stronger specific interaction. In the hybrid combinations Struna Myronivska/Elehiia Myronivska were at parental level, in the combination Struna Myronivska/Azhurnaia treated as inferior to the parental form on 10.9%, indicating the probability of maternal organism's effect on the trait formation due to the content of short-stem genetic factors in cytoplasm.
It was established that the coefficient of variation of stem length in first-generation hybrids when reciprocal crosses was in the range from 6.8% (Simkoda Myronivska/Struna Myronivska) to 9.3% (Azhurnaia/Struna Myronivska), indicating a slight variation of this index. Only in combinations of crosses Lehuan/Struna Myronivska, Heroinia/Struna Myronivska and Kolektyvna 3/Struna Myronivska variation of stem length is average and account for 15.8, 11.3 and 11.1% respectively.
A significant reciprocal effect was also noted – shorter-stem hybrids F_1 obtained in combinations when using low-growth varieties as a maternal form.
The smallest range of stem length was found in second-generation hybrids in the combination Struna Myronivska/Kolektyvna 3 – 16.1 cm with low variance 22.1 and the largest one – in the combination Heroinia/Struna Myronivska (34.1 cm) with variance 81.0.
The complex genetic nature of the stem length determination in the studied hybrids F_1 and F_2 was established. Starting from F_2, a significant form-creating process in the stem length can be traced in hybrids. In the majority of reciprocal crosses, a significant reduction of the stem length in F_2 hybrids is observed, when maternal form was a variety with shorter stem length. This indicates the influence of the maternal cytoplasm on this trait formation.
High-growth transgressions were found in the second generation of a third of soft spring wheat hybrids. In F_2 hybrids, the degree of transgression was in the range 2.1-6.2% with a frequency 6.0-10.0% in the hybrid combinations Struna Myronivska/Simkoda Myronivska, Simkoda Myronivska/Struna Myronivska, Elehiia Myronivska/Struna Myronivska, Kolektyvna 3/Struna Myronivska.
Thus, it can be argued that the highest rates of transgressive variability based on the stem length were found in those hybrids which had heterosis in F_2.

Keywords: soft spring wheat, reciprocal crosses, hybrids, stem length, variation, variability, transgression

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INTRODUCTION

One of the main ways to create varieties of agricultural crops is still hybridization, followed by the selection of recombinant genotypes with a bright manifestation of a selection-valuable traits complex.

In practical selection, it is important to compare the variability of the individual elements of the crop structure, the degree of their significance, which depends on the genotype and environmental conditions (Lozinska et al. 2018).

The assumption that modern wheat varieties are more susceptible to environmental changes than landraces and varieties of the previous breeding stages has been expressed repeatedly (Calderini et al. 2005, Fufa et al. 2005).

In order to stabilize yields, when rapidly changing weather conditions under sharply continental climate, as well as to increase the gross yield of grain, it is necessary to create and implement into agriculture new highly productive varieties of soft spring wheat (Krivobochek 1998). The selection process is continuous, so with the increase in production demand, climate change, new forms and varieties of agricultural plants with increased productivity, resistant to adverse environmental conditions are required. Therefore, the creation of new varieties remains an urgent problem (Zelensky 2000).

In current economic and climatic conditions, the main requirements for varieties are high yields, the possibility of cultivation using energy-saving technologies, environmental resistance to stresses, plasticity, high grain quality, and endurance against pathogens and pests (Mergoum et al. 2009). A prerequisite for the successful creation of such varieties may be a different response of plants to changes in environmental conditions, which is under genetic control (Merchuk-Ovnat et al. 2017).

Analysis of Recent Research and Publications

Productivity is the main feature that characterizes the economic value of the variety. It depends on the main elements of the yield structure of spring wheat, in particular the number of plants and productive stems per unit area, the number of spikelets and grains in the spike and their mass, the mass of grain in one spike, the ratio between grain and straw, which determine the potential of wheat productivity. All these elements vary depending on the soil-climatic conditions of the terrain, the agrotechnical factors and the biological characteristics of the varieties, which leads to an increase or a decrease in yield (Shevchenko 2008).

The effectiveness of the selection on many traits can be enhanced through the creation special artificial backgrounds that allow quite clearly select the desired plants from the hybrid population. The situation with the selection on productivity is somewhat different. The manifestation of this trait and its individual components to a large extent depends on the environmental conditions. Modification variability is so significant that one can never be absolutely sure that each selected highly productive plant will produce the same offspring. With selections in early generations, this situation is also complicated by the influence of heterosis effects. In this case, heterotic plants may look very powerful and attractive, but they will quickly lose their valuable properties after just one or two self-pollinations. When selecting for productivity, the most effective method is individual selection. Depending on the specific conditions, various modifications of it can be successfully applied (Dorofeev et al. 1987).

Vegetative part of plants is one of the crop structure components, on which the productivity of wheat depends to a large extent. It reflects the influence of meteorological conditions, the level of agrotechnics, the supply of nutrients and productive moisture on crops, etc.

One of the main features of quantitative traits is their high variability even with minor changes in environmental factors (Tsilke 2005).

Plant height is an important indicator of plant architectonics and the harvest index of grain and yield (Maccaferri et al. 2008, Sadeque and Turner 2010). It is controlled by many genes, of which the most important are the Rht genes (reduced height) (Lobachev 2000). With an excessive shortening of the straw, the conditions for the functioning of the photosynthetic apparatus deteriorate.

The height of plants in modern selection is a very important trait, since it is associated with resistance to lodging and, thus, indirectly affects the amount of yield. Plant height limits lodging resistance, which occurs due to the influence of climatic factors (Allan et al. 1966).

When cross varieties significantly differing in plant height, Orliuk (1972) notes the intermediate character of trait inheritance. Larionov (1977), based on his research, concluded that first-generation hybrids often approach a tall parent.

Formation of plant height occurs in almost 80% of the growing season duration. According to research data, the possibility of assessing the adaptability of varieties on plant height is expected more accurately than their yield, since the course of agroclimatic conditions and the suppressed state of plant development from disease and damage to pests have less effect on the height formation, and the accuracy of the plants height accounting is not limited by subjective difficulties. It takes a little more time to form a grain yield; adverse biotic factors are more destructive, objective crop yield accounting can be complicated by a number of subjective factors (Likhchvor 1999).

Plant height is a convenient quantitative trait for genetic analysis, which is easy to measure and is marked by wide variation in phenotypic manifestations.

The stem length of wheat plays an important role in the formation of resistance to lodging, which ensures the realization of reproductive potential and prevents losses in harvesting (Orlyuk 2002).

Works on the study of the inheritance of this trait and its interrelations with other economic-valuable attributes are still relevant. The study of the inheritance character of quantitative traits allows us to determine the selection value of the source material, to select and evaluate the breeding material in the early stages of selection (Marchenko et al. 2013).

Purpose

To create a new genetically diverse breeding material by the stem length of soft spring wheat based on intra-species hybridization, to determine the level of its manifestation and variability in the first generation and formation in the second generation of plants.

MATERIALS AND METHODS

As source material for hybridization, samples of soft spring wheat gene pool of various ecological and geographical origins, entered in the State Register of plant varieties suitable for cultivation in Ukraine, were used. The varieties were sown with a supply area 5x15 cm in single-meter sections with intermediate row width 15 cm in a three-time repetition. Sowing was carried out in optimal terms. The plants were manually harvested in a phase of full grain maturity. Biometric analysis was carried out according to generally accepted methods in quantitative genetics, based on the average sample 25-30 plants.

The quantitative assessment of the traits was carried out by the arithmetic mean ($\bar{x} \pm S\bar{x}$), the variability estimate – by standard deviation (S), variance (S^2), range (R) and the coefficient of variation (CV, %) (Dospekhov 1985).

The nature of inheritance, the degree and frequency of transgressions were determined according to the generally accepted method of Voskresenska – Shpot. Its essence is that all hybrid plants which exceed the average values of the trait from the three best plants of a better parent form refer to positive transgressions (Voskresenskaya and Shpot 1987).

We calculated such statistical characteristics: mean; minimum and maximum values of the trait (min-max); range ($R = X_{max} - X_{min}$).

The coefficient of variation was calculated by Dospekhov:

$$(CV = S/\bar{x} \times 100\ \%)$$

The coefficient of variation is a relative measure of variability. Using the coefficient of variation makes sense in studying the variation of the trait, which has only a positive value. Variability is assumed to be:

- CV < 10% – insignificant;
- CV > 10% <20% – average;
- CV > 20% – significant.

The degree of positive transgression is determined by the ratio of exceeding the maximum value of a certain quantitative trait in F_2 (M_F) above its maximum value in the best parental form (M_P) to the last, in %:

$$T = (M_F - M_P) / M_P \times 100$$

The degree of negative transgression is determined by the ratio of the difference between the minimum value of the trait in F_2 (m_F) and its minimum value and the worst parental form (m_p) to the last, in %:

$$T = (m_F - m_p) / m_p \times 100$$

The transgression frequency is determined by the number of individuals in F2 (%) that exceed (+ T) or inferior (-T) to the extreme value of the trait of parental forms.

The results of the experimental data were processed by statistical methods on the programs “Excel”, “Statistica 5.0”, Windows-98 on a personal computer.

RESULTS AND DISCUSSION

The stem length of the hybrids depends on the selection of parental pairs for crosses. Low-growth transgressions have a special value, since such forms are characterized by higher yields. Because of the development selection of short-stem varieties of wheat, it is important to study the inheritance of the stem length by hybrid generations of soft spring wheat.

In our studies, we explored the manifestation of the stem length in first generation hybrids obtained by direct and reciprocal crosses of seven varieties with different stem length. On the basis of previous studies it is possible to scientifically substantiate the program of crosses and predict the identification of transgressive forms for economically valuable features (Lozinska 2010).

In the studied varieties, the stem length varied within the range of variety composition, combinations of crosses and years of research. The stem length in the first generation of soft spring wheat hybrids at direct crosses ranged from 73.2 cm (Struna Myronivska / Lehuan) to 90.3 cm (Struna Myronivska / Simkoda Myronivska). In reciprocal crosses, the stem length ranged from 59.2 cm (Lehuan / Struna Myronivska) to 96.4 cm (Azhurnaia / Struna Myronivska). In the standard variety Elehiia Myronivska stem length was 62.6 cm (**Table 1**).

Concerning to the parental forms with direct crosses, all hybrids exceeded maternal form from 17.1% (Struna Myronivska / Lehuan) to 44.5% (Struna Myronivska / Simkoda Mironovska), and the parental form – from 0.8% (Struna Myronivska / Simkoda Mironovska) to 38.8% (Struna Myronivska / Lehuan). It means they did not reveal the influence of the maternal cytoplasm on the manifestation of the stem length. In the hybrid combinations Struna Myronivska / Elehiia Myronivska were at parental level; in the combination Struna Myronivska / Azhurnaia treated as inferior to the parental

Table 1. The stem length in F_1 soft spring wheat in reciprocal crosses, BTNAU (2017)

Crosses combinations	Indicators of stem length					
	hybrids ($\bar{x} \pm S\bar{x}$), cm		in % to parental forms in direct crosses		in % to parental forms in reciprocal crosses	
	direct	reverse	♀	♂	♀	♂
Struna Myronivska / Heroinia	86.2 ± 1.53	88.5 ± 2.66	137.7	105.0	108.3	142.0
Struna Myronivska / Simkoda Mironovska	90.3 ± 1.54	92.5 ± 1.05	144.5	100.8	103.2	148.1
Struna Myronivska / Elehiia Myronivska	73.7 ± 1.27	75.1 ± 1.81	118.0	100.0	102.1	120.2
Struna Myronivska / Kolektyvna 3	75.8 ± 1.39	74.2 ± 1.52	121.2	102.8	100.6	118.5
Struna Myronivska / Lehuan	73.2 ± 0.97	59.2 ± 2.12	117.1	138.8	112.6	94.8
Struna Myronivska / Azhurnaia	81.8 ± 2.28	96.4 ± 1.91	130.7	89.1	105.1	154.2
Elehiia Myronivska, St.	62.6 ± 1.21					

Table 2. Manifestation and variation of stem length in F_1 soft spring wheat, BTNAU (2017)

Combinations	$\bar{x} \pm S\bar{x}$, cm	Lim, cm		R, cm	S^2	V, %
		min	max			
Struna Myronivska / Heroinia	86.2 ± 1.5	65.3	98.3	33.1	50.2	8.1
Heroinia/ Struna Myronivska	88.6 ± 2.7	71.4	108.1	36.8	103.2	11.3
Struna Myronivska / Simkoda Mironovska	90.5 ± 1.5	77.6	102.3	24.8	66.2	9.1
Simkoda Mironovska / Struna Myronivska	92.5 ± 1.1	82.6	102.4	20.2	38.3	6.8
Struna Myronivska / Elehiia Myronivska	73.7 ± 1.3	61.6	81.6	20.2	31.2	7.7
Elehiia Myronivska/ Struna Myronivska	75.3 ± 1.8	55.5	84.8	29.6	59.9	10.2
Struna Myronivska/ Kolektyvna 3	75.8 ± 1.4	64.1	86.8	22.8	32.1	7.4
Kolektyvna 3 / Struna Myronivska	74.2 ± 1.5	53.6	89.1	35.4	66.1	11.1
Struna Myronivska / Lehuan	73.3 ± 1.0	58.3	82.4	24.2	27.6	7.3
Lehuan / Struna Myronivska	59.2 ± 2.1	48.4	79.6	31.3	89.2	15.8
Struna Myronivska / Azhurnaia	81.5 ± 2.3	73.7	91.7	18.1	41.3	7.8
Azhurnaia / Struna Myronivska	96.2 ± 1.9	83.2	118.1	34.8	79.4	9.3

form on 10.9%, indicating the probability of maternal organism's effect on the trait formation due to the content of short-stem genetic factors in cytoplasm.

Regarding to the parental forms with reciprocal crosses, all hybrids exceed the maternal form from 0.6% (Struna Myronivska / Kolektyvna 3) to 12.6% (Struna Myronivska / Lehuan), and the parental form from 18.5% (Struna Myronivska / Kolektyvna 3) to 54.2% (Struna Myronivska / Azhurnaia). In the hybrid combination Struna Myronivska / Lehuan treated as inferior to parental form on 5.2%.

In general, reducing the stem length in hybrids affects both the genetic origin of the varieties and their place in the hybrid combination, as evidenced by Wang Z. et al., as well as the additive type of gene interaction, manifested in the form of domination and over-domination (Lozinska 2010).

Watching the manifestation and fluctuation of the stem length in first-generation hybrids of soft spring wheat in the conditions of BTNAU experimental field in 2017, we see that the smallest range is characterized by a hybrid combination Struna Myronivska / Azhurnaia (18.1 cm) with average variance 41.3, and the biggest one in the combination Heroinia / Struna Myronivska (36.8 cm) with high variance 103.2 (**Table 2**). The researches have determined that the range (R) depends on the crosses combination and parental form.

It is clear from **Table 2** that the range is greater for reverse crosses than for direct, we wanted to note that the hybrid combination Struna Myronivska / Simkoda Myronivska has range 24.8 cm in direct crosses, while in reverse (Simkoda Myronivska / Struna Myronivska) is 20.2 cm, in all other combinations range is greater for reciprocal crosses.

The coefficient of variation of stem length in first-generation hybrids for direct and reverse crosses was in the range from 6.8% (Simkoda Myronivska / Struna Myronivska) to 9.3% (Azhurnaia / Struna Myronivska), indicating a slight variation of this index. Only in combinations of crosses Lehuan / Struna Myronivska, Heroinia / Struna Myronivska and Kolektyvna 3 / Struna Myronivska variation of stem length is average and stands for 15.8, 11.3 and 11.1% respectively.

The stem length in second-generation hybrids of soft spring wheat in direct crosses was from 36.7 cm (Struna Myronivska / Kolektyvna 3) to 55.1 cm (Struna Myronivska / Heroinia). For reverse crosses it was from 35.2 cm (Lehuan / Struna Myronivska) to 56.2 cm (Azhurnaia / Struna Myronivska) (**Table 3**).

Analyzing the range of stem length in second-generation hybrids, it is observed that the smallest index was found in the combination Struna Myronivska / Kolektyvna 3 – 16.1 cm with low variance 22.1, and the largest one in the combination Heroinia/Struna Myronivska (34.1 cm) with variance 81.0.

The coefficient of variation had a slight variability in the stem length in the combination Simkoda Myronivska / Struna Myronivska and was 8.8%. All other hybrid combinations had an average variability in the stem length and accounted from 10.6% (Elehiia Myronivska / Struna Myronivska) to 16.2% (Heroinia / Struna Myronivska).

Thus, the analysis of hybrids F_1 and F_2 reveals the complex genetic nature of the determination of the stem length in the studied hybrids. Starting from F_2, a significant form-creating process traces in the stem length in hybrids. Studies have shown that in most reciprocal crosses, a significant reduction in the stem

Table 3. Manifestation and variation of stem length in F_2 soft spring wheat, BTNAU (2018)

Combinations	$\bar{x} \pm S\bar{x}$, cm	Lim, cm		R, cm	S^2	V, %
		min	max			
Struna Myronivska / Heroinia	55.1 ± 1.1	43.6	66.2	22.4	46.0	12.2
Heroinia / Struna Myronivska	56.1 ± 1.8	32.3	66.5	34.1	81.0	16.2
Struna Myronivska / Simkoda Mironovska	51.5 ± 1.2	33.6	62.8	29.2	56.3	14.5
Simkoda Mironovska / Struna Myronivska	54.5 ± 0.9	47.1	64.7	17.9	23.2	8.8
Struna Myronivska / Elehiia Myronivska	53.3 ± 1.6	43.8	63.0	19.3	37.6	11.4
Elehiia Myronivska / Struna Myronivska	47.3 ± 0.8	37.7	59.8	22.4	25.5	10.6
Struna Myronivska / Kolektyvna 3	38.5 ± 1.6	28.3	50.4	21.7	34.7	15.2
Kolektyvna 3 / Struna Myronivska	39.7 ± 1.1	30.4	53.3	22.8	27.5	13.2
Struna Myronivska / Lehuan	36.7 ± 1.1	31.4	48.4	16.1	22.1	12.7
Lehuan / Struna Myronivska	35.2 ± 1.3	26.1	42.4	16.4	24.1	14.1
Struna Myronivska / Azhurnaia	52.5 ± 1.4	42.1	66.3	24.3	45.1	12.7
Azhurnaia / Struna Myronivska	56.2 ± 2.6	46.1	71.1	25.0	64.6	14.2

Table 4. Degree and frequency of transgressions of stem length trait in F_2, BTNAU (2018)

Combinations	Transgressions, %	
	high-growth	
	degree	frequency
Struna Myronivska / Simkoda Mironovska	2.1	6.0
Simkoda Mironovska / Struna Myronivska	6.2	10.0
Elehiia Myronivska / Struna Myronivska	3.3	7.1
Kolektyvna 3 / Struna Myronivska	5.5	3.6

length in F_2 hybrids is observed in the case when a variety with less stem length was taken as a maternal form, indicating the influence of the maternal cytoplasm on this trait formation.

Transgression is a phenomenon when recombinants are allocated in segregated generations of hybrids, in which the quantitative trait is expressed to a greater or lesser degree than in extreme variants of the parental forms with the corresponding minimum and maximum manifestation of the trait. In the first case we are talking about negative, in the second – about positive transgression. This phenomenon is usually associated with polymers.

The frequency and degree of transgression are interconnected, so if the hybrid forms are characterized by a high frequency but a low degree, it can be stated about the manifestation of intermediate inheritance (a slight excess of the values of the hybrids' trait over the parents). If hybrids have a high degree, but a low frequency, this indicates heterogeneity of the population and the presence of plants that are significantly different from the rest. Hybrid combinations, in which a high degree of transgression is combined with its high frequency, may indicate a strong heterosis effect in combination (Shepelev 2013).

Until now, there is no single theory that reveals the genetic nature of the transgressions phenomena, and therefore there are no generally accepted methods for the selection and use of transgressive forms in practical selection.

In second-generation of soft spring wheat hybrids, high-growth transgressions were detected in 4 combinations of crosses from 12. F_2 hybrids had transgression degree 2.1-6.2% at a frequency 6.0-10.0% in hybrid combinations Struna Myronivska / Simkoda Myronivska, Simkoda Myronivska / Struna Myronivska, Elehiia Myronivska / Struna Myronivska, Kolektyvna 3 / Struna Myronivska (**Table 4**).

Much of the plants F_1 are at the level of more tall parents, among which there are high-growth transgressions in subsequent generations. Therefore, short-stem transgression in subsequent generations is complicated. The success of breeding on short-stemming depends mainly on the use of transgressive forms with this trait. Difficulties arise in the process of obtaining low-growth transgressions with a complex of economic and valuable features, because tall forms included in crosses that make it difficult to isolate short-stem genotypes from common hybrid populations.

Thus, it can be argued that those hybrids in which the heterosis is observed in F2 have the highest rates of transgressive variability based on the stem length.

CONCLUSION

As a result of the analysis of soft spring wheat varieties during 2017-2018 we identified the following hybrid combinations by the stem length:

1. In 2017, hybrid combinations Struna Myronivska / Simkoda Myronivska (90.3 cm), Struna Myronivska / Azhurnaia (96.4 cm), and in 2018 Struna Myronivska / Heroinia (55.1 cm), Azhurnaia / Struna Myronivska (56.2 cm), Heroinia / Struna Myronivska (56.1 cm) were the best.
2. High-growth transgressions were found in second-generation hybrids with following combinations: Simkoda Myronivska / Struna Myronivska, Kolektyvna 3 / Struna Myronivska, Elehiia Myronivska / Struna Myronivska, Kolektyvna 3 / Struna Myronivska, the degrees of transgression of which amounted to 6.2 and 5.5% at frequencies 10.0 and 3.6% respectively.

We have proved that with the help of transgressive variability it is possible to achieve an increase in the diversity of the gene pool of soft spring wheat in the stem length and, by means of reciprocal crosses, obtain valuable perspective lines and hybrids that can be future varieties.

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