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MANIFESTATION OF PRODUCTIVITY TRAITS IN *Triticum aestivum/T. timopheevii* INTROGRESSION LINES IN DIFFERENT ENVIRONMENTAL CONDITIONS

S.I. VAKULA[1], O.A. ORLOVSKAYA[1], L.V. KHOTYLEVA[1], I.N. LEONOVA[2]

[1]*Institute of Genetic and Cytology of National Academy of Science of Belarus,* 27, ul. Akademicheskaya, Minsk, 220072 Republic of Belarus, e-mail svettera@yandex.ru (✉ corresponding author), O.Orlovskata@igc.by, L.Khotyleva@igc.by;
[2]*Federal Research Center Institute of Cytology and Genetics SB RAS,* Federal Agency for Scientific Organizations, 10, prosp. Akademika Lavrent'eva, Novosibirsk, 630090 Russia, e-mail leonova@bionet.nsc.ru
ORCID:
Vakula S.I. orcid.org/0000-0002-2242-7107
Khotyleva L.V. orcid.org/0000-0003-0295-5022
Orlovskaya O.A. orcid.org/0000-0002-1187-1317
Leonova I.N. orcid.org/0000-0002-6516-0545
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Abstract

Common wheat lines containing introgression of alien genetic material are an important source and donors of pathogen resistance genes. However, for the effective involvement of lines in breeding, information is needed on their ecological plasticity and productivity in different environments. This paper is the first report on estimates of adaptive responses, stability and breeding value of common wheat lines with alien substitutions and translocations in geographically distant regions. The aim of our investigation was comparative analysis of manifestation of agronomic important traits of common wheat introgression lines containing alien genetic material, when grown in different eco-geographical zones, the Western Siberia (the Russian Federation) and Eastern Europe (the Republic of Belarus). Twenty one fungal disease-resistant *T. aestivum/T. timopheevii* introgression lines (BC_1F_{22-24}, $2n = 42$) from crossing of five common wheat varieties (Saratovskaya 29, Skala, Irtyshanka 10, Tcelinnaya 20 and Novosibirskaya 67) with tetraploid wheat *T. timopheevii* var. *viticulosum* were tested. Field evaluation of the lines and parental wheat cultivars was carried out in 2015 in the conditions of the West Siberian (Novosibirsk Region) and Eastern European (Minsk, Republic of Belarus) agro-climatic zones. The field experiment was arranged in two replicates on 1 m plots, 40-60 grains per row and 20 cm distance between rows, according to the systematic method. The evaluation of the tiller number, plant height, ear length, spikelet number, ear grain number, ear grain weight and 1000-grain weight were carried out according to the methodological recommendations of the N.I. Vavilov All-Russian Institute of Plant Genetic Resources (VIR) (for 20-25 randomly selected plants of each line). Our results show conserved ranks of tiller number, ear length, number of spikelets per ear, and ear grain number in five groups of introgression hybrids in two agro-ecological regions, as influenced by growing conditions, while hierarchical structures for plant height, ear grain weight and 1000-grain weight dissociate due to effect of the genotype × environment interaction. In the West Siberian region, hybrid wheat lines, as a rule, overcome parental forms on productivity traits and are below them in height. In the Eastern European region, soft wheat varieties involved in crossings are inferior to the introgression lines created on their basis only on tiller number. The exception was cultivar Scala, which in the conditions of the Republic of Belarus was characterized as medium-sized with high spike-lengths and the number of spikelets per ear, but with low values of the ear grain number and ear grain weight. Approximation of the productivity of introgression lines and their parents by PCA also indicates a significant influence of environmental conditions. Observations corresponding to the Western Siberian region and Belarus constitute two relatively distant dispersion clouds, differing in the degree of overlapping of the areas corresponding to different cross combinations and their positions relative to the parental forms in the PCA space. According to the results of the research, introgression lines created on the base of varieties Saratovskaya 29, Skala and Irtyshanka 10 are recommended as sources of resistance genes without reducing productivity of recipient varieties.

Keywords: *Triticum aestivum,* common wheat, tetraploid wheat *T. timopheevii,* introgression lines, productivity, eco-genetic experiment

Common wheat (*Triticum aestivum* L.) is one of the most important crops, which plays a key role in providing food for people all over the world [1]. To obtain high yields of common wheat, it is necessary to develop varieties which combine high yields with low fluctuations of economically valuable traits when cultivated in regions with different soil and climatic conditions [2-4]. The range of ecological flexibility determines the area of optimal agro-ecological zoning of the variety [5-7].

Increasing productivity and maintaining a stable crop yield in changing environmental conditions depend on various factors, the most important of which are the varieties resistance to biotic and abiotic stressors. Fungal diseases lead to significant losses in yield of winter and spring common wheat: during the period of epiphytotics, the productivity of susceptible varieties decreases by 50-70%. A number of papers associate high yields of modern varieties and breeding samples of common wheat, including lines obtained by the involvement of foreign genetic material, with resistance to fungal pathogens [8-10].

Wild and cultivated relatives of common wheat are promising sources for expanding the genetic diversity of modern varieties for resistance loci. Currently, over 50 genes of resistance to leaf and stem rust, as well as powdery mildew, have been introduced into the genome of common wheat from relatives and cereals from distant taxonomic groups [11]. However, in the case of introgression of alien resistance loci, it is necessary to pay attention to the degree of influence of inherited genetic material on other economically important traits. For many alien genes, determining resistance to leaf-stem infections, there has been a decrease in the productivity of the ear and other yield components during gene transfer to commercial wheat varieties [12, 13].

Information on the ecological flexibility and adaptability of lines in various environmental conditions is needed in order to use introgression lines as sources and donors of fungal pathogen resistance genes. A collection of introgressive lines of common wheat, obtained with the participation of the tetraploid species *T. timopheevii* var. *viticulosum*, was studied earlier. Long-term observations have shown that the lines are characterized by effective resistance to leaf rust and powdery mildew, some of them are resistant to stem rust, septoria, and dust brand; a number of lines have group resistance to disease [14]. Effective genes which determine the resistance of introgression lines to leaf rust [15, 16] were mapped using molecular genetic analysis,

This paper for the first time presents estimates of the adaptive responses, stability, and breeding value of common wheat lines with alien substitutions and translocations, obtained in an eco-genetic study.

The purpose of the study was a comparative analysis of manifestation of economically important traits in common wheat lines containing alien genetic material of *Triticum timopheevii* when grown in Western Siberia of Russia and in the Republic of Belarus, located in different geographical areas.

Technoques. A total of 21 introgression lines of *Triticum aestivum/T. timopheevii* ($BC_1F_{22\text{-}24}$, $2n = 42$), obtained by crossing five varieties of common wheat (Saratovskaya 29, Skala, Irtyshanka 10, Tselinnaya 20 and Novosibirskaya 67) with tetraploid wheat *T. timopheevii* var. *viticulosum* [14] were used. Field testing of the lines and their parental forms was carried out in 2015 under the conditions of the West Siberian (Novosibirsk Province) and East European (Minsk, Republic of Belarus) agroclimatic regions.

The field experiment was laid out in 2 replications on plots with a width of 1 m, 40-60 grains per row and distance between rows of 20 cm, distributed over the plot according to the systematic method. The evaluation of the tiller number, plant height, ear length, spikelet number, ear grain number, ear grain weight, and 1000-grain weight were carried out according to the methodological recommendations of Vavilov All-Russian Institute of Plant Genetic Resources (VIR) (for 20-25 randomly selected plants of each line) [17].

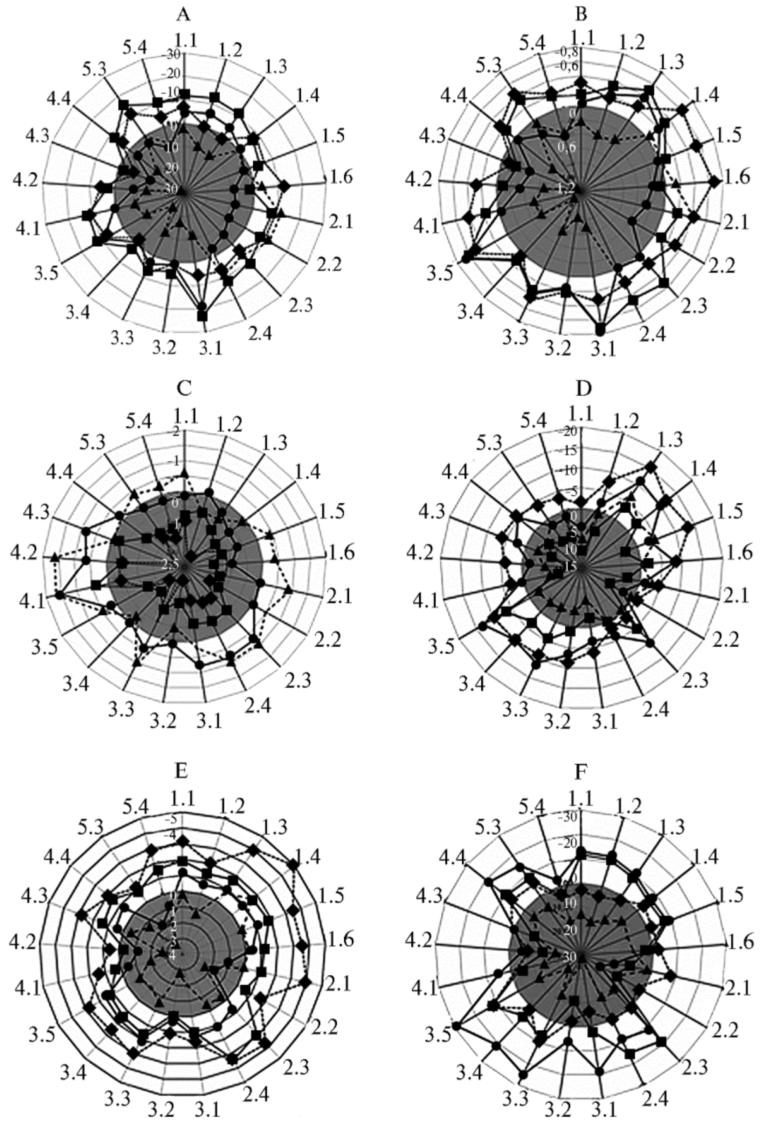
The obtained data were processed with STATISTICA 10.0 software (StatSoft, Inc., USA) and Microsoft Excel package. Descriptive statistics methods (the arithmetic mean *M* and the standard error of the mean ±SEM were calculated) and nonparametric correlation analysis (the Spearman correlation coefficient *r*) were used in the study. Radar charts were constructed according to the difference between the mean value of the introgression line trait and the mean value of each parental form trait in two tests. The commonality of each of the variables and its contribution to the main components of variability were evaluated using Principal Component Analysis (PCA).

Results. The climate of Western Siberia is continental and is characterized by long winters and short hot summers. The climate of Belarus is moderately continental and is characterized by frequent Atlantic cyclones, mild and wet winters, warm summers. The comparative analysis of meteorological conditions in 2015 (http://rp5.by) showed that the accumulation rate of the effective heat sum (EHS) in the West Siberian region was 11-15% higher than the values noted for the Eastern European experimental site. In the Novosibirsk Region, EHS for the May-July period exceeded 1600 °C required for the ripening of spring wheat [18], which contributed to the acceleration of growth and reproductive processes, reduction of the crop vegetation period. During the whole period of growth and development of wheat, there was an insufficient amount of precipitation (the lack of precipitation was more pronounced in the conditions of the Republic of Belarus).

The constructed radar charts reflect the difference between the mean value of the introgression line trait and the mean value of each of the parental forms traits during two tests and allow comparing the productivity of the studied wheat samples in the conditions of the West Siberian and East European regions. Plants of the *T. timopheevii* species were characterized by a maximum tiller number (on the average 2.7±0.1 stems in Novosibirsk, 4.7±0.2 stems in Minsk) and in terms of this trait were superior to the *T. aestivum* varieties involved in the crossing and introgressive lines derived from them (Fig. 1). Under the conditions of the West Siberian region, the lines created on the basis of the varieties Saratovskaya 29 and Novosibirskaya 67 were inferior to the parental variety *T. aestivum* in terms of tiller number. Regardless of the growing conditions, reliable transgressions of the trait (in relation to the variety) were shown in combinations based on the Skala and Tselinnaya 20 varieties.

Significant differences were found in the height of plants grown in different agro-climatic zones. Both hybrid forms and initial varieties formed a higher straw under the conditions of the continental climate of Siberia. At the same time, in the West-Siberian region, 75 and 57% of introgressive lines were inferior to the original variety and *T. timopheevii* in height. According to the results obtained in the conditions of the Belarusian experiment, only 48% of introgressive lines were below both parental forms.

T. timopheevii plants formed a short ear (5.3±0.1 and 5.6±0.1 cm, respectively, in the conditions of Belarus and Russia) with a small number of spikelets (10.8±0.7 pcs.) regardless of the conditions cultivation. Its parameters were superior to the ear of Irtyshanka 10 × *T. timopheevii* (see Fig. 1, G, 3.3)



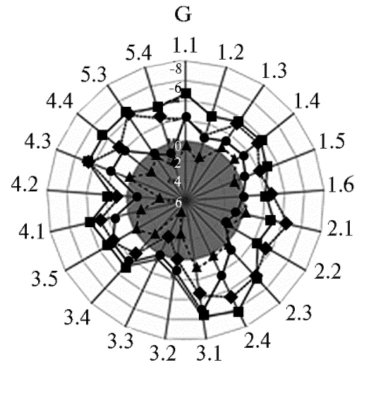


Fig. 1. The difference between traits (by the mean values) of the wheat introgression line and one of the parental forms, the *Triticum timopheevii* ··◆·· or a *T. aestivum* variety -▲- when grown in Belarus, and *T. timopheevii* —■— or a *T. aestivum* variety —●— when grown in the West Siberia region (2015). The following traits are presented: ear grains number (A), ear grain weight, g (B), tiller number, pcs. (C), 1000-grain weight, g (D), ear length, cm (E), plant height, cm (F), spikelet number, pcs. (G); 1.1-1.6 — lines created on the basis of the hybrid Saratovskaya 29 × *T. timopheevii*; 2.1-2.4 — Skala × *T. timopheevii*; 3.1-3.5 — Irtyshanka 10 × *T. timopheevii*; 4.1-4.4 — Tselinnaya 20 × *T. timopheevii*; 5.3-5.4 — Novosibirskaya 67 × *T. timopheevii.* The diagram dark sector means that the introgressive line is inferior to the parental form by the mean value of the analyzed trait, the bright sector means that the introgressive line is superior to the parental form by the average value of the analyzed trait.

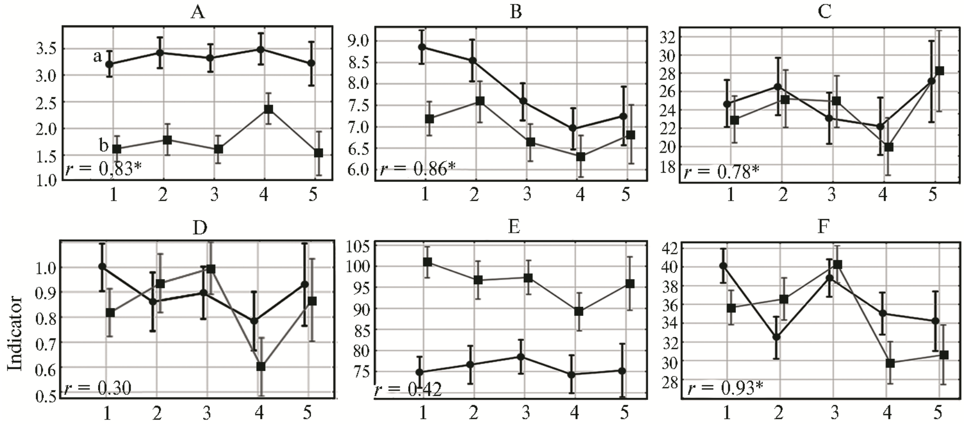
and Tselinnaya 20 × *T. timopheevii* (see Fig. 1, G, 4.2). Under the conditions of

Belarus, an increase in the ear length compared to the variety was noted in four lines created on the basis of the Saratovskaya 29 variety (the average length of the ear in Saratovskaya 29 was 8.6±0.3 cm, in hybrids it could reach 10.3±0.1 cm). In the West Siberian region, more than half of the lines obtained on the basis of the Skala and Tselinnaya 20 varieties, and all the lines of the Saratovskaya 29 × *T. timopheevi* and Irtyshanka 10 × *T. timopheevi* combinations were significantly superior to the initial wheat variety in terms of the ear length. In the Eastern European region, more than 60% of hybrid lines were inferior to the parent variety in terms of the spikelet number. The trait transgression was noted for six lines (in combination with the Saratovskaya 29, Skala, Irtyshanka 10 and Tselinnaya 20). Introgression of the *T. timopheevii* genetic material into the Novosibirsk 67 variety resulted in a significant decrease in the ear length in hybrids regardless of growing conditions, while the number of spikelets almost did not decrease as compared with that in the cultural variety.

In general, according to two environmental tests, the average ear grain number and ear grain weight (see Fig. 1, A, B) varied from 11.6±0.8 pcs. and 0.4±0.04 g for line 4.3 (combination of Tselinnaya 20 × *T. timopheevii*) to 32.03±2.9 pcs. and 1.13±0.09 g for line 3.1 (Irtyshanka 10 × *T. timopheevii*). Under the conditions of the West Siberian region, *T. timopheevii* plants formed on average 15.6±0.5 ear grains with a weight of 0.61±0.03 g. When grown in Belarus, the seed number of the *T. timopheevii* ear reached 19.4±0.9 pcs., but the average grain weight decreased to 0.59±0.04 g. That is, some of the introgressive lines were inferior to the wild-growing ancestor in terms of the grains number (10 and 20% of samples, respectively, in the conditions of the West Siberian region and Belarus) and the ear grain weight (20 and 15% of samples). In the Eastern European region, seed numbers of the cultural variety were exceeded only by four lines created on the basis of the Skala variety and two lines based on the Saratovskaya 29 variety. In the West Siberian region, transgression by the grains number and grains weight was observed for the combinations of Irtyshanka 10, Saratovskaya 29 and Tselinnaya 20.

The growing conditions affected the 1000-grain weight in the *T. timopheevii* species. While in the West Siberian region, this indicator reached 37.9±0.8 g, exceeding the value of all parental varieties and being inferior to that only in eight introgressive lines (three lines of the combination Saratovskaya 29 × *T. timopheevii*; four lines of Irtyshanka 10 × *T. timopheevii*; one line of Scala × *T. timopheevii*), then in Belarus, the 1000-grain weight in the *T. timopheevii* was only 30.4±1.3 g, which is lower than in the majority of varieties and introgressive lines grown under the same conditions. In terms of the 1000-grain weight, 76.2% of the wheat introgressive lines in the West Siberian region and 9.5% of the lines in the conditions of Belarus were superior to the cultural varieties. It is possible that this is due to the difference in the size of the seeds that form the parental forms when growing conditions are changed.

Reliable correlations of the mean values of the four traits in two growing regions are shown for the five hybrid combinations (Fig. 2). Compared with the West Siberian region, there was an increase in the tiller number by 87.0%, in the number of spikelets by 17.0%, in the ear length by 15.0%, in the number of grains by 2.6% under the conditions of Belarus. Lines on the basis of the Saratovskaya 29 variety, which were undersized under the conditions of Belarus, were characterized by the maximum height of the stem in the West Siberian region. Compared with the Belarusian experiment, the lines created with the involvement of the Scala and Irtyshanka 10 varieties showed an increase in the ear grains weight and 1000-grain weight when grown in the West Siberian region. However, under the conditions of Novosibirsk, the seed number of the lines created on the basis of the Saratovskaya 29, Tselinnaya 20 and Novosibirskaya 67 varieties decreased.



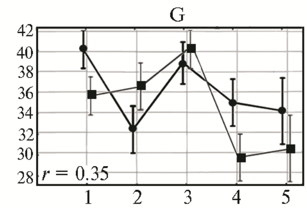


Fig. 2. Tiller number, pcs. (A), **ear length, cm** (B), **ear grain number, pcs.** (C), **ear grain weight, g** (D), **plant height, cm** (E), **spikelet number, pcs.** (F), **1000-grain weight, g** (G) **in groups of introgressive lines, obtained on the basis of *T. timopheevii* and *T. aestivum* varieties in the conditions of the East European** (a) **and West Siberian regions** (b)**:** 1 — Saratovskaya 29; 2 — Scala; 3 — Irtyshanka 10; 4 — Tselinnaya 20; 5 — Novosibirskaya 67 (2015). The figure shows arithmetic means with confidence intervals (95%); *r* is the Spearman correlation coefficient between the mean trait values of the wheat introgression line grown in the West Siberian region and Belarus; the asterisk indicates correlation coefficients statistically significant at $p < 0.05$.

The Principal Component Analysis (PCA) estimates the commonality of each of the variables and its contribution to the main components of variability. The PCA is used to classify introgressive lines and parental forms according to a set of phenotypic traits and comparative analysis of productivity when grown in two agroclimatic regions (Fig. 3). The method reduced the number of variables describing wheat productivity to three main components (eigenvalues higher than unity). The first two PCA factors together provided 66.2% of the variance, the third factor explained additional 15.5%. For interpretation of the obtained solution, a two-factor PCA model which reproduces commonalities for six traits of productivity 0.60-0.89 (dispersion share for a given number of factors) was selected. Based on the factor loadings, the first main component explained the variability of the main ear traits (length, number of spikelets, number and weight of ear grains). The tiller number and the height of the plant correlated with the second selected component, which allowed interpreting this factor as the plant habit. The addition of the third main component to the analysis significantly increased the commonality of the solution only for the 1000-grain weight (commonality of the trait was 0.28 for the two main components, 0.85 for the three main components) and did not affect the sample classification diagram.

PCA evaluation of the productivity of samples of introgressive lines and their parental forms grown in Western Siberia and Eastern Europe indicated a significant effect of growing conditions. The results of observations, corresponding to the Novosibirsk Region and Belarus, form two dispersion clouds with the centers of gravity in the second and fourth quarters of the graph. Regional variants of the experiment could be divided by a diagonal line through the third and first quarters of the graph (see Fig. 3). There was an increase in the values of tiller number, plant height, size and yield of the main ear along this line. Projections of the individual introgressive lines onto the PCA plane were combined into planar clusters corresponding to the same crossing combination tested in each of the growing regions. The clusters position was correlated with the projections of regional variants of tested parental forms (*T. timopheevii*, Saratovskaya 29, Scala, Irtyshanka 10, Novosibirskaya 67, Tselinnaya 20).

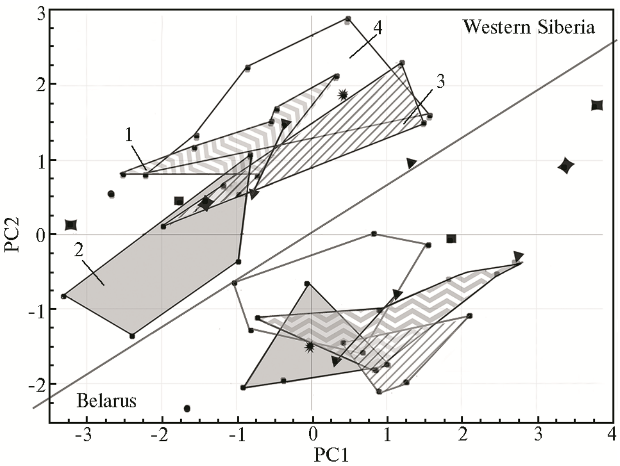


Fig. 3. The projection of observations of introgressive lines of common wheat Saratovskaya 29 × *T. timopheevii* (1)**, Tselinnaya 20 × *T. timopheevii*** (2)**, Scala × *T. timopheevii*** (3)**, Irtyshanka 10 × *T. timopheevii*** (4)**, Novosibirskaya 67 × *T. timopheevii*** (▼▼) **and parental forms *T. timopheevii*** (●)**, Saratovskaya** 29 (■)**, Tselinnaya 20** (✦)**, Novosibirskaya 67** (▲)**, Scala** (✷)**, Irtyshanka 10** (■) **onto the two first PCA components** (2015). The first main component: eigenvalue is 2.8, the variance explained is 39.8%; the second main component: eigenvalue is 1.9, the variance explained is 26.4%.

The total area of clusters overlapping and binding of the overlapping area to the analyzed samples for the conditions of Western Siberia and Belarus differed. The Belarusian experiment was characterized by greater compactness of the clusters, a wider range of spread and remoteness of the parental forms from the analyzed hybrid combinations. Under the conditions of the West Siberian region, the projections of parental wheat varieties were close to the region of variation in the group of introgressive lines based on the Tselinnaya 20 and Scala varieties. In the West Siberian experiment, the *T. timopheevii* fell into the range of variability of the hybrid combination based on the Saratovskaya 29 variety. The parent *T. timopheevii* showed lower values of the ear length, the number of spikelets and the number of seeds compared to the groups of lines created with the involvement of the Tselinnaya 20, Irtyshanka 10, Novosibirsk 67 and Scala varieties. The *T. timopheevii* species grown under the conditions of Belarus was characterized by a low value of the two main components (coordinates) compared to the varieties involved in crosses, which placed the clusters of introgressive lines of one crossing combination on the vector connecting the projections of the parental forms (see Fig. 3).

Factor analysis and its variants (principal component analysis, biplot analysis, etc.) are convenient for estimating components of a variety—year—growing conditions system, since they allow simultaneously estimating the variance and interrelation of a large number of traits, as well as reducing the number of experimental parameters to several factors explaining the observed variation of traits [19, 20]. Thus, Yu.F. Osipov et al. [21] identified five auto-compensatory systems based on factor analysis of 44 indicators of the winter wheat agrophytocenosis, which allowed determining the effect of photosynthetic activity, mineral nutrition and planting density on wheat productivity. In another paper, diversification of spring common wheat varieties according to the specificity of the genotype-environment response was carried out and the most productive and resistant varieties were identified for four sites of state variety testing in the Samara Region using the biplot analysis [22]. These approaches demonstrate a wide range of factor analysis capabilities for variety testing in specific soil and climatic conditions.

Currently, in addition to bioinformatics analysis methods, it has become possible to use molecular genetic methods that allow the dissection of economically important traits and identify minor loci (quantitative trait loci, QTLs) with various effects. As a result of an integrated approach, it is possible to identify genotypes containing combinations of QTLs in the genome, which make a positive contribution to the phenotypic manifestation of a number of traits under various environmental conditions [23-25].

Selection of the main factors determining the formation of the wheat yield in various ecological and geographical conditions allows creating varieties with high ecological flexibility, which has been convincingly demonstrated for various types of crops, including wheat [26, 27]. In this experiment, the principal component analysis used in the analysis of seven productivity traits allowed differentiating introgressive lines and parental forms of wheat grown in the conditions of the Republic of Belarus and in the West Siberian region, to distinguish two signs describing the main ear productivity and plant habit, and also to identify groups of introgressive lines that significantly change productivity depending on growing conditions (hybrids based on Irtyshanka 10 and Saratovskaya 29). It should be noted that in the case of parental forms and hybrids, in which productivity elements are less dependent on uncontrollable factors (as was observed, for example, in *T. timopheevii* parent plants), grain yield should be increased due to changes in the elements of crop cultivation technology.

The results obtained in the study show the prevailing influence of ecological and geographical conditions on the manifestation of economically important traits. At the same time, the most significant differences were noted for the tiller number, plant height, and ear length. Previously, using factor analysis of data on the assessment of lines in the conditions of the Novosibirsk Region, it was found that the genotype contribution to the phenotypic differences between lines and initial varieties is insignificant [28]. The identified fluctuations in the traits between groups of lines created on the basis of different common wheat varieties may be associated with a different response of the variety-founder to weather conditions, as shown by other researchers for both commercial varieties and introgressive lines [29-31].

Thus, introgression of the *Triticum timopheevii* genome in the *T. aestivum* varieties leads to a significant diversification of introgression lines according to a set of productivity traits. The degree of manifestation of the observed diversification depends on the growing conditions of the samples. In the West Siberian region, the hybrid lines of wheat, as a rule, are superior to the parental forms in terms of ear productivity and are inferior to them in terms of plant height. In the Eastern European region, the varieties involved in crossings are inferior to the introgressive lines created on their basis only in terms of tiller number. The exception is the Scala variety, which, under the conditions of the Republic of Belarus, is characterized as medium-grown with high values of ear length and the number of spikelets, but low values of the number and weight of ear grain. According to the study, introgression lines created with the involvement of the Saratovskaya 29, Scala and Irtyshanka 10 varieties are distinguished by higher adaptability to the stressful environmental conditions and can be recommended as sources of resistance genes that do not cause a decrease in the productivity of the recipient varieties.

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