ISSN 1068-3674, Russian Agricultural Sciences, 2019, Vol. 45, No. 2, pp. 105–111. © Allerton Press, Inc., 2019.
Russian Text © S.I. Voronov, A.M. Medvedev, V.V. Osipov, A.V. Osipova, S.D. Zhikharev, E.N. Liseenko, N.G. Poma, 2019, published in Rossiiskaya Sel'skokhozyaistvennaya Nauka, 2019, No. 1, pp. 3–8.

CROP PRODUCTION

The Selective-Genetic Value of Winter Triticale Cultivar Samples from the Collection for Cultural Breeding in the Central Nonblack Earth Region

S. I. Voronov[a, *], A. M. Medvedev[a], V. V. Osipov[a], A. V. Osipova[a], S. D. Zhikharev[a], E. N. Liseenko, and N. G. Poma[a]

[a]*Moscow Nemchinovka Research Institute of Agriculture (MosNIIKh), Moscow, Moscow oblast, 143026 Russia*

**e-mail: mosniish@yandex.ru*

Received October 16, 2018; revised October 16, 2018; accepted October 16, 2018

Abstract—Under the conditions of Moscow oblast, we investigated 1500 samples of X. *Triticosecale* Wittmack of different ecological-geographical origin concentrated at the World Gene Fund of the Vavilov All-Russia Research Institute of Crop Production and new cultivars and lines of the Moscow Nemchinovka Research Institute of Agriculture (MosNIIKh) obtained using gene sources and donors of valuable traits from Dias (5 × 5) and other field experiments. Results of the analysis of diallel crosses according to the method of B.J. Hayman (1954) suggest that all studied traits of triticale are characterized by the additive dominant inheritance scheme. Thousand-grain weight and grain protein and starch content in F_1 hybrids revealed overdominance. By ear grain weight, the character of inheritance varied from complete dominance to overdominance. The main contribution to the increase in productivity traits was made by dominant genes, the concentration of which was used to determine the viability of individual cross combinations. In terms of the 1000-grain weight trait, the Prag 468 line is promising, while the ADK 1369t line is promising in terms of the ear grain weight. The high starch content in the grain is due to the dominant alleles, in particular in the lines Prag 468 and 6418-145. We obtained fundamentally new varieties and lines with high rates of productivity and quality of grain, much higher than the standard cultivar Viktor. Grain yields in the control nursery of new lines (5802-10-5-6, 5802-10-5-59, and 154-11-55) ranged from 8.34 to 9.91 t/ha even under extremely adverse weather conditions in 2017. The yield of the standard cultivar Viktor was 5.04 t/ha, that is, almost two times lower than that of the line 154-11-5-5. In competitive varietal trials (2014–2017), the best cultivar was Gera. It was shown that the advantage of new genotypes over standards is that they form a well-grained ear with large full-weight grain (up to 80 grains), have increased productivity, good plant preservation for harvesting, and high resistance to environmental limiting factors.

Keywords: winter triticale, cultivars, genetics of quantitative traits, hybrids, resistance, productivity, grain quality

DOI: 10.3103/S106836741902023X

INTRODUCTION

Triticale (X. *Triticosecale* Wittmack) is artificially created grain fodder widely used in many countries of the world. In the Russian Federation, the area occupied by winter triticale is more than 300 000 hectares, and its yield is over 3 t/ha [1, 2]. The potential yield of new modern varieties reached 10 t/ha [3]. The increase in the actual yield of triticale in production is hampered by the tallness of winter-type cultivars prone to lodging and plant damage by snow mold [2, 4, 5]. In the Central Nonblack Earth Region of Russia, this crop is cultivated mainly for the production of grain forage; however, new cultivars are increasingly intended for baking needs [6].

The aims of this work are to study the World Triticale Gene Fund for productivity, grain quality, and resistance to environmental stress factors; to identify sources and donors of particularly valuable traits in systemic crosses; to create new highly productive cultivars of winter hexaploid triticale with yields of more than 12 t of high-quality grain per hectare.

METHODS

The studies were carried out in 1980–2017 on the experimental plots of the Moscow Nemchinovka Research Institute of Agriculture (MosNIIKh) as well as at the Moscow branch of the Vavilov All-Russia Research Institute of Crop Production (VIR, Mikhnevo, Moscow oblast). Observations and records were carried out according to the methodical instructions of B.A. Dospekhov [4], the State Commission for Testing and Protection of Breeding Achievements [7], the

Vavilov All-Russia Research Institute of Crop Production [8], etc. During the years of experiments, sharp fluctuations in weather factors during the growing season of winter triticale were observed. In the autumn, there was mainly precipitation deficit; thaws with repeated snow and its melting in winter (December–February); lack of heat with heavy precipitation in spring (April–May). The heat deficit was particularly clearly manifested in spring (May) and summer (June) 2017, when the accumulated active temperatures decreased by 15–20% compared with the average annual indicators, and the amount of precipitation increased by 1.5–2.0 times. The soil on the experimental crops was loamy, sod-podzolic, insufficiently fertile with humus content of 2.0–2.5%, and pH of the soil solution was 4.6–6.0. Before sowing triticale, the main fertilizer was applied (350 kg/ha Azofoska) in the autumn. Sowing was carried out with a seed drill with a seeding rate of 5 million viable seeds per hectare. The size of the registration area of plots in the competitive trials (KSI) was 12 m^2 with four-fold repetition; that in the control nursery was 3–4 m^2 and that in the collection nursery was 1 m^2. As top dressing, 150 kg/ha of ammonium nitrate was applied in the spring.

Quality indicators for grain, flour, dough, and bread were determined according to the complete technological analysis scheme (the falling number of Hatbert–Perten, GOST 27676–88; the amount of gluten in flour, manually with washing according to GOST 51412–99 and ISO 7495–90; the quality of gluten, using the instrument IDK-4).

RESULTS AND DISCUSSION

In perennial field experiments, from a large set of winter triticale cultivar samples (1500), we isolated genotypes with a complex of valuable traits, many of which were used in crosses to produce cultivars with increased high-quality grain yields compared to cultivars-standards (Germes, Viktor). Particularly interesting for breeding are new cultivars of MosNIISKh, the Don Zonal Research Institute of Agriculture (Donskoy ZNIISKh), the North Donetsk Agricultural Experimental Station, the Krasnodar, Voronezh, and Stavropol Research Institute of Agriculture, which have high yields, grain quality, and resistance to biotic and abiotic stressors (Table 1).

In conditions extremely unfavorable for plant overwintering (2016, 2017), including damping-out, wetting, and epiphytotic spread of snow mold, there remained no more than 30–50% of varietal samples from the World Collection of the VIR in the Moscow oblast by the spring with a score of 3–7. Only moderate temperatures and heavy precipitation in the second half of April and in May during those years in crops allowed for fairly high grain yields (500–900 g/m^2) (Table 2). The best were cultivars Viktor, Doktrina 110, line 266/12, as well as Preco (Kill) Rex (AOS) Rex of Polish breeding, which are involved in the breeding process.

Of great interest are the data obtained in MosNIIKh using diallel crosses (5 × 5) of the best cultivar samples of the collection: short-stem lines Prag 468 (Dagestan Experimental Station of the VIR), ADK 1369t (Krasnodar Research Institute of Agriculture); and high-yield cultivars and lines of Nemchinovka breeding: Nina, Nemchinovsky 56, and 6418-145 (Table 3). The Dias materials were processed according to the methodical rules of B.J. Hayman [9] and B. Mather [10] using the AGROS 2.09 software. The inheritance of such valuable traits as 1000 grain weight, ear grain weight, and protein and starch content in the grain was analyzed.

According to the analysis of F_1 hybrids, it was determined that all traits are characterized by the additive dominant inheritance scheme. For example, for 1000 grain weight, the correlation coefficient r (x_{rr}; $W_r + V_r$) in experiments of 2011 and 2012 had negative values. This means that the coarse-grained cultivars have a greater number of additional alleles, and the indicated trait is determined by dominant genes. Regression graphs of W_r on V_r, which characterize the variability of the genetic determination of the trait, show that the average dominance was close to overdominance in both years. The latter is confirmed by the ratio $H_1/D = 10.38$ (2011) and 53.00 (2012), which is always greater than one for overdominance (Table 4). The value $(H_1/D)^{1/2} = 3.22$ (2011) and 7.28 (2012), which characterizes the average degree of dominance in individual loci, also indicates overdominance of this trait.

It is important to note that none of the studied cultivars and lines possessed all dominant or all recessive alleles. At the same time, the Prag 468 line in both the years carried approximately 75% of the alleles exhibiting dominant effects, while the ADK 1369t line showed it only under the conditions of 2011. In 2012, the Nina cultivar of Nemchinovka breeding was also dominated by dominant alleles. Thus, there is a prospect of isolating the positive transgressions for 1000 grain weight in subsequent generations, especially in hybrids involving the Prag 468 line.

For the 1000 grain weight trait, the H_1D, which reflects the average level of dominance for all polymorphic loci, was close to one in 2012, which indicates the complete dominance of the trait. However, overdominance was observed under the difficult conditions of 2011 (Table 4).

The regression graphs of W_r on V_r confirm that the average dominance of the trait in 2012 was close to complete (the regression line almost passed zero), and overdominance was observed (the regression line passed through zero) in 2011. The correlation coefficient r (x_{rr}; $W_r + V_r$) had negative values in both years, which means that cultivars with higher ear grain

Table 1. Gene pool for sources of winter triticale's valuable traits isolated in different geographic locations according to the results of research in 1980—2017

Trait	Genetic source
High grain productivity and completeness of caryopsis	AD 206, Germes, Antey, Viktor, Nemchinovsky 56, Nina, Dokuchaevsky 13, Doktrina 110, Prag 468, Prag 489, ADK 1369t, Qrado K-1500, Dagro K-1501, Tsekad 90 K-3906, Amfidiploid 10 K-2777, AD Kishinevsky K-1655, Efremovskaya, Zimogor, Don, Legion, Kornet, Vocaliz, Valentin 90, Svat, Brat, Knyaz, Tit, Kvazar, Mamuchar, Dar Belarusi, Antos, Amulet, Ideya
Increased plant frost resistance	Germes, Antey, Viktor, Nemchinovsky 56, Nina, Yaguar K-3594, Legion K-3860, Kentavr K-3601, Amfidiploid 10 K-2777, Prag 4 K-2456, AD Kishinevsky K-1655, Efremovskaya, Doktrina 110 K-3492, Dokuchaevsky 8 K-3766, N 15283, Stavropolsky 1, Stavropolsky 3, Stavropolsky 5, Bashkirskaya korotkostebelnaya
Comprehensive disease and pest resistance	Stavropolsky 1, Stavropolsky 2, Blits 81, Kentavr, Zimogor, Don, Valentin 90, Knyaz, Tit, Dagro, Coloa AD, Almaz, Topaz, Qrado K-1500, SND-1089, K-3289, Sokol K-3758, AD Kishinevsky K-1655, N 23370/95 K-3585, N 21832/90 K-3590, KN 91240 K-3626
Short stems, plant resistance to lodging	Bashkirskaya korotkostebelnaya, Flamingo K-3548, Dokuchaevsky 13, K-2103 (Denmark), K-2025 (Bulgaria), Purdy, Dagro, Grado (Poland), Konsul (Belarus), Armadillo 133 (Mexico), K-3267 , K-3268 (UK), K-3914, Vodoley K-3603, AD-60, Antuco, Amfidiploid 10
Precocity	K-2040 (Poland), Kentavr, K-1636 (Moldova), K-2025 (Bulgaria), Vodo, RAH 121/94, Presto (Poland), Maara, Modul (Belarus), Razgar, Vodoley, Vocaliz Zimogor, Bard, Legion, Sargau, B-533, B175 (Hungary), Blagodarny, Granik, Dvuruchka 77
Drought-heat resistance of plants	Bashkirskaya 1, Sargau, Viktor, Germes, Antey, Nemchinovsky 56, Nina, Stavropolsky Zernovoy, Zernetko, Yergeni, Mamuchar, Polyus 90, Kornet, Don, Tarasovskaya Yubileynaya, Zimogor, Kentavr, Veleten, ADM-9 (Ukraine), Valentin 90, Mudrets, Proryv
Increased number of grains per ear and ear productivity	Germes, Viktor, Nemchinovsky 56, Nina, Kentavr K-3601, Kornet K-3836, Legion K-3860, Tsekad 90 K-3906, Kaskad K-3717, AD Zeleny K-2564, Newton K-3462, AD Coloa K- 3426, Targo, K-2042, RAH 121/94, K-3679, Talva 100 K-1508, Dokuchaevsky 8 K-3766, Prag 468, Prag 489

weight possess an increased number of dominant alleles. The ADK 1369t and 6418-145 lines and the Nina cultivar showed the prevalence of dominant alleles in crosses; the Prag 468 line showed them only in 2011, while the Nemchinovsky 56 cultivar only in 2012.

When determining the inheritance of the protein content trait, it was established that cultivars with a higher value are also characterized by a higher number of recessive alleles. The average dominance of this trait was close to overdominance (in the regression graph of W_r on V_r, the regression line passed below zero) in both 2011 and 2012. This conclusion is confirmed by the ratio $H_1D = 4.40$ (2011) and 1.14 (2012) presented in Table 4. The value of $(H_1/D)^{1/2} = 2.10$ (2011) and 1.07 (2012), which characterizes the average degree of dominance in individual loci, also indicates overdominance of this trait. The largest number of recessive alleles responsible for high protein content in the winter triticale grain was characteristic of the ADK 1369t line (75%). The ratio of dominant and recessive alleles in the Prag 468 and 6418-145 lines was 50 : 50, while that in the Nemchinovsky 56 cultivar was 75 : 25. Dominant alleles prevailed in the Nina cultivar in 2011, while recessive ones prevailed in 2012. In general, the results of analysis of diallel crosses according to the method of B.J. Hayman [9] suggest that all the studied traits are characterized by the additive dominant inheritance scheme. For 1000 grain weight and protein and starch content in the grain, the first generation of hybrids showed overdominance. For ear grain weight in 2011—2012, inheritance patterns varied from complete dominance to overdominance.

The main contribution to the increase in productivity traits is made by dominant genes, whose concentrations can be used to predict the prospects of individual crossing combinations. With account for the noted factors, the Prag 468 line is distinguished for the 1000 grain weight trait, while the ADK 1369t line is

Table 2. Triticale cultivar samples isolated in 2015–2017 according to the degree of overwintering of plants, resistance to diseases, and other traits

No.	Cultivar sample, line	Plant height, cm	Overwintering, score (2017)	Resistance to lodging, score	Resistance to diseases, score (2017)			Ear analysis (2017)			Grain yield, g/m^2		
					snow mold	brown rust	ear fusarium	number of grains, pcs.	ear grain weight, g	1000 grain weight, g	2015	2016	2017
1	St 1 Germes, MosNIISKh	118	1–3	7	7	1	3	50	3.29	66.3	1160	640	370
2	St 2 Moskovskaya 39, MosNIISKh	90	1	7	7	3	3	47	2.89	59.9	825	580	237
3	St 3 Viktor, MosNIISKh	120	5–7	9	3	1	3	53	3.44	64.6	970	800	801
4	AD 4306, K-1770, Ukraine	105	3–5	7	3	3	3	42	2.57	61.0	760	650	640
5	Legion, K-3860, DZNIISKh	95	3–5	7	3	0	1	64	4.09	63.9	870	510	570
6	Doktrina 110, K-3690, VNIISKh	120	5	7	3	3	3	52	3.93	75.2	1260	830	840
7	Line 266/12, MOVIR	110	5	9	5	0	3	43	3.34	68.4	975	735	730
8	Line 280/12, MOVIR	100	3	9	3	3	3	49	3.49	71.3	860	88	570
9	K-1616, VNIISKh	120	5	9	3	1	3	46	3.32	71.6	1080	510	650
10	Efremovskaya, MOVIR	120	5	7	3	0	3	47	3.43	73.6	1380	950	590
11	K-3625, KNIISKh	130	3–5	9	5	1	1	56	3.54	68.8	875	560	770
12	Imprint, Stavropol NIISKh	105	3–5	9	5	3	5	44	2.74	61.8	1290	850	630
13	Line 2, SP-2 (Tal. × Novinka 2), Voronezh NIISKh	100	3–5	9	5	1	3	46	3.53	76.5	950	700	640
14	Impuls, Belarus	100	3	9	3	1	3	64	3.82	60.3	1010	890	400
15	Preco (Kill) Rex/AOS/Rex, Poland	120	5	9	3	1	1	60	3.74	68.3	775	650	860
16	Uro-S/AOS/Bushen/Rex, Poland	110	3	9	3	0	0	43	2.53	59.5	920	880	510

Table 3. Characteristics of cultivars, winter triticale lines, and hybrids with their participation

Cultivar, line, hybrid	1000 grain weight, g		Ear grain weight, g		Protein content, %		Starch content, %	
	2011	2012	2011	2012	2011	2012	2011	2012
Prag 468	47.99	47.75	2.88	2.98	17.50	14.01	59.01	56.28
×ADK1369t	49.62	46.04	2.29	2.07	19.70	15.56	53.96	52.08
×6418-145	51.67	47.40	3.01	2.52	16.36	14.46	58.98	54.22
×Nina	46.41	50.97	2.59	2.59	16.90	14.09	59.77	53.90
×Nemchinovsky 56	47.26	43.46	2.75	2.45	16.43	13.76	62.32	54.38
ADK 1369t	43.86	41.65	2.12	1.67	16.16	15.52	52.66	56.07
×6418-145	47.90	45.40	2.72	2.41	15.58	12.81	64.47	54.35
×Nina	48.81	50.37	2.72	2.33	16.12	13.64	61.56	51.22
×Nemchinovsky 56	54.96	47.76	2.64	2.25	15.67	14.03	59.93	51.75
6418-145	47.58	43.25	2.71	2.41	13.99	11.69	54.16	51.94
×Nina	59.43	51.78	3.10	2.58	17.76	12.02	59.99	51.68
×Nemchinovsky 56	47.76	53.31	2.35	2.33	17.31	12.79	62.50	53.66
Nina	47.78	48.97	2.15	2.60	15.08	25.03	54.42	56.79
×Nemchinovsky 56	52.59	50.26	3.23	2.68	18.06	11.58	61.88	55.04
Nemchinovsky 56	42.03	44.51	1.78	2.19	15.09	12.54	52.52	55.49
$LSD_{0.05}$	2.39	1.87	0.22	0.19	0.80	0.73	2.19	1.01

Table 4. Components of genetic dispersion obtained on the basis of analysis of diallel crosses 5 × 5

Genetic parameter	1000 grain weight		Ear grain weight	
	2011	2012	2011	2012
$D \pm S_D$	7.67 ± 2.99	0.55 ± 4.93	0.20 ± 0.01	0.25 ± 0.03
$F \pm S_F$	10.07 ± 7.46	–4.21 ± 12.30	0.26 ± 0.03	0.20 ± 0.07
$H_1 \pm S_{H_1}$	79.59 ± 8.07	29.15 ± 13.30	0.62 ± 0.03	0.21 ± 0.08
$H_2 \pm S_{H_2}$	72.60 ± 7.32	26.99 ± 12.06	0.50 ± 0.03	0.10 ± 0.03
$h^2 \pm Sh^2$	58.72 ± 4.94	18.93 ± 8.14	0.44 ± 0.02	0.03 ± 0.01
$E \pm S_E$	1.87 ± 1.22	13.43 ± 2.01	0.01 ± 0.005	0.05 ± 0.01
H_1D	10.38	53.00	3.10	0.84
$(H_1/D)^{1/2}$	3.22	7.28	1.78	0.92
$H_2/4H_1$	0.23	0.23	0.20	0.12
Genetic parameter	**Grain protein content**		**Grain starch content**	
	2011	2012	2011	2012
$D \pm S_D$	1.74 ± 0.09	0.79 ± 0.32	5.90 ± 0.92	2.78 ± 1.04
$F \pm S_F$	1.38 ± 0.23	–1.24 ± 0.81	14.74 ± 2.31	4.17 ± 2.60
$H_1 \pm S_{H_1}$	7.65 ± 0.25	–0.69 ± 0.88	68.45 ± 2.49	11.75 ± 2.81
$H_2 \pm S_{H_2}$	7.26 ± 0.22	–0.37 ± 0.80	58.21 ± 2.26	9.86 ± 2.54
$h^2 \pm Sh^2$	5.21 ± 0.15	–0.62 ± 0.54	90.76 ± 1.53	10.20 ± 1.72
$E \pm S_E$	0.01 ± 0.04	0.83 ± 0.13	1.11 ± 0.38	1.23 ± 0.42
H_1D	4.40	1.14	11.60	4.23
$(H_1/D)^{1/2}$	2.10	1.07	3.41	2.05
$H_2/4H_1$	0.24	0.13	0.21	0.21

Table 5. Yield (t/ha) of the best cultivars and lines in competitive trials, 2014–2017

Cultivar, line	2014	2015	2016	2017	Average
Viktor standard	6.90	9.30	6.17	8.9	7.82
Germes	6.98	10.72	5.47	–	7.72
Nemchinovsky 56	8.12	8.86	6.63	–	7.87
Nina	7.40	9.65	6.78	7.65	7.96
Gera (121-1-9)	9.51	11.34	7.49	7.28	8.91
6355-26-2-26	7.11	8.46	8.75	–	8.11
150-1-5	6.95	9.48	8.35	–	8.26
$LSD_{0.05}$	0.35	0.57	0.51	0.45	–

distinguished for ear grain weight. The high starch content in the grain was determined by dominant alleles, in particular in the lines Prag 468 and 6418-145.

To determine the best hybrid combinations, the total combination ability (TCA) and specific combination ability (SCA) of cultivar samples were analyzed. In the inheritance of the 1000 grain weight trait, genes with dominant effects are greatly important. In the genotypic dispersion of this trait in 2011—2012, the share of variance of SCA was 52.8%, which is 1.5 times higher than that of the variance of TCA (37.3%). A consistently high variance of TCA was observed only in plants of the Nina cultivar of Nemchinovka breeding. Prag 468 × 6418-145 and ADK 1369t × Nemchinovsky 56 were distinguished in terms of SCA. In the genotypic dispersion of the ear grain weight trait, the variance of TCA was 59.2% (SCA, 33.6%) on average over the 2 years. Thus, in this set of cultivar samples, additive effects of genes make a greater contribution to the genotypic variation. The best in terms of TCA were the lines Prag 468 and 6418-145 and the Nina cultivar. Presumably, the Prag 468 line equally consistently conveys this trait to all hybrids, as evidenced by the high variance of TCA and low variance of SCA.

For the grain protein content trait, the proportion of variance of TCA in the genotypic dispersion of the trait was 58.4% (SCA, 36.3%). It follows from this that the additive effects of genes in this set of cultivars make the greatest contribution to the genotypic variation. Stable high effects of TCA were characteristic of the lines Prag 468 and ADK 1369t. In terms of the effects of SCA with the participation of short-stem donors, not a single crossing combination was distinguished.

The results of plant gene fund studies played a positive role in the selection of winter triticale in Moscow oblast. In addition to the highly productive cultivars with complex resistance to bio- and abiostressors Germes, Viktor, Antey, Nemchinovsky 56, and Nina, which have already been introduced to the State Register of Breeding Achievements of the Russian Federation, a whole series of cultivars and lines with high grain yields (up to 13 t/ha) and resistance to stress factors of the environment, which were obtained with the participation of the best cultivar samples of the World Collection, are tested in the experimental fields. They include the short-stem cultivar Gera, which is resistant to lodging and several dangerous pathogens, with potential yields over 12.0 t/ha of high-quality grain.

At all stages of breeding, 15000–20000 winter triticale samples (15330 in 2017) and 200–400 hybrid combinations (308 in 2017) were studied in the fields of MosNIISKh. In the extremely unfavorable weather conditions of 2017, 35 lines and cultivars were tested in the control nursery. The grain harvest from new lines (5802-10-5-6, 5802-105-59, and 154-11-5-5) and the Nina 185-177 cultivar amounted to 8.349.91 t/ha. The crops of the best line 154-11-5-5 formed yields of 9.91 t/ha; its plants are resistant to lodging and have shortened stems (95 cm). The grain yield of the Viktor standard cultivar was 5.04 t/ha, or almost two times lower than that of the noted line 154-11-55. In competitive cultivar trials, the Gera cultivar was the best on average over 4 years (Table 5). The advantage of new cultivars and lines over standard cultivars is due to the excellent graininess of the ear, better preservation of plants for harvesting, and increased resistance to limiting environmental factors.

Compared with the cultivar-standard and other regionalized cultivars, the new triticale genotype Gera has a shorter stem (80–100 cm), high ear graininess (up to 80 grains), a significantly larger grain weight per ear (up to 4 g), and complex resistance to most dangerous pathogens (rust species, powdery mildew, septoria, root rot). This promising cultivar also has increased fodder value of grain, which ensures its successful use in compound feeds for various animal and poultry species.

In the competitive trials of 2009–2015, the cultivars Nemchinovsky 56, Nina, and Gera proved to be the best in terms of the biochemical composition of the grain. In comparison with the cultivar-standard Viktor (13.6%), the protein content in the grain of the Nina cultivar was 13.9%, Nemchinovsky 56 was 14.1%, Gera (2014–2015) was 13.9%; the content of gluten in the grain was 21.2, 17.0, 24.5, and 21.0%; starch content was 64.5, 68.6, 67.3, and 66.9%; and grain yields were 7.3, 6.43, 6.91, and 10.17 t/ha, respectively. Technological and baking properties in the competitive trials for 2014–2016 in the subsequent cultivars were also better than the Viktor standard.

On average over 3 years, the highest protein content compared to the cultivar-standard Viktor (13.7%) was observed in the cultivars Germes (14.08%) and Gera (14.08%) and hybrid lines 6408-19-71 (14.73%) and 698-1-19 (13.9%). The highest content of raw gluten was in the cultivars Germes (24.4%), Nemchinovsky 56 (23.5%), line 698-1-19 (26.0), and the cultivar-standard (20.7%). At the same time, the Gera cultivar proved to have a higher grain test value than the Viktor cultivar-standard (740 and 733 g/L) as well as the grain protein content (14.08 and 13.71%); the starch content in the grain (70.43 and 69.9%), the falling number (102 and 99 s), and the gluten deformation index (91 and 79 units). At the same time, the volumetric yield of bread in the Viktor cultivar (605 cm^3) was higher than that in the Germes cultivar (645 cm^3) and lines 6355-26-2-26 (626 cm^3) and 150-1-5 (625 cm^3).

Thus, long-term experiments using the large set of cultivar samples from the World Winter Triticale Collection allowed us to isolate valuable genotypes with a set of positive traits and properties, the use of which in crossings with local assortment provided a number of new, high-productive, environmental stress-resistant cultivars and lines. Of particular value for production is the new, resistant to lodging, Gera cultivar with high potential productivity (more than 12 t/ha). It is recommended for breeding institutions to use for crossbreeding the highly productive, high-quality winter triticale cultivars of Nemchinovka breeding resistant to dangerous pathogens and abiotic stresses: Viktor, Germes, Antey, Nemchinovsky 56, and Nina as well as cultivars-donors of valuable traits that showed good results in diallel crosses: lines Prag 468, ADK 1369t, and 6418-145 and cultivars Nina and Nemchinovsky 56. In breeding programs, outstanding cultivars of domestic and foreign selection, which showed excellent results in the long-term trials in the Moscow oblast, are promising as starting material: Dokuchaevsky 13, Doktrina 110, Zimogor, Don, Legion, Kornet, Svat, Brat, Knyaz, Tit, Mamuchar, Run, Ideya, Adas, and other genotypes (Table 1).

COMPLIANCE WITH ETHICAL STANDARDS

The authors declare that they have no conflict of interest. This article does not contain any studies involving animals or human participants performed by any of the authors.

REFERENCES

1. Grabovets, A.I. and Krokhmal', A.V., Specific features of triticale breeding on the Don in a changing climate, in *Tritikale* (Triticale), Rostov-on-Don: DZNIISKh, 2014, pp. 37–43.
2. Sandukhadze, B.I., Medvedev, A.M., Osipov, V.V., and Vasyutin, A.S., *Tekhnologiya proizvodstva zerna ozimykh zernovykh kul'tur* (The Technology for Production of Winter Grain Crops), Moscow, 2015.
3. Medvedev, A.M., Medvedeva, L.M., Poma, N.G., Osipov, V.V., and Osipova, A.V., *Ozimaya i yarovaya tritikale v Rossiiskoi Federatsii. Kollektivnaya monografiya* (Winter and Spring Triticale in the Russian Federation. Collective Monograph), Moscow: Nemchinovka, 2017.
4. Dospekhov, B.A., *Metodika polevogo opyta* (Methodology of Field Experiments), Moscow: Kolos, 1979.
5. Osipov, V.V. and Medvedev, A.M., On lodging resistance of winter triticale due to stem height, pathogen resistance, other stress factors, and productivity, *Zernobobovye Krupyanye Kul't.,* 2016, no. 2, pp. 40–46.
6. Grabovets, A.I., Krokhmal', A.V., Dremucheva, G.F., and Karchevskaya, O.E., Selection of triticale for baking purposes, in *Tritikale* (Triticale), Rostov-on-Don, 2016, pp. 4–19.
7. *Metodika gosudarstvennogo sortoispytaniya s.-kh. kul'tur. Vyp. 2. Zernovye, krupyanye, kormovye kul'tury* (Methods of State Variety Testing of Crops. Issue 2. Grain, Cereal and Feed Crops), Moscow, 1989, p. 228.
8. Merezhko, A.F. and Udachin, R.A., *Metodicheskie ukazaniya* (Methodical Instructions), St. Petersburg, 1999.
9. Hayman, B.J., The analisis of variance of dialel tables, *Biometries,* 1954, vol. 10, pp. P. 235–244.
10. Mather, K. and Jinks, J.L., *Biometrical Genetics. The Study of Continuous Variation,* London: Chapman and Hall, 1982.

Translated by K. Lazarev