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DONORS OF POTATO (*Solanum* L.) PLASTICITY AND YIELD STABILITY TRAITS IN THE ENVIRONMENTAL CONDITIONS OF NORTH FOREST STEPPE OF WESTERN SIBERIA

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Abstract

Potato (*Solanum tuberosum* L.) varieties possessing sustainable high yield under varying environmental conditions and other valuable properties, e.g. resistance to diseases and pests, are much appreciated by practitioners. Seeking for donor plants with high environmental plasticity and stability in specific cultivation zone is a key point, especially in creating highly productive adaptive varieties for regions with severe agro-climatic conditions. This paper reports the first assessment of new potato hybrids created in the soil and climatic conditions of Western Siberia, as donors of high yielding and complex relative resistance to fungal diseases, potato Y-virus, and golden potato nematode. The best of them are already involved in practical selection for productivity and high adaptability. Our goal was to assess the parameters of adaptability in created potato hybrids under the conditions of the northern forest-steppe of Western Siberia (Kuznetsk Basin, Kemerovo Region, Kemerovo District, 2014-2018; 70 m^2 plots with 20 m^2 test area arranged randomly in four repetitions). Planting was carried out in the third decade of May at 35.0 thousand bushes per 1 ha (70×35 cm; a Cramer potato planter, CRAMER Technik, Germany). The samples ($n = 170$) including collection potato hybrids created in Kemerovo Research Institute of Agriculture were examined in a collection nursery. The varieties Lyubava (early season), Nevskii (medium-early ripening) and Tuleevskii (medium-ripening) were the standard. According to our research data, the Lyubava, Nevskii, Tuleevskii varieties and hybrids 6-4-11 and 22103-10 are extensive type potato genotypes with low environmental plasticity ($b_i = 0.28$-$0.91 < 1$). Hybrid 3-21s-11 ($b_i = 1.53$) with medium yield stability ($S_i^2 = 14.6$) showes the greatest response to external conditions. Hybrids 22103-10 and 3-21c-11 are donors of resistance to potato virus Y (gene *Ry*$_{chc}$), golden potato nematode *Globodera rostochiensis* (Woll.) (gene *H1*) and pale nematode *G. pallida* (Stone) Behrens. (gene *Gpa2*). According to a complex of the traits, three hybrids of the intensive type (17-5/6-11, 1-5-12 and 1615-10) possess high adaptiveness, i.e. an increased environmental plasticity ($b_i = 1.38$, 1.20, and 1.17) and high stability ($S_i^2 = 1.1$, 9.4, 5.2), and are of particular value for breeding. Moreover, the hybrid 17-5/6-11 is a donor of resistance genes to potato virus Y (PVY) (*Ry*$_{chc}$) and golden potato nematode (*H1*, with three markers — TG689, 57R, and N195). Hybrid 1-5-12 contains a combination of the *H1* genes (for all three markers) and *Gro1-4* gene of resistance to *G. rostochiensis*, *Gpa2* gene of resistance to *G. pallida*, and genes *Ry*$_{chc}$ and *Ry*$_{sto}$ conferring resistance to PVY. Long-term field surveys of resistance to fungal pathogens, *Phytophthora infestans* (Mont.) De Bary, *Alternaria solani* (Ell.Et Matr) Sor., *Fusarium oxysporum* Schlet., *Rhizoctonia solani* J.G. Kühn) and *Actinomyces scabies* Gussow showed a 7-9 point relative stability in all tested hybrids.

Keywords: *Solanum tuberosum* L., potato, yields, adaptability, genotype×environment interaction, plasticity, stability

Potato (*Solanum tuberosum* L.) is one of cornerstone food crops cultivated in more than one hundred countries; it is the fourth ranking production crop in the world and the first ranking non-corn crop [1, 2]. The advantage of potato is its capacity to form crop yield in a wide range of agrosystems and high specific production of dry weight of food product per unit of crop acreage [3]. Potato gets increasingly greater attention as the source of not only carbohydrates but also of vitamins, minerals, dietary fibers [4]. This is the reason of ongoing interest in studies to improve nutrient properties of potato and to increase its resistance to biotic and abiotic factors of the environment [5].

The availability of warmth and humidity has significant impact on potato plants during their active growth and during tuber formation [6, 7]. Drought is one of the main factors preventing the growth of plants and reducing productivity of land ecosystems in many regions of the world [8]. Due to global warning, there are steps that need to be taken to ensure adaptation of cultures in these conditions, including creation of new genotypes with mechanisms of protection against stresses [9].

It is no less relevant to increase potato resistance to the most harmful and ubiquitous diseases, such as phytophthora rot, viruses, potato cyst nematode, Alternaria blight, rhizoctonia disease and bacterial rot [10]. Success in breeding varieties which provide complex protection against pathogens depends in many aspects on selection and systemization of donors, and on mobilization of *Solanum* wild forms and varieties to create on their basis the effective sources of resistance [11]. Molecular markers, closely associated with resistance genes, significantly intensify the search for valuable forms due to broader testing and simultaneous selection of genotypes with a complex of oligogens [12], notably reducing the time to create new varieties.

Genetic diversity of plant collection facilitates assessment of primary agronomic characters manifestation in specific edaphoclimatic conditions and identification of most valuable donors [13, 14]. Indeed, creating a variety implies not only obtaining and selecting new genotypes, but also identifying an ecological niche in which these genotypes will provide high productivity, ecological sustainability and product quality [15].

Harsh agroclimatic conditions, late blight epidemics of 1800s, and spreading viral diseases during plant reproduction reduced genetic diversity of potato varieties [16, 17]. Therefore, researchers and breeders around the world are actively seeking for economically valuable properties among the tuber forming *Solanum* L. species of *Petota* section [18].

In this study, we identified samples with high crop yield, resistance to unfavorable environmental conditions and complex relative resistance to fungal diseases, potato virus Y and golden potato nematode under edaphoclimatic conditions of Siberia among potato hybrids that we obtained. These samples have already been involved in breeding adaptive and high yielding potato varieties.

The purpose of this study was to evaluate donor properties of potato forms in terms of adaptability in the environmental and geographical conditions of Western Siberia.

Techniques. The experiments were performed in the northern forest-steppe of Western Siberia (Kuznetsk Basin, Kemerovo Province, Kemerovo District) in the years which differed in meteorological condition. Particularly, 2014 and 2016 were the most unfavorable, with insufficient precipitations at the beginning of the vegetation and high temperatures in combination with overwetting during the tuber formation; 2015, 2017 and 2018 were the most favorable in the hydrothermal regime during the vegetation period with sufficient wetting and moderate temperatures.

A total of 170 samples, including collection potato hybrids (*Solanum tuberosum* L.) of Kemerovo Research Institute of Agriculture, were examined in a collection nursery. The varieties Lyubava (early season), Nevskii (medium-early ripening) and Tuleevskii (medium-ripening) were standards.

Planting was carried out in III decade of May (35.0 thousand plants per hectare, 70×35 cm scheme; a Cramer potato planter, CRAMER Technik, Germany) in four replications. The total plot area was 70 m^2, 20 m^2 test plots were randomly distributed. Complete fallow (heavy loamy leached chernozem soil with 8.52% humus, 25.0 mg/kg $N\text{-}NO_3$, 140 mg/kg P_2O_5, and 80 mg/kg K_2O, pH 6.1) was a predecessor.

Morphological and economic traits were described and assessed according to methodological guidelines [19]. Scores of plant resistance to fungal disease was assessed visually at a 9-point scale (1 — very low, 3 — low, 5 — moderate, 7 — high, 9 — very high) in field conditions under natural infection as per the Council for Mutual Economic Assistance (CMEA) International Classification of potato species of *Tuberarium* (Dun.) Buk. section, genus *Solanum* L. [20] and methodological guidelines [21].

Eberchart and Russel [22] parameters of environmental plasticity (b_i), stability (Si^2), and index of environmental conditions (I_j) were calculated based on evaluation of positive response of the genotype to the improved cultivation environment.

DNA markers linked to potato virus Y (PVY) resistance genes (Ry_{adg}, Ry_{chc}, Ry_{sto}, markers RYSC3, Ry186, YES3-3A) [23-25], *Globodera rostochiensis* (Woll.) golden potato nematode Rol, Ro4 subtypes resistance genes (*H1* and *Gro1-4*, markers TG689, 57R, N195, Gro1-4-1) [11, 26, 27] and *Globodera pallida* (Stone) Behrens pale nematode Pa2 subtype resistance genes (*Gpa2*, Gpa2-2 marker) [11] were identified by multiplex PCR. DNA was extracted from 200 mg of tuber tissue with GMO-MagnoSorb Kit (Syntol, Russia). Tissue samples were homogenized (Precellys 24, Bertin Corp., USA) with 800 μl lysing buffer from the kit and transferred to a 2 ml tube for DNA isolation using Savraska 02 robot work station (Syntol, Russia) as per the manufacturer's protocol. The amplification was performed in multiplex using 2.5× PCR mixture M428 (Syntol, Russia). The reaction mixture (25 μl) contained a 10× buffer for Taq DNA-polymerase (Syntol, Russia), a 2.5 mM mixture of dNTPs (Evrogen, Russia), 25 mM magnesium chloride (Fermentas, Latvia), 5-10 pmol of each primer (Syntol, Russia), 0.5 U Taq DNA polymerase (Syntol, Russia), 10 ng of analyzed DNA and 10-13 μl autoclaved double-distilled water. The described primers [28] were used and protocols were optimized during validation tests in a single cyclogram [12] as follows: 10 min at 94 °C; 30 s at 94 °C, 30 s at 68 °C, 30c at 72 °C (5 cycles); 30 s at 94°C, 30 s at 58 °C, 30 s at 72 °C (35 cycles); 30 s at 94 °C, 5 min at 72 °C. For sequencing, DNA fragments were pre-amplified as follows: 10 min at 94 °C; 30 s at 94 °C, 30 s at 68 °C, 1.5 min s at 72 °C (5 cycles); 30 s at 94 °C, 30 s at 58 °C, 1.5 min at 72 °C (35 cycles); 30 s at 94 °C, 5 min at 72 °C. Multiplex PCR for eight markers was performed using an Applied Biosystems 2720 Thermal Cycler (Thermo Fisher Scientific, USA). The amplification products were analyzed using a genetic analyzer Nanofor® 05 (Institute for Analytical Instrumentation RAS, Russia). The forward primers were marked with fluorescent dyes 6FAM or 5R6G (Syntol, Russia). The data were processed with DNA Fragment Analysis software (Institute for Analytical Instrumentation RAS, Russia) [29].

The statistical processing was performed with Sne-decor program (developed by O.D. Sorokin, Russia) using variation and dispersion analysis methods [30, 31]. Means (*M*), standard deviations (±SD) and coefficients of variation (*Cv*, %) of yield values we calculated. In dispersion analysis, *F*-Fischer test were used at a 5% level of significance, and mean (*M*) and their standard errors (±SEM) were determined along with contribution of each factor to the total dispersion (q_v^2, squared factor loading). The least significant difference was calculated at a 5% level of significance (LSD_{05}).

Results. Long study of wild tuber producing plants of *Tuberarium* section of *Solanum* genus has revealed numerous sources of resistance to a wide range of pathogens (fungi and oomycetes, bacteria, viruses and nematodes) and unfavorable environment factors (ground frosts, temperature increase, drought), which appeared due to natural selection pressure [32, 33].

In view to creation of valuable sources of resistance to pathogens, in our work we used in hybridization potato varieties and interspecific hybrids from the VIR collection (St. Petersburg, Russia). These were Mors (Z77. 1/24 × III.74.562/3 N), resistant to wart disease, golden potato nematode, relatively resistant to viral diseases; Post 86 (П77196/190 × Polesye pink), resistant to wart disease, moderately resistant to scab, bacterial rot, phytophthora rot; hybrid 89-1-12 {Preikulskii ranii × [Wilja × (*S. andigenum* US-W 1793 × *S. rubinii* k-2890-4)]} × {[[Primerosa × (*S. andigenum* US-W 1793 × *S. rubinii* k-2890-4)] × (Suna × *S. stoloniferum* k-2490-5)] × (*S. demissum* k-1539 × *S. vernei* D 459)}, resistant to phytophthora rot, nematode, viruses X and Y; Sagitta [Schwalbe × (S.adg. 54/3/14 × Oberarnbacher Frahe)], resistant to wart disease, potato nematode (Rol), virus X; Baszta (PW 31 × Granola), resistant to wart disease, golden potato nematode, relatively field resistant to phytophthora rot, is poorly affected by potato scab, resistant to virus Y. All in all, 19 hybrids obtained in Kemerovo Agricultural Research Institute in 2014-2018 tested. These hybrids are deposited to the collection of the institute as 27-7c-11, 12-7c-11 (Lyubava × Mors); 22103-10 (Lazar × 89-1-12); 175-10 (Alpinist × Adretta); 5-20c-12, 9-20c-12 (Nikulinskii × Belorusskii 3); 1-5-12 (Lazar × Karlena); 15-13c-11 (Udalets × Garant); 9-14-12, 141-13 (Nakra × pollen mix Udacha variety + 180-1 + 89-1-12); 11-13 (Nikulinskii × Karlena); 81-13 (Lyubava × Sagitta); 161-13 (Zarevo × Karlena); 84-13 (Lyubava × Sagitta); 6-14-11 (Tuleevskii × Post 86); 3-21c-11 (Tuleevskii × Mors); 3-11-11 (Bora valley × Avrora); 1615-10 (Nevskii × Zhukovskii ranii); 17-5/6-11 (Baszta × 89-1-12). The use of interspecific hybrids allowed us to produce potato forms and varieties resistant to bacterial disease, phytophthora rot, nematodes and viruses [34].

Field resistance of potato hybrids to diseases. As per CMEA International Classification of potato species of *Tuberarium* (Dun.) Buk. section of *Solanum* L. genus [20], the scale we used is applicable to generalized estimation of perennial data of field resistance of breeding material. We annually recorded plant diseases in field conditions (breeding nurseries) due to natural infection; whereas 2014 and 2016 were the years of epiphytoty furthered by high temperatures in combination with overwetting during the second period of vegetation.

Based on the perennial visual survey of plants for fungal diseases caused by *Phytophthora infestans* (Mont.) de Bary (phytophthora rot), *Alternaria* solani (Ell. et Mart.) Sor. (Alternaria blight), *Fusarium oxysporum* Schlecht. (Fusarium blight), *Rhizoctonia solani* J.G. Kühn (rhizoctonia disease) and *Actinomyces scabies* Gussow (potato scab) [18], we can say that samples with complex resistance of 7 points and more are of selective value (Table 1). Potato hybrids 3-21c-11, 1615-10, 6-14-11, 22103-10, 17-5/6-11, 1-5-12, 27-7c-11, 12-7c-11, 175-10, 5-20c-12, 9-20c-1, 15-13c-11, 9-14-12, 141-13, 81-13, 161-13, 84-13, 3-11-11 and standard varieties Lyubava, Tuleevskii and Nevskii displayed high and extremely high resistance to fungal diseases (7-9 points) on the average during years of testing in field conditions. All samples listed in Table 1 with the exception of 11-13 hybrid (Nikulinskii × Karlena) with moderate resistance to rhizoctonia disease showed high and very high tuber resistance to phytophthora rot, rhizoctonia disease and potato scab.

1. **Scores of potato (*Solanum* L.) hybrid resistance to diseases as compared to standard varieties** (st) (Kemerovo Province, 2014-2018, natural infection load)

Variety, hybrid	Origin	Resistance to diseases, points						
		Fusarium blight	Alternaria blight	rhizoctonia disease (tops)	Phytophthora rot (tops)	rhizoctonia disease (tubers)	phytophthora rot (tubers)	potato scab
Lyubava (st)		9	9	9	7	7	9	7
Nevskii(st)		9	9	9	8	7	9	9
Tuleevskii (st)		9	9	8	7	7	9	8
3-21c-11	Tuleevskii × Mors	9	9	9	6	7	9	8
1615-10	Nevskii × Zhukovskii ranii	9	9	9	6	7	9	9
6-14-11	Tuleevskii × Post 86	9	8	9	6	7	9	8
22103-10	Lazar × 89-1-12	9	9	8	8	7	9	9
17-5/6-11	Baszta × 89-1-12	9	9	8	8	9	9	8
1-5-12	Lazar × Karlena	9	8	8	8	7	9	8
27-7c-11	Lyubava × Mors	8	8	9	8	7	9	9
12-7c-11	Lyubava × Mors	9	9	8	8	8	9	8
175-10	Alpinist × Adretta	8	9	9	8	7	9	8
5-20c-12	Nikulenskii × Belorusskii 3	9	9	9	7	7	9	8
15-13c-11	Udalez × Granat	8	9	7	8	7	9	8
9-20c-12	Nikulenskii × Belorusskii 3	9	9	9	7	7	9	8
9-14-12	Nacra × pollen mix (Udacha + 180-1 + 89-1-12)	9	9	9	8	9	9	8
141-13	Nacra × pollen mix (Udacha + 180-1 + 89-1-12)	9	9	9	8	7	9	8
11-13	Nikulenskii × Karlena	9	9	9	8	5	9	8
81-13	Lyubava × Sagitta	9	9	9	8	8	9	9
161-13	Zarevo × Karlena	9	9	8	8	9	9	9
84-13	Lyubava × Sagitta	8	8	7	7	7	9	8
3-11-11	Bora valley × Avrora	9	9	7	7	9	9	7

Note. Causative agents (columns from left to right): *Phytophthora infestans* (Mont.) de Bary, *Alternaria* solani (Ell. et Mart.) Sor., *Fusarium oxysporum* Schlecht., *Rhizoctonia solani* J.G. Kühn, *Actinomyces scabies* Gussow.

Susceptibility of potato hybrids to viral infections and nematodes. More than 40 viruses were described, which affect potato in natural conditions [35]; however, potato virus Y (PVY) is deemed the most dangerous and widespread [36, 37]; potato virus X (PVX) also causes significant damage [38, 39]. The DNA markers associated with genes of resistance to diseases and pests significantly improve the efficiency of selection of valuable genotypes during early stages [25] and intensify search for such genotypes [40-42]. Multiplex PCR is a new methodology of simultaneous testing varieties and lines for several genes controlling resistance to viruses and nematodes based on DNA markers [11, 43]. Table 2 shows markers and the corresponding diagnostic fragment sizes used in the study.

2. ***R*-genes and associated DNA markers used for molecular screening of potato (*Solanum* L.) samples**

Gene	Chromosome	Trait	DNA marker (diagnostic fragment size, bp)	Ссылка
Ry_{adg}	11	Immunity to potato virus Y (PVY)	RYSC3 (321	[22]
Ry_{chc}	7	Immunity to PVY	Ry186 (587)	[23]
Ry_{sto}	12	Immunity to PVY	YES3-3A (341)	[24]
H1	5	Resistance to *Globodera rostochiensis* pathotypes Ro1, Ro4	TG689 (141)	[25]
H1	5	Resistance to *G. rostochiensis* pathotypes Ro1, Ro4	57R (452)	[26]
H1	5	Resistance to *G. rostochiensis* pathotypes Ro1, Ro4	N195 (337)	[11]
Gro1-4	7	Resistance to *G. rostochiensis* pathotypes Ro1, Ro4	Gro1-4-1 (602)	[11]
Gpa2	12	Resistance to к *G. pallida* pathotype Pa2	Gpa2-2 (452)	[11]

The resolving power of capillary electrophoresis is sufficient for identification of fragments similar in length, inter alia due to fluorophores varying in spectrum. The genetic analyzer used in the study (Nanofor 05) with high sensitivity allows us to determine the amplicon size at single nucleotide accuracy. The molecular and genetic analysis that we performed identified the markers of dominant alleles of genes for PVY resistance *Ry*$_{chc}$ and golden potato nematode resistance *H1* (for three markers, TG689, 57R and N195) in 17-5/6-11 hybrid (Table 3). Furthermore, in 22103-10 and 3-21c-11 samples we revealed YES3-3A marker linked to *Ry*$_{sto}$ gene and TG689, 57R, and N195 markers identifying *H1* gene, as well as Gpa2-2 marker of *Gpa2* gene (see Table 3). The 1-5-12 hybrid carried the combination of dominant allele genes *H1* (for all three markers), *Gro1-4* which controls resistance to *G. rostochiensis*, *Gpa 2* encoding resistance to *G. pallida*, and also *Ry*$_{chc}$ and *Ry*$_{sto}$ genes for PVY resistance. In 6-14-11 hybrid genotype we detected two markers, 57 R and N 195, for *H1* gene controlling resistance to *G. rostochiensis.*

3. Detection of *R*-genes controlling resistance to pathogens and nematode pests in potato (*Solanum* L.) standard varieties (st) and obtained hybrids by DNA markers

Diseases agent	*R*-gene	DNA marker	Variety, sample								
			Lyubava (st)	Nevskii (st)	Nuleevskii (st)	17-5/6-11	16-15-10	3-21c-11	22103-10	6-14-11	1-5-12
Potato virus Y (PVY)	*Ry*$_{adg}$	RYSC3	0	0	0	0	0	0	0	0	0
	Ry$_{chc}$	Ry186	0	0	0	+	0	0	0	0	+
	Ry$_{sto}$	YES3-3A	0	0	0	0	0	+	+	0	+
Globodera rostochiensis	*H1*	TG689	0	0	0	+	0	+	+	0	+
		57R	0	0	+	+	0	+	+	+	+
		N195	0	0	+	+	0	+	+	+	+
	Gro1-4	Gro1-4-1	0	0	0	0	0	0	0	0	+
G. pallida	*Gpa 2*	Gpa2-2	0	0	0	0	0	+	+	0	+

Note. 0/+ means presence or absence of the gene marker.

Crop yield, environmental plasticity and stability of potato hybrids. We evaluated the crop yield and resistance to unfavorable factors in 3-21c-11, 1615-10, 6-14-11, 22103-10, 17-5/6-11 and 1-5-12 hybrids which stood out in terms of complex resistance to PVY, golden potato nematode and fungal diseases (Table 4). The results show that the impact of the environment on potato crop yield amounts to 55.9 %, and genotype contribute 11.5 %.

4. Crop yield (t/ha) **stability and plasticity in potato (*Solanum* L.) hybrids depending on environmental conditions in different year as compared to standard varieties** (st) (Kemerovo Province)

Variety, hybrid	Years					Yj	*Cv*, %	b_i	S_i^2
	2014	2015	2016	2017	2018				
Early maturity group									
Lyubava (st)	16,7	12,4	17,7	20,0	24,2	18,2	23,9	0,81	26,2
3-21c-11	25,2	12,7	20,7	22,3	32,3	22,6	31,4	1,53	14,6
1615-10	22,4	12,8	21,6	21,2	27,6	21,1	25,2	1,17	5,2
6-14-11	30,4	15,9	24,7	20,0	22,3	22,7	23,9	0,91	26,9
Medium-early maturity group									
Nevskii (st)	26,3	15,0	22,8	21,7	22,8	21,7	19,0	0,88	4,4
17-5/6-11	28,3	15,3	26,1	26,1	31,1	25,4	23,6	1,38	1,1
Mid-season group									
Tuleevskii (st)	13,8	15,3	19,7	20,3	21,1	18,0	18,1	0,28	18,4
22103-10	30,1	16,4	24,7	26,6	20,8	23,7	22,3	0,84	25,8
1-5-12	27,8	13,9	18,5	23,1	25,8	21,8	25,8	1,20	9,4
$\sum x_{ij}$	221,0	129,7	196,5	201,3	228,0	976,5			
x_j	24,6	14,4	21,8	22,4	25,3	21,7			
LSD_{05}						4,1			

Note. *Cv* — variation coefficient, Y_j — averaged variety crop yield on the j-the test year, b_i — regression coefficient, S_i^2 — stability coefficient, $\sum x_{ij}$ — sum of crop yields of all varieties on the j-th test year, x_j — averaged crop yield of all varieties on the j-th test year.

Potato (*S. tuberosum*) is believed to be rather sensitive to the combination of high temperatures and precipitation deficit. The droughts that become more frequent threaten stable production of the crop, therefore, a possibility of complex phenotypic response of potato plants to drought [44, 45[and genetic foundations of potato tolerance to such conditions [46] are being studied globally. Plant response to water availability is determined by biologic properties of plants and by other factors. Among other things, it depends on genotype × environment interaction resulting in protective response at the level of functions of leaf stomatal apparatus [47]. We compared annual environmental indices (I_j) in order to characterize environmental factors in places where the genotypes were assessed. In 2014, 2015, 2016, 2017 and 2018, I_j value was 2.9; –73; 0.1; 07 and 3.6, respectively.

Based on the calculations the conditions that can be deemed most favorable were in 2014 and 2018. During these years the average crop yield for the test group was the highest, 24.6 and 25.3 t/ha, respectively. In 2014, the crop yield was the highest in hybrids 22103-10 of mid-season group (30.1 t/ha which is 16.4 t/ha higher than 13.8 t/ha for Tuleevskii standard variety), and 6-14-11 of early maturity group (30.4 t/ha which exceeded the 13.7 t/ha yield of Lyubava standard variety). In the early-season group reliable increase of crop yield compared to the standard was demonstrated by hybrids 1615-10 (by 5.7 t/ha) and 3-21c-11 (by 8.5 t/ha) (LSD_{05} = 0.77 t/ha). The mid-season 1-5-12 hybrid in 2014 shwed almost 2 times higher yield (27.8 t/ha) than Tuleevskii standard variety. In 2018, at LSD_{05} = 1.0 t/ha, the most productive hybrids were 1-5-12 (25.8 t/ha vs. 21.1 t/ha for Tuleevskii standard), 17-5/6-11 (31.1 t/ha vs. 22.8 t/ha for Nevskii standard) and 3-21c-11 (32.3 t/ha vs. 24.2 t/ha for Lyubava standard). In years with favorable weather conditions, all of these hybrids exceeded standards by 16.0 to 31.5% in terms of average crop yield for 5 years. Yield variability (*Cv*) for varieties and hybrids was from 18.1 to 31.4%, where Tuleevskii variety showed the lowest value in general for the test group, which proves its plasticity and stability, whereas 3-21c-11 hybrid showed the highest variability.

Potato plants interact both with abiotic and biotic factors. As a result of effect of a combination of factors the metabolism changes differently than under the effect of each factor individually (which additionally depends both on the nature of the effect and on biological peculiarities of the genotype) because molecular signaling pathways that control abiotic and biotic tension can manifest both synergism and antagonism. Abiotic tensions intensify plant stress and can cause cell damage, which negatively affects potato crop yield, quality and market value of tubers [7, 48].

We evaluated the dependence of crop yield in potato varieties and hybrids on external factors using regression coefficient b_i for plasticity and stability coefficient S_i^2 for stability as related to the dispersion of character deviations of each sample from regression line. The calculations showed low plasticity ($b_i < 1$) of Lyubava ($b_i = 0.81$), Nevskii ($b_i = 0.88$) and Tuleevskii varieties ($b_i = 0.28$). They poorly respond to the cultivation conditions, which is due to extensive genotypes. Among extensive varieties Nevskii displayed high stability ($S_i^2 = 4.43$), which guarantees high annual crop yields. The extensive hybrid group also included 6-4-11 ($b_i = 0.91$) and 22103-10 ($b_i = 0.84$) hybrids. 3-21c-11 hybrid ($b_i = 1.53 > 1$) stood out in terms of plasticity. It belongs to the intensive type due to high response to cultivation conditions. We qualified 3-21c-11 hybrid as belonging to genotypes with average crop yield stability ($S_i^2 = 14.6$).

Hybrids with $b_i > 1$, whereas S_i^2 approaches zero, are of the highest value. Among the analyzed genotypes, 17-5/6-11 produced the most stable crop yield ($S_i^2 = 1.1$) although its responsiveness to cultivation environment was high (b_i = 1.38). The hybrids 1615-10 (b_i = 1.17, S_i^2 = 5.2) and 1-5-12 (b_i = 1.20, S_i^2 = 9.4) with high crop yield stability were recognized in the intensive genotype group.

So we revealed the following extensive type genotypes: Lyubava (b_i = 0.81), Nevskii (b_i = 0.88), Tuleevskii (b_i = 0.28) varieties, 6-4-11 (b_i = 0.91) and 22103-10 (b_i = 0.84) hybrids. Hybrid 3-21c-11 (b_i = 1.53; S_i^2 = 14.6) is a genotype of intensive type with average crop yield stability. Intensive potato hybrids with increased environmental plasticity and crop yield stability, i.e. 17-5/6-11 (b_i = 1.38; S_i^2 = 1.1), 1615-10 (b_i = 1.17; Si^2 = 5.2) and 1-5-12 (b_i = 1.20; S_i^2 = 9.4), are of the highest value. All hybrids of extensive and intensive types with improved environmental plasticity and stability are relatively resistant (7-9 points) to fungal diseases (phytophthora rot, Alternaria blight, Fusarium blight, rhizoctonia disease and potato scab). Hybrid 17-5/6-11 is the donor of resistance to potato virus Y (Ry_{chc} gene) and golden potato nematode (*H1* gene revealed with three markers, TG689, 57R and N195). Hybrids 22103-10 and 3-21c-11 can be donors of resistance to potato virus Y (Ry_{chc} gene), golden potato nematode (*H1* gene) and pale nematode (*Gpa 2* gene). Hybrid 1-5-12 combines dominant alleles of *H1* and *Gro1-4* genes controlling resistance to golden potato nematode, *Gpa2* gene for resistance to pale nematode, and genes for PVY resistance Ry_{chc} and Ry_{sto}.

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