

## COLLECTIONS OF THE WORLD'S CROP GENETIC RESOURCES FOR THE DEVELOPMENT OF PRIORITY PLANT BREEDING TRENDS

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### Earliness of spring bread wheat accessions under the conditions of the Middle Volga Region

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**Background.** Development of early-ripening high-yielding cultivars of spring bread wheat is a complicated and difficult process. Striving for higher yields has triggered a trend to prolong the growing season of the cultivars released by the Tatar Research Institute of Agriculture (TatRIA). Our breeding efforts to produce early cultivars, based on using an early-ripening sample as one of the parents, were unsuccessful. This paper presents a search for solutions to the said problem.

**Materials and methods.** We studied spring bread wheat accessions from the collections of the N.I. Vavilov All-Russian Institute of Plant Genetic Resources (VIR) and Baicheng Academy of Agricultural Sciences (China) as well as promising lines developed by TatRIA. The study of the material was based on conventional spring bread wheat breeding methods. Phenological phases of wheat development were identified using the Zadoks scale.

**Results.** An ambiguous role played by the vernalization response (*Vrn*) and photoperiod sensitivity (*Ppd*) genes in wheat earliness was shown, which is consistent with the data repeatedly presented in other publications. We identified accessions with the shortest period from sprouting to heading. Under our climate conditions, the earliest cultivars were those from Novosibirsk Province, Russia, and the North-Eastern China, where wheat development from sprouting to heading lasted 36–46 days.

**Keywords:** early spring bread wheat cultivars, *Vrn* and *Ppd* genes, phenological phases, heading dates

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# КОЛЛЕКЦИИ МИРОВЫХ ГЕНЕТИЧЕСКИХ РЕСУРСОВ КУЛЬТУРНЫХ РАСТЕНИЙ ДЛЯ РАЗВИТИЯ ПРИОРИТЕТНЫХ НАПРАВЛЕНИЙ СЕЛЕКЦИИ

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## Скороспелость образцов яровой мягкой пшеницы в условиях Среднего Поволжья

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**Актуальность.** Создание скороспелых продуктивных сортов яровой мягкой пшеницы – трудная и сложная задача. В связи с «гонкой» за продуктивностью идет тенденция на увеличение вегетационного периода у сортов селекции Казанского научного центра РАН. Проводимая нами селекционная работа по созданию скороспелых сортов, основанная на использовании в качестве одного из родителей раннеспелых образцов, не дает желаемого результата. Поиски путей решения этой проблемы отражены в данной работе.

**Материал и методы.** Материалом для исследований служили образцы яровой мягкой пшеницы из коллекции ВИР и Байченской сельскохозяйственной академии (Китай), а также перспективные линии яровой пшеницы селекции Татарского НИИСХ. Селекционная проработка материала осуществлялась по традиционным методикам. Фенологические фазы развития растений пшеницы определяли на основании шкалы Задокса.

**Результаты.** Продемонстрирована неоднозначная роль генов, детерминирующих реакцию растений на яровизацию (*Vrn*) и отзывчивость растений на фотопериод (*Ppd*), в формировании скороспелости, что согласуется с данными, показанными неоднократно в других работах. Выявлены образцы с наименьшим межфазным периодом «всходы – колошение». Самыми скороспелыми в наших климатических условиях оказались сорта из Новосибирской области России и сорта северо-восточной зоны Китая с межфазным периодом «всходы – колошение» 36–46 дней.

**Ключевые слова:** раннеспелые сорта яровой мягкой пшеницы, *Vrn* и *Ppd* гены, фенологические фазы, дата колошения

**Благодарности:** работа выполнена в рамках государственных заданий:

ВИР, проект № 0481-2022-0001 «Структурирование и раскрытие потенциала наследственной изменчивости мировой коллекции зерновых и крупяных культур ВИР для развития оптимизированного генбанка и рационального использования в селекции и растениеводстве»;

КазНЦ РАН «Эколого-генетические подходы к созданию и сохранению ресурсов растений и животных, расширению их адаптивного потенциала и биоразнообразия, разработка сберегающих агротехнологий с целью повышения устойчивости производства высококачественной продукции, достижения безопасности для здоровья человека и окружающей среды».

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## Introduction

Development of spring bread wheat cultivars combining high yields and earliness under specific soil and climate conditions is a complicated task that is not always achievable. As a rule, early-ripening wheat cultivars in the Middle Volga Region cannot compete with those having medium and long growing seasons. Only three mid-early cultivars with a 39–43-day-long period from sprouting to heading are recommended for cultivation in the Middle Volga Region: they are 'Zlata', 'Ekaterina' and 'Chelyaba Stepnaya'. All three have significantly lower yields than the mid-ripening cultivar 'Yoldyz' traditionally cultivated in the region.

There are several reasons to broaden the range of commercial early wheat cultivars in this region:

1. In the Middle Volga Region, harvesting is the hardest part of the wheat cultivation practice. Organizational measures to reduce losses while ensuring the high grain quality have been undertaken. Weather change during harvesting sometimes prevents obtaining high-quality grain at minimum costs. Thus, growing cultivars that differ in maturity time will provide for a chain of harvesting operations that will minimize the loss of high-quality grain.

2. Since 2016, wheat stem rust has become more harmful. The infection tends to manifest itself when early-ripening cultivars enter the middle grain dough stage, which does not have a strong negative effect on their yield.

3. When cultivating winter cereals in this region, there is a risk of low overwinter survival. A way to preserve such crops could be complementary springtime seeding of early spring cultivars.

Breeding for a specific trait always implies a search for and examination of source material. For wheat, breeding for the duration of the sprouting-to-heading period (strongly correlated with maturity) generally takes into account three genetic systems: 1. vernalization response, i.e., the way plants respond to lower temperature during sprouting (*Vrn*); 2. sensitivity to photoperiod (*Ppd*); and 3. earliness *per se* (*Eps*) (Dubcovsky et al., 1998). The exact effect size of each system in the plant development duration has not yet been determined. It is possible to combine these genetic systems for greater phenotypical diversity in the plant development rate. Therefore, information on the input of each system into the feature of earliness will be useful for the selection of parents for hybridization in order to produce promising early-ripening cultivars.

To denote genes that determine vernalization response, A. Pugsley introduced the symbol *Vrn* for 'vernalization' (Pugsley, 1971). Classical sources describe the genes *Vrn1*, *Vrn2*, *Vrn3*, *Vrn4* and *Vrn5* (Pugsley, 1972; Maystrenko, 1980; Stelmakh, 1987). In a more contemporary interpretation used in the catalogue of gene symbols for wheat (McIntosh et al., 2010), the development type is marked in a slightly different way: what used to be marked as *Vrn1*(5AL), *Vrn2*(5BL), and *Vrn3*(5DL) are now referred to as *Vrn-A1*, *Vrn-B1*, and *Vrn-D1*. For the rare *Vrn4* and *Vrn5* genes, alternative molecular modifications have been published; in the latest version they were marked as *Vrn-D4* (Yoshida et al., 2010) and *Vrn-B3*, respectively (Yan et al., 2006). At least for *Vrn-A1*, *Vrn-B1*, *Vrn-D1*, and *Vrn-D4* almost isogenic lines were developed (Pugsley, 1968; Stelmakh, Avsenin, 1983; Koval et al., 2001). Winter plants are homozygous recessive for these genes and require low above-zero temperatures to enter the flowering stage. Spring plants have at least one dominant allele of these genes (Kobylyansky, Fadeeva, 1986; Goncharov, 2004).

Plants with dominant alleles of *Vrn-A1* do not respond to vernalization, while plants with other dominant alleles demonstrate low sensitivity to the level and duration of cold temperatures (Shindo, Sasakuma, 2002). The *Vrn-A1* gene is fully epistatic to other vernalization genes. Therefore, its presence inhibits the need for vernalization, notwithstanding the presence of dominant or recessive alleles of other genes (Pugsley, 1983). At the same time, for the *Vrn-1* locus, there is a series of multiple alleles that further increase diversity in terms of vernalization response (Stelmakh, 1986; Yan et al., 2004).

It has been observed that dominant alleles of *Vrn* genes do not only influence springtime development, but also the flowering time (Rigin, Goncharov, 1989). All ultra-early accessions of spring bread wheat do not respond to vernalization (Rigin et al., 2019). A. F. Stelmakh (1987) believes that these genes determine up to 70% of the development rate in a wheat plant. Plants in which dominant alleles of *Vrn-A1* were present had an earlier-ripening phenotype, while plants where only the dominant *Vrn-B1* allele was present demonstrated the latest maturity. B. V. Rigin and colleagues calculated that *Vrn-A1* is present in 85.7% early and ultra-early wheat accessions, *Vrn-B1* was present in 6.3%, and *Vrn-D1* in 1.8% (Rigin et al., 2015). In terms of the effect on the flowering time, the dominant allele sequence is as follows: *Vrn-A1* > *Vrn-D1* > *Vrn-D4* ≥ *Vrn-B1* > *Vrn-B3* (Goncharov N., Goncharov P., 2009). However, it is worth mentioning that different *Vrn* loci demonstrate different genetic effect values under specific conditions, thus leading to varying trait prominence in certain genotypes (Dzhalpakova et al., 1996; Moiseeva, Goncharov, 2007), i.e., a number of plant cultivars combining the same *Vrn* loci will demonstrate different response under different soil and climate conditions, which will affect the productivity and early maturity. This is especially important for the development of a breeding strategy targeted at earliness.

Response to Photoperiod (*Ppd*). Spring bread wheat is a long-day plant; however, some varieties enter the heading stage at the same time both during long and short days, i.e., these plants are not sensitive to photoperiod. Lack of photoperiod sensitivity is controlled by the dominant allele of *Ppd*, while sensitivity is controlled by its recessive allele. Response to photoperiod in hexaploid wheats is controlled by *Ppd-A1*(2A), *Ppd-B1*(2B), *Ppd-D1*(2D), and *Ppd-B2*(7B), as per the contemporary gene nomenclature system (Khlestkina et al., 2009). Before, the first three genes used to be denoted as *Ppd3*, *Ppd2*, and *Ppd1*, respectively.

It is believed that the *Ppd-D1* gene is fully epistatic to other photoperiod sensitivity genes (Merezhko et al., 1997). At the same time, in terms of influence on photoperiodism, some researchers point to a possible domination of *Ppd-B1* (Keim et al., 1973; Voronin, Stelmakh, 1991; Tanio, Kato, 2007). This may be explained not only by the isogenic lines used, which could have yielded a false result, but also from the fact that in isolated cases *Ppd-B1* has been observed to produce an effect comparable to that of *Ppd-D* (González et al., 2005); however, such effect is an exception. The degree of photoperiod sensitivity increases for the *Ppd* genes in the following order: *Ppd-D1* > *Ppd-A1* > *Ppd-B1* (Pugsley, 1966). While breeding precocious cultivars to be grown in different climatic zones, it is necessary to be in the *Ppd-D1* genotype, since the heading date will not depend on the length of the day.

Earliness *per se* (*Eps*). At present, molecular tests are carried out for the *Eps-A1m*, *Eps-A1a*, *Eps-A1b*, and *Eps-D1* genes in wheat (Zikhali et al., 2016). The expressivity of these genes is contingent on temperature and impacts the timing of development stages, thereby influencing the plant's yield (Ochagavía et al., 2019). It is possible that *Eps*, which controls wheat

ultra-earliness *per se*, is not an independent structural unit, but a block of polygenes (modifiers) with low effect, which determine continuous variability and are associated with the gene (Rigin et al., 2018).

The purpose of the research was to identify accessions with the shortest period from sprouting to heading from the different spring bread wheat collections, and demonstrate the effect of the *Vrn* and *Ppd* genes in accessions with different maturation periods under the conditions of the Middle Volga Region.

### Materials and methods

We studied spring bread wheat (*Triticum aestivum* L.) accessions with a short growing season provided by the N.I. Vavilov All-Russian Institute of Plant Genetic Resources (VIR) and received through interinstitutional exchange (372 accessions).

Hybridization, observation, selection and nursery establishment took place in 2015–2020 in TatRIA's experimental fields in the north of the Middle Volga Region, Republic of Tatarstan, Russia (55°38'60"N, 49°18'25"E), 90 m above sea level.

Local soils are of the well-cultivated Alfisol (USDA soil taxonomy) type. The climate is continental, with large seasonal differences: cold and snowy winters, and warm and dry summers. The mean air temperature in January, the coldest month of the year, is –13.6°C. The maximum soil freezing is 95 cm; and the average snow cover depth in February is 39 cm, while the snow melts in the fields by the end of April. Summertime weather conditions establish themselves at the beginning of June and end by late August. The mean air temperature in July, the warmest summer month, is 19.5°C. The mean annual precipitation is 560 mm, with 176 mm in the summer months.

The weather conditions during the study were typical of the forest-steppe zone, with frequent summer droughts in each year, except 2017 when the rainy and cold summer resulted in a prolonged growing season. Under the local climate, given that the seeding took place at the optimal time, i. e., in early May, the air temperature in most years rapidly grew and

the daylight period between sprouting and heading was 16.5–17.3 hours long, i.e., the day was relatively long. Meteorological data were obtained from a weather station located in the immediate vicinity where the experiment was conducted.

The phenological results were obtained in accordance with the Zadoks scale (Zadoks et al., 1974). The tests were carried out without watering. The seeding rate was 600 pieces per 1 m<sup>2</sup>. The fertilizer background corresponded to the ratio of N:85, P:40, and K:40 kg/ha active ingredient. There was no treatment with fungicides or insecticides. A sulfonylurea class herbicide was used against weeds.

The relationships between the indicators were analyzed using the Pearson correlation coefficient.

The collection nursery was seeded in a single replication, with a frequent standard reference cultivar. on a plot of 1 m<sup>2</sup>. The selection nurseries were seeded in accordance with the conventional spring wheat breeding methods adopted in Russia (Table 1).

### Results and discussion

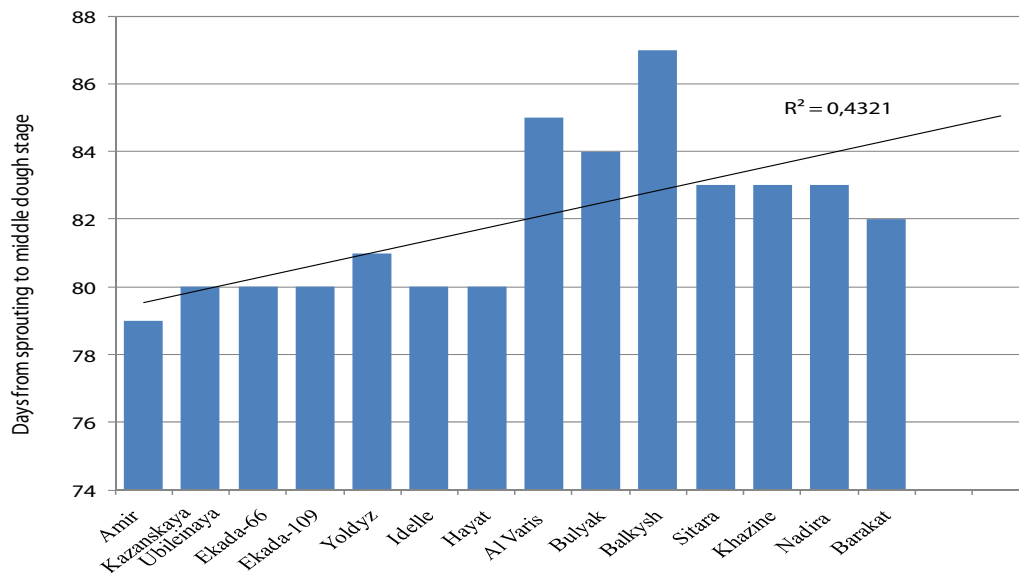
The current phase of spring bread wheat breeding at TatRIA, located in the north of the Middle Volga Region, was launched twenty years ago. All cultivars developed before 2015 were mid-early wheats. However, due to the pursuit of higher yields, the cultivars released in recent years have a longer growing season (Figure). Cvs. 'Al Varis' and 'Balkysh' are within the mid-late category.

Our breeding efforts, based on the use of early-ripening accessions as one of the parents, failed to yield desirable results and did not guarantee identifying lines with short duration of the growing season that meet breeders' criteria. On average, we made 10–17% of combinations using early cultivars (total year-by-year number varied from 435 to 523). Starting with F<sub>3-5</sub>, early-maturing plants were selected, and this process continued in the first-year breeding nursery (BN-1), where the maturity period was used as a screening criterion. In 2018, after field screening for early maturity, only 227 breeding lines out of 16343, i.e., 1.4%, were selected for the second-year breeding nursery (BN-2). After laboratory

**Table 1. Scheme of the breeding process in the development of early spring wheat cultivars**

**Таблица 1. Схема селекционного процесса при создании скороспелых сортов яровой мягкой пшеницы**

Year	Nursery. Generation	Nursery sowing method. Description.
first	Crossing	Pollination by the Twell method.
second	F <sub>1</sub>	Manual sparse seeding. Reproduction of the progeny.
third	F <sub>2</sub> – F <sub>3</sub>	Seeding with a seeder – on a plot of 1 m <sup>2</sup> – 5 m <sup>2</sup> . Reproduction of the progeny.
fourth	F <sub>4</sub>	Seeding with a seeder on a plot of 10 m <sup>2</sup> . Individual selection of plants
fifth	Breeding nursery of the first year (BN-1)	Seeding of the best selected ears was carried out manually by kin. Selection of disease-resistant kin. Selection of early-maturing lines.
sixth	Breeding nursery of the second year (BN-2)	Seeding with a seeder on a plot of 1 m <sup>2</sup> . Selection of disease-resistant kin and assessment of their productivity. Selection of early-maturing lines.
seventh	Breeding nursery of the third year (BN-3)	Seeding with a seeder on a plot of 10 m <sup>2</sup> . Selection of productive and disease-resistant lines.
eighth	Preliminary variety testing (PVT)	Seeding with a seeder on a plot of 10 m <sup>2</sup> in triple replication. Selection of productive and disease-resistant lines.
ninth	Competitive variety testing (CVT)	Seeding with a seeder on a plot of 25 m <sup>2</sup> in quadruple replication. Selection of productive and disease-resistant lines. Grain quality assessment.



**Figure.** Retrospective changes in the duration of the growing season for wheat cultivars developed by the Tatar Research Institute of Agriculture, 2015–2019  
**Рисунок.** Ретроспективное изменение продолжительности вегетационного периода сортов Татарского НИИСХ, 2015–2019

screening for grain quality and seed weight, only 23 lines were kept for further seeding, and their future is quite vague, as the productivity of these lines is significantly inferior to the standard mid-ripening reference cultivar.

Breeding for earliness has not yet yielded desirable results. Therefore, researching the ways to solve this problem is one of the main areas of our work.

Most researchers use the period between sprouting and heading to characterize the duration of the growing season. This may be due to the ability of establishing more precise temporal boundaries of this period, which is more difficult to do if the more ‘vague’ and difficult to observe middle dough stage is selected as the ultimate boundary. In addition, for spring bread wheat, there is a strong correlation between the number of days to heading and maturity (Rigin, 2012). We observed medium or strong year-by-year correlations in the accessions from the VIR collection. Such correlation decreased only during the years when the heading/middle dough stage fell on droughty weather (Table 2).

In breeding for earliness, the collection of N.I. Vavilov All-Russian Institute of Plant Genetic Resources (VIR) plays a vital role as it contains a sufficient set of early-ripening accessions (Zuev et al., 2009). In the studied collection, the number of early accessions was minimal and averaged 5.6% (Table 3).

Annual assessment of the collection by the date of heading allowed us to identify a number of accessions with the shortest period from sprouting to heading. Most of the accessions from Novosibirsk Province, Russia, in the southeast of the West Siberian Plain were classified as early-ripening cultivars. Some of the accessions from the northeast of China were characterized by a minimum duration of the period from sprouting to heading. This is the so called northeastern zone of spring wheat cultivation. The cultivars typical for this region possess the short-duration genotype of *Vrn-A1+Vrn-B3* (Zhang et al., 2008) (Table 4). At the same time, this genotype is also characteristic of ‘Ekada-6’ which we classify as a mid-ripening cultivar. All early accessions demonstrated yields far lower than those of the mid-ripening cultivar ‘Simbirtsit’.

**Table 2.** The Pearson correlation coefficient between days from sprouting to heading and to the middle dough stage in spring bread wheat (VIR collection)

**Таблица 2.** Корреляционные связи у яровой мягкой пшеницы между количеством дней от всходов до колошения и восковой спелости (коллекция ВИР)

Year	Days from sprouting to heading (Zadoks 10–51)	Days from sprouting to the middle dough stage (Zadoks 10–71)	Pearson correlation factor	SCC between the heading and middle dough stages (Zadoks 51–71)
2015	lim 39–53	lim 75–94	0.777*	1.86
2016	lim 36–49	lim 67–75	0.517*	0.19
2017	lim 43–62	lim 77–92	0.634*	0.37
2018	lim 36–53	lim 67–83	0.781*	0.55
2019	lim 35–58	lim 73–97	0.828*	2,14
2020	lim 36–52	lim 72–86	0,732*	1,35

Note: \* □ significant at the 0.01 level

Примечание: \* □ значимо на уровне 0,01

**Table 3. The number of spring bread wheat accessions included in the experiment and their earliness groups****Таблица 3. Доля коллекционных образцов яровой мягкой пшеницы по группам спелости**

Year	Number of accessions	Percentage of accessions, %		
		Early	Mid-ripening	Late
2015	147	7,5	76,2	16,3
2016	120	8,3	87,6	4,1
2017	184	3,8	87,5	8,7
2018	265	4,2	86,8	9,0
2019	305	5,7	85,5	8,8
2020	360	4,2	91,6	4,2
Average		5,6	85,9	8,5

**Table 4. Spring bread wheat accessions with minimum interphase periods from sprouting to heading****Таблица 4. Образцы яровой мягкой пшеницы с минимальным межфазным периодом «всходы – колошение»**

VIR catalogue No.	Accession	Origin	Days from sprouting to heading (Zadoks 10-51)						Grain yield, g/m <sup>2</sup>
			2015	2016	2017	2018	2019	2020	2015-2019
65473	Long Fu-12	China, Heilongjiang	41	36	44	38	37	40	258
65863	Shen-68-71	China, Liaoning	-	-	40	36	35	36	270
-	2004R-177-4-7-2	China, Jilin	42	36	41	37	36	37	246
-	Baichun N 0.7	China, Jilin	42	36	41	37	36	37	262
57079	Yershovskaya-32	Russia, Saratov Prov.	41	38	46	41	38	43	306
64856	Polyushko	Russia, Novosibirsk Prov.	39	37	45	37	37	39	333
64257	Novosibirskaya-15	Russia, Novosibirsk Prov.	39	37	46	39	37	41	320
65131	Novosibirskaya-20	Russia, Novosibirsk Prov.	41	38	45	39	38	41	326
65132	Pamyati Vavenkova	Russia, Novosibirsk Prov.	41	38	-	-	38	43	296
66414	Zlata, mid-early standard	Russia, Moscow Prov.	41	39	48	39	38	42	325
64548	Simbirtsit, mid-ripening standard	Russia, Ulyanovsk Prov.	46	44	53	44	45	47	459
LCD 0.5									43

A complex long-term hybridological analysis that is sometimes unable to distinguish multiple allelism from close linkage leads scientists to molecular research. A number of catalogues and research papers publish the results of molecular tests on the *Vrn* and *Ppd* genes in wheat cultivars and breeding lines. The role of allele variants in wheat earliness was demonstrated (Emtseva et al., 2012; Likhenko et al., 2014; Chumanova et al., 2020). Some cultivars with the identified *Vrn* and *Ppd* genes are presented in Table 5. It is obvious that the same genotype is characteristic of both early and mid-ripening wheat cultivars, so it is impossible to speak unambiguously about these “earliness” genes in our climate zone. The

late-maturing cultivar ‘Buryatskaya ostistaya’, having the winter wheat cultivar ‘Odessa-66’ in its pedigree, has only one dominant *Vrn-A1a* allele, which is consistent with the data of many authors on the additive effect of *Vrn* genes on precocity.

Wheat growth in our zone under optimal seeding rates occurs with a long day, so it is impossible to identify the contribution of *Ppd* genes in the field. All early cultivars with identified *Ppd* genes have the genotype in recessive state and do not manifest phenotypically at our light day.

In the breeding for high yields, we often use winter cultivars in our work. However, there is a possibility of a significant shift towards late maturity. At the same time, there are

**Table 5. Plant genotype of Russian spring bread wheat cultivars from different groups of earliness (Lysenko et al., 2014)****Таблица 5. Генотип растений российских сортов яровой пшеницы различных групп спелости (Lysenko et al., 2014)**

VIR catalogue No.	Accession	Origin	Days from sprouting to heading, (Zadoks 10-51)	Presence in the genotype	
				<i>Vrn</i>	<i>Ppd</i>
<b>Early cultivars</b>					
64856	Polyushko	Novosibirsk Prov.	39	<i>Vrn-A1a, Vrn-B1a, vrn-D1, vrn-B3</i>	<i>ppd-D1c</i>
64257	Novosibirskaya-15	Novosibirsk Prov.	40	<i>Vrn-A1a, Vrn-B1a, vrn-D1, vrn-B3</i>	<i>ppd-D1c</i>
65132	Pamyati Vavenkova	Novosibirsk Prov.	40	<i>Vrn-A1a, vrn-B1, vrn-D1, vrn-B3</i>	<i>ppd-D1c</i>
64872	Chelyaba stepnaya	Chelyabinsk Prov.	43	<i>Vrn-A1a, Vrn-B1a, vrn-D1, vrn-B3</i>	<i>ppd-D1c</i>
<b>Mid-ripening cultivars</b>					
65250	Ulyanovskaya-100	Ulyanovsk Prov.	46	<i>Vrn-A1a, Vrn-B1c, vrn-D1, vrn-B3</i>	<i>ppd-D1c</i>
62644	Prokhorovka	Saratov Prov.	45	<i>Vrn-A1a, Vrn-B1c, vrn-D1, vrn-B3</i>	<i>ppd-D1c</i>
64544	Ester	Moscow Prov.	46	<i>Vrn-A1a, Vrn-B1a, vrn-D1, vrn-B3</i>	<i>ppd-D1c</i>
64543	Ekada-6	Samara Prov.	44	<i>Vrn-A1a, Vrn-B1c, vrn-D1, Vrn-B3</i>	<i>Ppd-D1a / ppd-D1c</i>
63714	Tulaykovskaya-10	Samara Prov.	44	<i>Vrn-A1a, Vrn-B1a, vrn-D1, vrn-B3</i>	<i>ppd-D1c</i>
64377	Kazanskaya Yubileinaya	Rep. of Tatarstan	46	<i>Vrn-A1a, Vrn-B1a, vrn-D1, vrn-B3</i>	<i>ppd-D1c</i>
63206	Omskaya-33	Omsk Prov.	45	<i>Vrn-A1a, Vrn-B1c, vrn-D1, vrn-B3</i>	<i>ppd-D1c</i>
<b>Late cultivars</b>					
64113	Buryatskaya ostistaya	Rep. of Buryatia	48	<i>Vrn-A1a, vrn-B1, vrn-D1, vrn-B3</i>	<i>ppd-D1c</i>

examples of transgression when crosses between winter and spring wheat resulted in earlier-ripening cultivars than that of the spring component (Nettevich, 2008). Our experiments failed to demonstrate transgressive early cultivars in segregating populations. The expected prolongation of the growing season compared to the spring component was observed. No influence of the cytoplasm of winter cultivars on the duration of maturation was identified. Thus, in  $F_1$  reciprocal crossings between winter wheat accessions and spring ones with short maturation did not result in any difference in heading dates (Table 6).

### Conclusion

As shown above, earliness cannot be explained by the *Vrn* and *Ppd* gene systems alone. Breeding for early maturity involves a number of interconnected factors and genetic systems;

therefore, it is evident that the development of cultivars with short growing seasons is a difficult and complicated task. Having analyzed the data of molecular tests and hybridological analyses conducted by various researchers, we can make the following conclusion on the presence of *Vrn* and *Ppd* in the studied accessions. For our set of accessions, the dominant genes *Vrn-A1* and *Vrn-B1* are not enough to achieve the earliest maturity for the precocious phenotype. The long daylight period in our region results in a weak impact of photoperiod on earliness. The presence of a recessive *ppd-D1* gene in the earliest Novosibirsk cultivars confirms this observation. As for the genetic system of earliness *per se*, determining its special significance for earliness in our region, it requires a large set of ultra-early accessions that are not available at present. Given that three genetic systems influence precocity; we can assume that in our zone the key role in precocity will be played by the earliness *per se* system.

**Table 6. Heading dates in F<sub>1</sub> after reciprocal crossing of winter and spring accessions, 2018****Таблица 6. Даты наступления колошения у гибридов первого поколения при реципрокных скрещиваниях озимых с яровыми, 2018 г.**

Growth habit	Crossing combination	Date
Winter / spring	Skipetr / Baichun N 0.7	July 3
	Skipetr / 2004R-177-4-7-2	June 29
Spring / winter	Baichun N 0.7 / Skipetr	July 3
	2004R-177-4-7-2 / Skipetr	June 29

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