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STUDY OF VERNALIZATION REQUIREMENT AND PHOTOPERIOD SENSITIVITY IN WINTER WHEAT VARIETIES OF MYRONIVKA BREEDING IN THE CONDITIONS OF THE CENTRAL FOREST-STEPPE OF UKRAINE

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Background. The vernalization requirement and photoperiodic sensitivity are significant indicators as they determine the adaptability of plants to environmental conditions. The aim of the study was to characterize modern winter wheat genotypes by genetic systems that determine vernalization processes.

Materials and Methods. The winter wheat varieties of Myronivka breeding, such as Vezha Myronivska, Avrora Myronivska, MIP Yuvileina, MIP Lada, MIP Fortuna, MIP Darunok, MIP Nika, MIP Roksolana, MIP Feieriia, MIP Vidznaka, and MIP Lakomka, were studied. The vernalization requirement duration and photoperiodic sensitivity of winter wheat varieties were determined according to the methodological recommendations (Demydov *et al.,* 2019). Five winter bread wheat varieties, MIP Darunok, MIP Roksolana, MIP Nika, MIP Feieriia and MIP Vidznaka were crossed on incomplete diallele scheme with three near-isogenic lines derived from Erythrospermum 604 with different genotypes for the Vrd gene system 1) *Vrd1Vrd1vrd2vrd2*, 2) *vrd1vrd1Vrd2Vrd2*, and 3) *vrd1vrd1vrd2vrd2*. Hybridological analysis was performed in F_2 populations by the comparison of the fact segregation of the plant phenotypes' number with theoretically expected using χ^2 criterion.

Results and Discussion. The Vezha Myronivska, Avrora Myronivska, MIP Yuvileina, MIP Nika and MIP Roksolana varieties demonstrated low photoperiod sensitivity; the MIP Lada, MIP Fortuna, MIP Darunok, MIP Feieriia and MIP Vidznaкa varieties showed medium photoperiod sensitivity; the MIP Lakomka variety was characterized by high photoperiod sensitivity. The Vezha Myronivska, MIP Yuvileina, MIP Fortuna, MIP Nika, MIP Roksolana, MIP Feieriia, MIP Vidznaка and MIP Lakomka varieties required vernalization duration for 30 days, whereas varieties Avrora Myronivska, MIP Lada and MIP Darunok for 40 days. The results of the hybridological analysis indicate the presence of the dominant allele *Vrd1* in the MIP Darunok and MIP Roksolana varieties, which contributes to shortening the vernalization duration. In the MIP Nika variety, the vernalization requirement duration is controlled by the dominant allele *Vrd2*, while in the varieties MIP Feieriia and MIP Vidznaka, it is controlled by two dominant alleles of *Vrd1* and *Vrd2* genes.

Conclusions. The obtained results indicate the possibility of recombining different levels of photoperiodic sensitivity and vernalization requirement duration in the winter wheat genotype through breeding and developing varieties with their optimal combination for specific ecological conditions.

Keywords: winter wheat, vernalization requirement duration, photoperiodic sensitivity, hybridological analysis, variety

INTRODUCTION

Wheat is one of the most important and widely grown food crops, playing a crucial role in feeding 35 % of the world's population by providing 19 % of calories and 21 % of proteins (Tadesse *et al*., 2019; Filip *et al*., 2023). Climate change is currently impacting a range of environmental factors that directly and indirectly influence wheat adaptability and productivity (Zahra *et al*., 2023; Johansson *et al*., 2023).

Important indicators closely related to the adaptability of winter wheat varieties are the vernalization requirement duration and photoperiodic sensitivity. The vernalization requirement duration is the number of days with low positive temperatures necessary for plants to transition to the generative state (Milec *et al*., 2023). The vernalization requirement duration affects the heading date, as well as drought, winter, and frost resistance, the grain mass per ear, and, consequently, the yield (Deng *et al*., 2015; Atar, 2020). Differences between winter wheat varieties in the vernalization duration, ranging from 15 to 60 or more days, have been established (Baloch *et al*., 2003).

Photoperiodism, the response of plants to day length (photoperiod), is a very important circadian rhythm, influencing their flowering time. The variability of the photoperiodic response in different plants ensures their adaptation to various environmental conditions (Totsky *et al*., 2011). Photoperiodism is defined as the response of living organisms to periodic, seasonal fluctuations in the duration of daylight hours. The change in the day length serves as a signal to the organism, indicating variations in a whole range of environmental factors during the alternation of seasons (Gendron & Staiger, 2023). The response of plants to photoperiod is manifested in the acceleration or slowing down of their growth and development depending on the complex of seasonal climatic conditions of a specific region (Osnato *et al*., 2022). Winter wheat is a long-day crop. Its ability to delay development with shortening daylight in autumn is an important adaptive mechanism ensuring plant survival under stress factors during wintering (Pérez-Gianmarco *et al*., 2020).

For the optimal survival of soft winter wheat plants during wintering, it is important to combine a certain vernalization requirement duration and the level of photoperiodic sensitivity. These traits allow the optimal selection of sowing time to prevent overgrowth of plants in autumn before entering winter, as this can reduce resistance to abiotic factors and, consequently, yield (Bloomfield *et al*., 2023). Determining the breeding value of wheat varieties based on vernalization requirement duration and photoperiodic sensitivity is particularly relevant, as it allows for a more objective characterization of their adaptability and prediction of their behavior in corresponding environmental conditions (Amo *et al*., 2022).

The resistance of winter wheat to environmental stress conditions is associated with the rate of passage and duration of organogenesis stages, largely influenced by genetic systems controlling the vernalization requirement duration and photoperiodic sensitivity (Stelmakh & Fait, 2019). To date, significant aspects of the genetic processes occurring during vernalization, which ensure the transition of winter cereals to generative development, have been elucidated. The mechanism that underlies vernalization sensitivity and the timing of ear emergence is based on mutations in the *Vrn* gene loci, which adjust the dependence of the transition to the ear emergence stage on the vernalization factor and convert the gene from a recessive to a dominant state (Distelfeld *et al*., 2009; Fırat, 2020). Wheat's response to low positive temperature, *i.e*., vernalization, is determined by the expression of the *Vrn-A1*, *Vrn-B1*, *Vrn-D1*, and *Vrn-D4* genes. They are located on chromosomes 5A, 5B, and 5D (Yoshida *et al*., 2010; Jin & Wei, 2016). The *Vrn-B3* gene, which affects ear emergence time, is located on the short arm of chromosome 7B (Zhang *et al*., 2008).

A. F. Stelmakh *et al*. (2005) reported the identification of three genes regulating the vernalization requirement duration. These genes were designated *Vrd1*, *Vrd2* and *Vrd3*. The *Vrd1* gene is located on chromosome 4A, and the *Vrd2* gene is on 5D. It has been established that the presence of the dominant *Vrd1* gene reduces the vernalization requirement duration to 20–35 days, depending on the variety's photoperiod sensitivity, and *Vrd2* to 40–45 days (Balashova *et al*., 2006). A third gene (*Vrd3*), which determines the vernalization duration of up to 40 days, is also considered present and is located on one of chromosomes 1A, 6A, or 4B (Fait, 2007; Fayt *et al*., 2013). Genotypes carrying recessive *Vrd* alleles require at least 50-60 days of vernalization to transition to the generative growth stage (Balashova *et al*., 2006). V. I. Fayt (2012) reported the identification of vernalization requirement duration genes in winter bread wheat genotypes. The author emphasized that the reduced vernalization requirement in most samples was due to the presence of the *Vrd1* or *Vrd2* gene, as well as their combination. Additionally, some samples were found to carry the new *Vrd3* gene. In our previous studies, based on hybridological analysis using tester lines, the absence of *Vrd1* and *Vrd2* genes in the studied winter bread wheat varieties was established (Pirych *et al*., 2021).

Given the above, characterizing modern winter wheat genotypes by genetic systems determining vernalization processes, which influence overall adaptive potential, is relevant. The aim of this study was to determine the vernalization requirement duration and photoperiodic sensitivity of winter wheat varieties developed at the V. M. Remeslo Myronivka Institute of Wheat of the National Academy of Agrarian Sciences of Ukraine (MIW) under the conditions of the central part of the Forest-Steppe of Ukraine, and to identify the vernalization requirement duration genes in modern winter bread wheat varieties.

MATERIALS AND METHODS

The research was conducted in 2021–2023 at the MIW. We used new Myronivka varieties of winter wheat Vezha Myronivska, Avrora Myronivska, MIP Yuvileina, MIP Lada, MIP Fortuna, MIP Darunok, MIP Nika, MIP Roksolana, MIP Feieriia, MIP Vidznaka (*Triticum aestivum* L.) and MIP Lakomka (*Triticum durum* Desf.).

The vernalization requirement duration and photoperiodic sensitivity of winter wheat varieties of Myronivka breeding were determined according to the methodological recommendations (Demydov *et al*., 2019). To determine photoperiod sensitivity of the winter wheat varieties, two variants of the experiment were laid: in the first the plants were grown under natural daylight; in the second, they were under artificially shortened daylight (**Fig. 1**).

Fig. 1. Winter wheat plants under shortened and natural day length

Before sowing, the germinated seeds were artificially vernalized for 60 days (at 0…+ 1 °C). Using a special marker, germinated seeds of each variety were planted 20 pcs in each of two vegetative pots per variant of the experiment. Then, the pots were placed in an open area. For comparison, wheat plants were grown under natural and artificially shortened day length conditions. To shorten the day length, the plants in the pots were covered with black boxes daily, starting from the 3rd leaf stage and continuing until the heading stage. The duration of the shortened photoperiod was 12 hours per day, from 8 a.m. to 8 p.m. The date of heading occurrence for individual plants was marked with labels. According to photoperiod sensitivity, wheat varieties were divided into three groups: high-, medium- and low sensitive. In our experiment, the first group included varieties that responded to the daylight reduction with significant heading delay of 10–13 days, the second group with delay of 6–9 days, and the third group with less than six days.

To determine vernalization requirement duration, 100 seeds of each variety were watered and placed for germination in a thermostat at the temperature of +19…+20 °C for one day. To go through vernalization, the seedlings were placed in the LVN-200G chamber at the temperature of 0…+1 °C for different periods (50, 40, and 30 days).

The vernalized seedlings were planted in spring on April 18. Previously, the field was divided into strips of 1 m in width and 50 cm tracks between the strips. The seedlings were planted on two rows for each variant of the experiment, about 50 seeds per row (**Fig. 2**). The plants were counted in early August using the envelope method. The vernalization duration was considered to be sufficient if most plants of the variety reached heading.

Fig. 2. Winter wheat plants under different vernalization durations

We carried out gene identification in five new winter bread wheat varieties MIP Darunok, MIP Nika, MIP Roksolana, MIP Feieriia and MIP Vidznaka. As testers that allow establishing differences in wheat plant development at early stages of organogenesis, we used near-isogenic by genes *Vrd* winter wheat lines Erythrospermum 604

Vrd1Vrd1vrd2vrd2, Erythrospermum 604 *vrd1vrd1Vrd2Vrd2* and Erythrospermum 604 *vrd1vrd1vrd2vrd2*, created at the Plant Breeding and Genetics Institute, National Center of Seed and Cultivar Investigation of NAAS (Fayt, 2002). The varieties and testers were crossed according to the incomplete di-allel scheme using twirl-method of female plant pollination. The F_1 seeds obtained were sown in autumn for reproduction of the genetic material. F_2 seeds were vernalized for 40 and 30 days. To determine the allele status of the *Vrd* genes, the plants of each hybrid population were divided into two phenotypic classes according to the ratio "heading occurrence: no heading occurrence" (Fayt, 2003).

Experimental data were processed by methods of variation statistics using MS Office software. Statistical processing of photoperiod sensitivity data (**Table 1**) was conducted using the Student's *t*-test method. Data of vernalization requirement duration (**Table 2**) were analyzed statistically by the ANOVA using the Fisher's Least Significant Difference (LSD) test. P values of < 0.05 were interpreted as statistically significant. Hybridological analysis was performed in F_2 populations by the comparison of the fact segregation of the plant phenotypes' number with theoretically expected using chi-square (χ^2) criterion (**Table 4**).

RESULTS AND DISCUSSION

Photoperiod sensitivity. It was found that all studied wheat varieties responded to the reduction in photoperiod with a significant delay in plant development. It should be noted that since the experiment was conducted under natural conditions, there was some variation in the delay of plant development from year to year. However, the relative ranking of the varieties is mostly maintained.

As a result of three years of research, it has been established that the Vezha Myronivska, Avrora Myronivska, MIP Yuvileina, MIP Nika and MIP Roksolana varieties were characterized with low photoperiod sensitivity. The MIP Lada, MIP Fortuna, MIP Darunok, MIP Feieriia and MIP Vidznaka varieties were classified into the group with medium photoperiod sensitivity. A high photoperiod sensitivity was found in the MIP Lakomka variety (**Table 1**). It is worth noting that in 2021, the durum wheat variety MIP Lakomka, compared to bread wheat varieties, exhibited a significantly longer "emergence to heading" period under both natural and shortened photoperiod conditions. This phenomenon can be explained by the fact that in 2021, the beginning of the "emergence to heading" period was considerably colder compared to 2022 and 2023, with the presence of frosts (on April 28, the minimum temperature dropped to -0.7 °C). Such weather conditions were unfavorable for the normal growth and development of seedlings. It is known that durum wheat is more sensitive to low temperatures at early stages of development compared to bread wheat (Braun & Sãulescu, 2002). This is why it reacted worse to such stressful conditions, particularly with delayed growth, resulting in a significantly prolonged vegetative period.

Vernalization requirement. For normal generative development, the Vezha Myronivska, MIP Yuvileyna, MIP Fortuna, MIP Nika, MIP Roksolana, MIP Feieriia, MIP Vidznaka and MIP Lakomka varieties required vernalization duration for 30 days, whereas Avrora Myronivska, MIP Lada and MIP Darunok varieties required vernalization duration for 40 days (**Table 2**).

Table 1. **Photoperiod sensitivity of winter wheat (2021–2023)**

Variety	2021					2022					2023				
	the "emergence to heading" period, days				photoperiod sensitivity	the "emergence to heading" period, days				photoperiod sensitivity	the "emergence to heading" period, days				photoperiod sensitivity
	natural photoperiod	shortened photoperiod	d	t		natural photoperiod	shortened photoperiod	d	t		natural photoperiod	shortened photoperiod	d	t	
Vezha Myronivska	52.2	55.9	3.8	6.5***	L	55.8	61.0	5.2	5.5***	L	48.6	52.6	4.0	9.0***	L
Avrora Myronivska	52.1	54.8	2.7	3.0**	L	54.8	58.9	4.1	2.4*	L	47.0	52.8	5.8	12.1***	L
MIP Yuvileina	55.7	57.6	1.9	2.9**	L	63.4	67.4	3.9	2.3*	L	53.2	59.1	5.9	9.6***	L
MIP Lada	56.9	63.1	6.2	7.9***	M	60.3	70.1	9.9	7.2***	M	56.0	65.4	9.4	14.6***	M
MIP Fortuna	56.4	58.4	2.0	4.3***	L	59.4	65.8	6.4	3.7***	M	55.4	63.7	8.3	18.0***	M
MIP Darunok	57.3	65.4	8.0	12.5***	L	58.3	63.1	4.8	2.7**	L	54.9	61.9	7.0	9.4***	M
MIP Nika	54.9	59.3	4.4	6.1***	L	57.4	65.8	8.4	4.8***	M	54.0	59.4	5.4	2.3*	L
MIP Roksolana	56.2	58.3	2.1	3.6***	L	57.8	67.6	9.9	6.4***	M	53.8	58.8	5.0	9.9***	L
MIP Feieriia	55.7	58.7	3.0	5.3***	L	60.0	69.8	9.7	7.7***	M	54.4	62.0	7.5	9.5***	M
MIP Vidznaka	54.4	57.1	2.7	5.1***	L	57.6	65.3	7.7	5.3***	M	52.4	59.9	7.5	10.4***	M
MIP Lakomka	116.5	131.7	15.2	8.6***	H	71.6	83.3	11.7	12.2***	H	54.0	61.0	7.0	8.8***	M

Comments: *, **, *** – significance level $P < 0.05$, $P < 0.01$, $P < 0.001$; d – difference in the duration of the "emergence to heading" period between plants grown under a shortened and natural photoperiod; t – Student's criterion; L – low; M – medium; H – high

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Table 2. **Vernalization requirement duration of winter wheat (2021–2023)**

Variety	2021		2022		2023	
	vernalization requirement duration, days	percentage of headed plants, %	vernalization requirement duration, days	percentage of headed plants, %	vernalization requirement duration, days	percentage of headed plants, %
Vezha Myronivska	30	100±0.0	30	100±0.0	30	100±0.0
Avrora Myronivska	40	85±4.9	40	78±4.6	40	94±3.0##
MIP Yuvileina	30	97±2.1	30	82±4.4*	30	100±0.0###
MIP Lada	40	100±0.0	40	100±0.0	40	100±0.0
MIP Fortuna	30	86±4.9	30	76±4.7	30	88±3.7#
MIP Darunok	40	84±5.5	40	75±5.8	40	83±4.7
MIP Nika	30	91±4.4	30	72±5.1*	30	96±2.4###
MIP Roksolana	30	99±1.2	30	80±4.6**	30	100±0.0###
MIP Feieriia	30	99±1.1	30	78±5.2**	30	100±0.0###
MIP Vidznaka	30	99±1.1	30	86±4.0*	30	100±0.0###
MIP Lakomka	30	100±0.0	40	76±5.1**	30	83±4.6**

Comments: *, ** – significant difference compared to 2021 (P <0.01, P <0.001); #, ##, ### – significant difference compared to 2022 (P <0.05, P <0.01, P <0.001)

A shorter vernalization duration, on the one hand, contributes to an earlier resumption of spring vegetation, and thus a more intensive development of plants and an increase in their productivity. On the other hand, it can cause some decrease in their resistance to adverse winter conditions. A longer vernalization duration can lead to slower plant development in the spring and a reduction in their productivity (Prasil *et al*., 2005).

For the identification of vernalization requirement duration genes, it is necessary to consider both the vernalization requirement and the photoperiod sensitivity of the parental forms. V. I. Fait *et al*. (2017) notes that if the vernalization requirement duration genes are in a recessive state, the variety has the genotype *vrd1vrd1vrd2vrd2*. Varieties in which plant heading is caused by the dominant *Vrd1* gene have the genotype *Vrd1Vrd1vrd2vrd2*, and if by *Vrd2*, the genotype of the variety will be *vrd1vrd1Vrd2Vrd2*. Even if only one allele is in a dominant state, it leads to plant heading. Plants that do not head have a recessive genotype (Fayt & Popova, 2003).

Vernalization requirement duration under environmental conditions of the Ukrainian Forest-Steppe was determined also in winter wheat near-isogenic lines with the *Vrd* gene system Erythrospermum 604 *Vrd1Vrd1vrd2vrd2*, Erythrospermum 604 *vrd1vrd1Vrd2Vrd2* and Erythrospermum 604 *vrd1vrd1vrd2vrd2*.

In 2023, in the Erythrospermum 604 *Vrd1Vrd1vrd2vrd2* line, which carries the dominant *Vrd1* allele, complete plant heading was observed in all artificial vernalization variants. For the line Erythrospermum 604 *vrd1vrd1Vrd2Vrd2*, the vernalization requirement duration was 30 days. More than 44 % of the Erythrospermum 604 *vrd1vrd1vrd2vrd2* line headed after 40 days of artificial vernalization, while plants did not head at all after 30 days. In the variants with 60 and 50 days of vernalization, complete plant heading was observed (**Table 3**).

Table 3. **Percentage of plants of winter wheat near-isogenic lines that headed at different periods of artificial vernalization, 2023**

Genotype of near-isogenic line	Vernalization requirement, days			
	30	40	50	60
Erythrospermum 604 *Vrd1Vrd1vrd2vrd2*	100	100	100	100
Erythrospermum 604 *vrd1vrd1Vrd2Vrd2*	77.2	95.1	100	100
Erythrospermum 604 *vrd1vrd1vrd2vrd2*	-	44.0	100	100

Hybridological analysis. To determine the allele status of the *Vrd* genes in our studies, we relied on the obtained F_2 segregation results. In these populations, we counted the number of plants that headed and those that remained in the tillering or stem elongation stage at the time of field harvesting.

V. I. Fayt (2012) notes that the use of 40-day artificial vernalization allows the division of the hybrid population into carriers of the *Vrd* gene(s) in homo- and heterozygous states (heading plants) and recessive genotypes (non-heading plants).

After 40-day vernalization in the combination of the variety MIP Darunok with the recessive tester *vrd1vrd1vrd2vrd2* the fact segregation ratio for “heading occurrence: no heading occurrence” was 97:21, which corresponds to the theoretical ratio of 3:1 (**Table 4**). This indicates the presence of dominant alleles of the *Vrd1* or *Vrd2* gene. In the combination *Vrd1Vrd1vrd2vrd2* / MIP Darunok the fact segregation ratio was 131:0, which corresponds to the theoretical ratio of 1:0. The fact segregation ratio with the tester *vrd1vrd1Vrd2Vrd2* was 127:8, which corresponds to the theoretical ratio of 15:1. This indicates that the vernalization requirement duration of the MIP Darunok variety is controlled by the dominant allele of the *Vrd1* gene.

Table 4. **The segregation ratio in F_2 population for “heading occurrence: no heading occurrence” after vernalization duration of 40 days, 2023**

Variety	*vrd1vrd1vrd2vrd2*			*Vrd1Vrd1vrd2vrd2*			*vrd1vrd1Vrd2Vrd2*		
	fact	theoretical*	χ^2	fact	theoretical*	χ^2	fact	theoretical*	χ^2
MIP Darunok	97:21	3:1	3.24	131:0	1:0	-	127:8	15:1	0.02
MIP Roksolana	68:14	3:1	2.74	121:0	1:0	-	118:11	15:1	1.14
MIP Nika	16:38	3:1	0.009	67:3	15:1	0.46	109:0	1:0	-
MIP Feieriia	85:2	15:1	2.32	105:0	1:0	-	73:0	1:0	-
MIP Vidznaka	110:5	15:1	0.71	98:0	1:0	-	115:0	1:0	-

Comment: * $\chi^2 < 3.84$

Such segregation is also observed in the population created by crossing the winter wheat variety MIP Roksolana with these testers. In the combination *Vrd1Vrd1vrd2vrd2* / MIP Roksolana the fact segregation ratio for “heading occurrence: no heading occurrence” was 121:0, which corresponds to the theoretical ratio of 1:0. In the combinations with the testers *vrd1vrd1Vrd2Vrd2* and *vrd1vrd1vrd2vrd2* the fact segregation ratio was 118:11 and 68:14 respectively, which corresponds to the theoretical ratio of 15:1 and 3:1, respectively. This indicates that the vernalization requirement duration of the MIP Roksolana variety is also controlled by the dominant *Vrd1* allele.

The segregation ratio in populations *Vrd1Vrd1vrd2vrd2* / MIP Nika, the fact segregation ratio was 67:3, which corresponds to the theoretical ratio of 15:1. In the combination with the *vrd1vrd1Vrd2Vrd2* tester, the fact segregation ratio was 109:0, which corresponds to the theoretical ratio of 1:0. In the combination with the recessive tester *vrd1vrd1vrd2vrd2*, the fact segregation ratio was 16:38, which corresponds to the theoretical ratio of 3:1. This indicates the presence of the dominant allele of the *Vrd2* gene in the MIP Nika variety.

In the combinations of the varieties MIP Feieriia and MIP Vidznaka with the tester of recessive genes (*vrd1vrd1vrd2vrd2*) the fact segregation ratio was 85:2 and 110:5 respectively, which corresponds to the theoretical ratio of 15:1 for both. The absence of segregation (all plants headed) in the combinations of these varieties with the *Vrd1Vrd1vrd2vrd2* and *vrd1vrd1Vrd2Vrd2* testers indicates the identity of the *Vrd* genes in these varieties and the corresponding testers. Thus, the MIP Feieriia and MIP Vidznaka varieties have dominant alleles of both *Vrd1* and *Vrd2* genes in their genotypes.

Therefore, based on the results of the hybridological analysis using tester lines, the presence of the dominant allele of the *Vrd1* gene, which contributes to the reduction of the vernalization requirement duration, was established in the genotypes of the varieties MIP Darunok and MIP Roksolana (**Table 5**). In the MIP Nika variety, the vernalization requirement duration is controlled by the dominant allele of the *Vrd2* gene, whereas in the MIP Feieriia and MIP Vidznaka varieties is controlled by two dominant alleles of the *Vrd1* and *Vrd2* genes.

Table 5. **Genotypes of winter bread wheat varieties by *Vrd* genes, 2023**

Variety	Genotype	Alleles of genes*
MIP Darunok	*Vrd1Vrd1vrd2vrd2*	*Vrd1vrd2*
MIP Roksolana	*Vrd1Vrd1vrd2vrd2*	*Vrd1vrd2*
MIP Nika	*vrd1vrd1Vrd2Vrd2*	*vrd1Vrd2*
MIP Feieriia	*Vrd1Vrd1Vrd2Vrd2*	*Vrd1Vrd2*
MIP Vidznaka	*Vrd1Vrd1Vrd2Vrd2*	*Vrd1Vrd2*

Comment: * only the dominant alleles of the gene present in the tester’s genotype are indicated

The identified varieties can be used as donors of dominant *Vrd* gene alleles when selecting parental forms for crossing in breeding programs for vegetation period duration.

CONCLUSIONS

1. It was determined that winter wheat varieties MIP Lada, MIP Fortuna, MIP Darunok, MIP Feieriia and MIP Vidznaka are characterized by medium photoperiod sensitivity. The Vezha Myronivska, Avrora Myronivska, MIP Yuvileina, MIP Nika and MIP Roksolana varieties were identified as having low photoperiod sensitivity. In the MIP Lakomka variety, a high photoperiod sensitivity was noted.
2. For normal generative development, the varieties Vezha Myronivska, MIP Yuvileina, MIP Fortuna, MIP Nika, MIP Roksolana, MIP Feieriia, MIP Vidznaкa and MIP Lakomka required vernalization duration for 30 days. The Avrora Myronivska, MIP Lada and MIP Darunok varieties required vernalization duration for 40 days.
3. In the varieties MIP Darunok and MIP Roksolana, the presence of the dominant allele of the *Vrd1* gene, which contributes to the reduction of the vernalization requirement duration, was established in their genotypes using tester lines. In the MIP Nika variety, the vernalization requirement duration is controlled by the dominant allele of the *Vrd2* gene, whereas in varieties MIP Feieriia and MIP Vidznaka, it is controlled by two dominant alleles of the *Vrd1* and *Vrd2* genes.

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COMPLIANCE WITH ETHICAL STANDARDS

Conflict of Interest: the authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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AUTHOR CONTRIBUTIONS

Conceptualization, [T.Y.; S.P.; A.P.]; methodology, [T.Y.; A.P.]; validation, [T.Y.]; formal analysis, [T.Y.; S.P.; A.P.]; investigation, [T.Y.; S.P.; A.P.; M.K.]; resources, [O.D.; V.K.]; writing – review and editing, [T.Y.; S.P.; A.P.]; visualization, [T.Y.; S.P.; A.P.], supervision, [O.D.; V.K.]; project administration, [O.D.; V.K.].

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ВИВЧЕННЯ ЯРОВИЗАЦІЙНОЇ ПОТРЕБИ ТА ФОТОПЕРІОДИЧНОЇ ЧУТЛИВОСТІ У СОРТІВ ПШЕНИЦІ ОЗИМОЇ МИРОНІВСЬКОЇ СЕЛЕКЦІЇ В УМОВАХ ЦЕНТРАЛЬНОГО ЛІСОСТЕПУ УКРАЇНИ

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Вступ. Яровизаційна потреба та фотоперіодична чутливість є важливими показниками, оскільки вони визначають адаптивність рослин до умов навколишнього середовища. Характеристика сучасних генотипів пшениці озимої за генетичними системами, що визначають процеси яровизації, є актуальним завданням сьогодення.

Матеріали та методи. Вивчали сорти пшениці озимої миронівської селекції – Вежа миронівська, Аврора миронівська, МІП Ювілейна, МІП Лада, МІП Фортуна, МІП Дарунок, МІП Ніка, МІП Роксолана, МІП Феєрія, МІП Відзнака та МІП Лакомка. Визначення тривалості яровизаційної потреби іфотоперіодичної чутливості сортів пшеницiозимоїпроводилизаметодичнимирекомендаціямиО.А.Демидова(Демидов *та ін*., 2019). П'ять сортів пшениці м'якої озимої МІП Дарунок, МІП Роксолана, МІП Ніка, МІП Феєрія та МІП Відзнака були схрещені за неповною діалельною схемою з трьома майже ізогенними лініями, отриманими від Erythrospermum 604 з різними генотипами за системою генів *Vrd*: 1) *Vrd1Vrd1vrd2vrd2*, 2) *vrd1vrd1Vrd2Vrd2* і *vrd1vrd1vrd2vrd2.* Гібридологічний аналіз проводили в популяціях F_2 методом порівняння фактичної сегрегації кількості фенотипів рослин із теоретично очікуваною з використанням χ^2 критерію.

Результати. Сорти Вежа миронівська, Аврора миронівська, МІП Ювілейна, МІП Ніка та МІП Роксолана продемонстрували низьку фотоперіодичну чутливість; сорти МІП Лада, МІП Фортуна, МІП Дарунок, МІП Феєрія та МІП Відзнака мали середню чутливість до фотоперіоду; сорт МІП Лакомка характеризувався високою фотоперіодичною чутливістю. Сорти Вежа миронівська, МІП Ювілейна, МІП Фортуна, МІП Ніка, МІП Роксолана, МІП Феєрія, МІП Відзнака та МІП Лакомка потребували тривалості яровизаційної потреби 30 діб, тоді як сорти Аврора миронівська, МІП Лада та МІП Дарунок – 40 діб. Результати гібридологічного аналізу вказують на наявність домінантного алеля *Vrd1* у сортів МІП Дарунок та МІП Роксолана, який сприяє скороченню тривалості яровизації. У сорту МІП Ніка тривалість яровизаційної потреби контролюється домінантним алелем Vrd2, водночас у сортів МІП Феєрія та МІП Відзнака – двома домінантними алелями генів *Vrd1* та *Vrd2*.

Висновки. Отримані результати вказують на можливість рекомбінувати в генотипі пшениці озимої різні рівні прояву фотоперіодичної чутливості та яровизаційної потреби за допомогою селекції, а також розробляти сорти з їхнім оптимальним поєднанням для певних екологічних умов.

Ключові слова: пшениця озима, тривалість яровизаційної потреби, фотоперіодична чутливість, гібридологічний аналіз, сорт

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