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Prospects of creating Indian dwarf wheat varieties *Triticum sphaerococcum* Perciv. based on samples endemic to the Hindustan peninsula

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Abstract

Pre-breeding study of five spring samples of *Triticum sphaerococcum* (Perciv.) endemic to the Hindustan Peninsula was carried out in the Middle Volga Region of Russia in 2011–2018. The study demonstrated that all the samples were highly susceptible to powdery mildew disease, with infection up to 90% on infected leaf surface. Maximum yield was observed in sample k-33748 of *T. sphaerococcum* and did not exceed 2.25 t/ha as compared to 4.83 t/ha yield of the standard bread wheat variety Simbircit. Sample k-45738 of *T. sphaerococcum*, was crossed with *T. aestivum* and the wheat lines with significantly high yield and 1000-grain weight as well as better powdery mildew resistance as compared to Indian dwarf wheat were obtained. The selected lines resembles *T. sphaerococcum* with the spherical grain shape, the ratio between length and width of grain characteristics and other species-specific traits, such as compact head, short erect leaves, and short firm stem.

Key words: *Triticum sphaerococcum, Triticum aestivum,* improvement, powdery mildew, grain yield.

Introduction

T. sphaerococcum is endemic to India, which was discovered in the Hindustan Peninsula (Punjab state and western borders of undivided India) where it was in cultivation mainly on rainfed as well as irrigated soil. Howard has described it as various indigenous native forms of “dwarf”, bread wheat varieties called “Punjab”. Percival (1921) distinguished all these forms, for their special characteristic features, into a special species - *T. sphaerococcum* wheat with spherical shaped grain (Indian dwarf wheat). It was described in accordance with the botanical nomenclature as a separate species by Percival (1921) and recognized by triticologists (Flaksberger 1935, 1939; Vavilov 1964; Zhukovsky 1971; Goncharov 2011). Mac Key (1954) classified it as sub-species of hexaploid wheat *Triticum aestivum* L. ssp. *sphaerococcum* (Percival) Mac Key. The main traits of the species presented by strong short stem that is hard to bend, wide short erect leaves and an almost spherical grain (Kobylyanskij 1986). In India, its cultivation could be traced back to pre-historic times in the geographical region lying between Northwest Himalayas and the Hindukush (Pal 1966). Archaeological evidences gathered from the excavation at Mohan-jo-Daro indicate that shot wheat *T. sphaerococcum* was in cultivation around 3000 BC. Its cultivation was also recorded in the neighboring historic regions of Agra and Oudh (Flaksberger 1935). Ellerton (1939) pointed out that the species was widely spread in Hindustan in Sindh, east of Balochistan, and on the area of the present-day state of Madhya Pradesh. At present, *T. sphaerococcum* is no longer cultivated in its site of origin (Dorofeev et al. 1979). However, in 2010, three Indian dwarf wheat cultivation sites were documented in the Karnataka and Maharashtra (South West India) and in 2011 its cultivation was sited only in one of those sites (Mori et al. 2013).

There has been a conflicting opinion about *T. sphaerococcum* that Indian dwarf wheat is not native to the Hindustan Peninsula. Wheat with compact head

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and semispherical grains was discovered in the Neolithic sites in Switzerland (5000-3000 BC) and described by Heer (1865) as *Triticum vulgare* Vill. *var. antiquorum*. Sinskaya (1969) referred to the reports published by Duveyrier (1864), Unger (1866), Buschan (1895) and Werth (1939). Udachin (1991), has discovered the wheat varieties like this ancient species, similar to *T. àntiquorum* Heer ex Udacz in Tajikistan. It was later demonstrated that *T. àntiquorum* samples from Tajikistan and *T. sphaerococcum* samples were similar. These two species have demonstrated the same allelic states of the recessive gene, responsible for the spherical grain shape (Goncharov and Gaidalenok 2005). It is possible that during Neolithic period, *T. sphaerococcum* was Europe's main bread cereal, but lately it was replaced by more productive and drought-resistant *T. compactum* and *T. aestivum* due to climate change (Dorofeev et al. 1979).

Although views of the evolutionary hierarchy of *T. aestivum* and *T. sphaerococcum* differ, the evolution of these species from India and Pakistan was coupled, which is clearly seen in the genetic similarity of Indian dwarf wheat with landrace wheat from those regions (Mitrofanova et al. 2009).

At present, Indian dwarf wheat is preserved in the world's wheat collections, including the N. I. Vavilov All-Russian Institute of Plant Genetic Resources (VIR) collection (St. Petersburg, Russia). Percival contributed the first Indian dwarf wheat samples to the VIR collection. Later samples of *T. sphaerococcum* were collected during VIR expeditions to Hindustan led by Markovich in 1926-1928 (Flaksberger 1935) and by Ter-Avanesyan in 1956-1959 (Ter-Avanesyan 1961). At present, the VIR collection also contains winter bread wheat varieties Sharada (k-64739) and Eremeevna (k-66037) created with germplasm of recombinant mutant sample KN 4333, which express several phenotype traits of Indian dwarf wheat. This mutant sample is a result of interspecific crossing of winter bread and hard wheats (Bespalova et al. 2015). There is an ongoing controversy as to whether such varieties may be considered to be part of *T. sphaerococcum* (Zoz 1975). Sharada and Eremeevna varieties are cultivated in Russia.

Recently, India has developed a variety of bread wheat derived from an interspecific cross involving *T. shpaerococcum* and *T. aestivum*, which is being cultivated under rainfed (moisture stress, drought) conditions in eastern part of the country (Singh et al. 2007). The variety produces a bit round grains with good appearance, high hectoliter weight, better tillering capacity and pink peduncle at the time of maturity.

The idea of using Indian dwarf wheat in breeding is by no means a novel one due to some of its positive traits: spherical grain, stout and short culm, erect leaves, heat resistance, and good baking quality (Vavilov 1964, Singh 1946). The attractive features of the species are apparent, although they have not been implemented in commercial varieties. The main problem lies in the impossibility to achieve significant selective improvement of Indian dwarf wheat samples due to the strong pleiotropic effect of *s1*, *C2* and *Vrn4* genes (Table 1), which are responsible for the negative traits of the species, such as small grain size and low head productivity (Tsunewaki and Koba 1979). The recessive gene *s1* determines the spherical grain shape in samples from India and Pakistan, while *s2* and *s3* are responsible for this trait in *T. aestivum* samples similar to *T. sphaerococcum* obtained through induced mutagenesis (Salina et al. 2000). The gene responsible for ear compactness, *Ñ2*, in *T. sphaerococcum* is not allelic to *T. compactum* (Goncharov 2012). When *Vrn4* is expressed, it is impossible to select plants with contrasting early-ripening traits (Goncharov 2012).

Table 1. Genes responsible for the main phenotype expressions in *T. sphaerococcum*

Gene	Synonym	Chromosome	Trait
S-D1b	*s1*, *sp1*,	3D *Tasg-D1*	Spherical grain
C2	-	2D	Compact ear
Vrn-D4	*Vrn4*	5D	Vernalization response

It is possible that *T. sphaerococcum* varieties created from samples endemic to India and Pakistan will not be wide-spread in contemporary agriculture and may disappear in the future. To preserve Indian dwarf wheat *T. sphaerococcum*, many years of routine selective improvement are required. Controlled breeding with this species implies a long and incremental selection process, while careless selection may take up decades.

The objective of the present research was to identify the positive and negative properties of the Indian dwarf wheat samples in the Middle Volga region of Russia and to find ways to improve these samples, endemic to India and Pakistan in terms of disease resistance and lowering the pleiotropic effect of *s1* and *C2* genes.

Materials and methods

The material included samples of Indian dwarf wheat varieties (*Triticum sphaerococcum* Perc.) from the world collection of the All-Russian Institute of Plant Genetic Resources (VIR) (k-23769, k-33748, k-33750 from India, k-33767, k-45738 from Pakistan). The objectives of the study were also to use several Indian dwarf wheat breeding lines (Table 2). Hybridization (Twell-method) of *T. sphaerococcum* samples with *T. aestivum* L. from the VIR collection (we have used the VIR nomenclature) was done in 2011-2012.

Table 2. The lines derived from two different crosses involving *T. sphaerococcum*

Name	Pedigree
Sh-346-11-2	(S, F_3) k-51767(*T.sph.*)//Krasnoufims-kaya-100/Dalen
Sh-359-11-1	(S, F_3) 350-10/k-45738 (*T. sphaerococcum*)
Sh-359-11-2	(S, F_3) 350-10/k-45738 (*T. sphaerococcum*)
Sh-359-11-5	(S, F_3) 350-10/k-45738 (*T. sphaerococcum*)
Sh-359-11-6	(S, F_3) 350-10 / k-45738 (*T. sphaerococcum*)
Sh-361-11	(S, F_3) k-33750 (*T. sph.*)/Ishimskaya-98

Hybridization, observation, selection in different generations and nursery seeding were carried out at the experimental field of the Tatar Scientific Research Institute of Agriculture (TSRIA) in 2011-2018 near the city of Kazan, Russia, in the north of the Middle Volga Region, in the forest-steppe zone.

The climate conditions were typically European with large seasonal differences including cold and snowy winters and warm and dry summers. The average temperature in January was -13.60°C. Maximum soil freezing is 95 cm; average snow cover depth in February was 39 cm, while the snow melts in the fields by the end of April. Summer climatic conditions establish themselves at the beginning of June and end by the end of August. The average air temperature in July, the warmest summer month, was 19.5°C. The average annual precipitation was 560 mm, with 176 mm in the summer months. The soil is well-cultivated Alfisol (USDA soil taxonomy) type. The weather in the summers during the experimentation was typical of the forest-steppe zone in Russia, with frequent droughts. The summer of 2017 was exceptionally cold and rainy. The seeding was carried out at the beginning of May as per the agricultural tradition and the crops were harvested in August.

The quantitative traits assessment in F_1 hybrids was carried out in accordance with Petr and Frey (1966). The materials were planted in single replication with the frequent repetition of standard variety at regular interval in a plot of 1 m^2. Normal seeding methods adopted in Russia were followed with minor changes introduced (Table 3).

Table 3. Scheme of creating a variety during hybridization of *T. sphaerococcum* x *T. aestivum* for the period 2011-2018

Year	Nursery generation	Nursery sowing method, description
		Selection in different generations, plant reproduction
First	Crossing	Pollination by Twell-method
Second	F_1	Manual sparse seeding, reproduction of offsprings
Third	F_2	Seeding with a seeder on a plot of $1m^2$, reproduction of off-springs
Fourth	F_3	Seeding with a seeder on a plot of $10m^2$, individual plant selection with traits of *T. sphaerococcum*
		Plant reproduction, surveillance, culling of undesirable lines
Fifth	Breeding nursery of the first year	Seeding of the best selected ears is carried out manually, selection of disease-resistant of progeny and assessment of their productivity
Sixth	Breeding nursery of the second year	Seeding with a seeder on a plot of $1m^2$, selection of productive and disease-resistant lines
Seventh	Breeding nursery of the third year	Seeding with a seeder on a plot of $10m^2$, selection of productive and disease-resistant lines
Eighth	Preliminary variety testing	Seeding with a seeder on a plot of $10m^2$ in triple replication. Selection of productive and disease-resistant lines Grain quality assessment

For measurements of quantitative characteristics, e.g., roundness, the λ index was used. The grain index λ shows the ratio of length to maximum grain width. The glume index λ shows the ratio of glume length (without the beak) to maximum glume width. Head density was calculated as the number of developed spikelets per 10 cm of head length.

The severity of the *Erysiphe graminis* infection, caused wheat powdery mildew disease, was described according to Saari, Prescott (1975): 0 - Free from infection. 1 - Resistant: Several isolated lesions on the lowest leaves only. 2 - Resistant: Scattered lesions on the second set of leaves with first leaves slightly infected. 3 - Resistant: Light infection of the lower third of the plant; the lowermost leaves infected at moderate to severe levels. 4 - Moderately resistant: Moderate infection of lower leaves with scattered to light infection.

Results and discussion

The characteristic plants traits during pre-breeding study of Indian dwarf wheat in 2011-2018 in the Middle Volga Region of Russia are described. It was detected several specific characteristic features: short and strong stem, plant height not more than 70 cm., greater tillering capacity (the production up to 5 tillers at the seeding stage at the seed rate of 550 germinated seeds/1 m^2) was observed erect leaves and straight dense heads with 26-32 spikelets per head, which theoretically, allows greater number of plants per unit area, spherical grain, i.e. a greater flour to hull ratio preferable for milling, and resistance to *Bipolaris sorokiniana* Shoem., spot blotch infection on the flag leaf was no greater than 7%.

The samples of the species produced small-sized grain with 1000-grain weight of 25-28 g, which may result in smaller flour recovery, low yields with great annual variation. The maximum yield was recorded in 2017, under greater humidity it was 2.25 t/ha for the sample k-33748. The coefficient of variance (CV) for k-45738 was as high as 74%.

The number of days from emergence of seedlings to heading is closely linked to the duration of the vegetation period (Rigin 2012). At the soil and climatic condition of Volga region, Indian dwarf wheat is categorized as mid-late in maturity, with full heading by 5-6 days later than in the mid-season standard bread wheat variety Simbirtcit. It is well-known that the number of days to heading is controlled by three genetic systems i.e., genes responsible for vernalization response (*Vrn*), photoperiod response (*Ppd*) and earliness *per se* (*Eps*). However, it is not fully ascertained, how much different systems contributes to the rate of development, but *Vrn* gene expression has been thoroughly described for spring bread wheats of various maturity (Pugsley 1972; Zhang et al. 2008). In the present case, relatively late maturity is most likely to be determined by *Vrn4*, which is present in some of the *T. sphaerococcum* samples that have been tested earlier (Goncharov 2012). It was also observed that Indian dwarf wheat samples were highly susceptible to powdery mildew (up to 90% of plant tissue infected in the epiphytotic year of 2017), stem rust, and the local population of covered smut, but moderate susceptibility to brown leaf rust (Table 4). In India too, most of the accessions of *T. sphaerococcum* (except two accessions with moderate resistance) were reported highly susceptible (Tomar

Table 4. Characteristics recorded in *T. sphaerococcum* samples during the 2012-2017 period

VIR Sample	Degree of infection at two stages of heading (in %)						No. of days from emergence of seedlings to full heading time		Yield (t/ha)	
	Powdery mildew		Leaf rust		Stem rust					
	2012 min	2017 max	2016 min	2017 max	2017 min	2016 max	2015 min	2017 max	min-max	CV, %
k-23769	40	80	15	30	35	70	47	55	0. 57-1.47	38. 6
k-33748	35	75	5	10	10	70	46	59	0. 34-2.25	52. 7
k-33750	35	75	15	25	2	50	47	55	0. 39-1.97	41. 3
k-33767	50	80	10	25	25	70	46	60	0. 34-1.66	70. 3
k-45738	60	90	10	20	åä.	50	46	60	0. 25-1.79	74. 0
Simbirtcit, st	30	40	10	40	20	70	41	55	2. 15-4.83	27. 2

St= Standard variety, min. =Minimum, max. = Maximum and Menon 2001). The observations are consistent with data of Sukhanberdina (1977) about the absence of *T. sphaerococcum* samples, immune to powdery mildew.

The amount of leaf rust infection (*Puccinia recondita* Rob. ex Desm) during the study was lower than in the susceptible standard bread wheat variety, Simbirtcit. Stem rust (*Puccinia graminis tritici* Pers.) susceptibility was recorded in epiphytotic year of 2016. The severity of stem rust infection was similar or lower than in the highly susceptible standard bread wheat variety, Simbirtcit (50-70%). Before that, stem rust was only observed in different localities.

The first stage of investigation was focused on the selection for grain weight per head and resistance to powdery mildew. During the selection the high 1000 grain weight along with the kernel number, lower head density and increased no. of glumes were kept in mind.

In the segregating population, derived from *T. aestivum/T. sphaerococcum*, there was a strong connection between the size and shape of the grain. Afanas'ev (1985) had pointed out that attempts to increase the relative grain weight in *T. sphaerococcum* and *T. aestivum* hybrids do not produce the desired results. The 1000-grain weight does not increase, while large grain size is observed only in oblong grains and not in spherical ones. In the selected lines even if the grain size is large, they are characterized by wrinkled endosperm and therefore, rejected at the primary stage of breeding. The lines derived from two different crosses involving *T. sphaerococcum* (Indian dwarf wheat type) and F_1 crosses, Sh-346-11-2/43-04-1 and Sh-359-11-1/43-04-1 were subjected to observations on head density, grain length–breadth ratio, glumes, grain weight per head and 1000 grain weight (Table 5).

In first-generation hybrids, between Indian dwarf wheat and bread wheat the relative glume width, ë (length to width ratio) demonstrated intermediate behaviour in the direction of bread wheat. The grain weight is higher than that of the parents. An increase of the 1000-grain weight was accompanied by lower head density. The grain shape was dominant producing oblong shape in the cross, Sh-346-11-2 / 43-04-1, ë = 1. 9, which is consistent with long-grain bread wheat. Partial domination of spherical grain was also observed in the cross, Sh-359-11-1 / 43-04-1 (ë = 1. 6). Schmidt et al. (1963) reported spherical grain trait is recessive or partially dominant.

In F_2 generation, different morphotype of soft and Indian dwarf wheat were observed. Spherical grain hybrids had lower head density and higher 1000-grain weight than the spherical grain parents (Table 6).

Table 5. F_1 grain and glume parameters, studied in 2017

Sample and crossing combination	Head density*	λ**glume without beak	λ grain	Grain weight/ head (g)	1000-grain weight (g)
Sh-346-11-2 *T. sphaerococcum*	25. 0	1. 5	1. 5	0. 8	28. 2
Sh-359-11-1 *T. sphaerococcum*	26. 6	1. 6	1. 5	1. 1	36. 2
43-04-1 *T. aestivum*	16. 2	2. 2	2. 0	1. 7	36. 3
Sh-346-11-2/43-04-1	17. 7	2. 0	1. 9	1. 6	38. 1
Sh-359-11-1/43-04-1	17. 3	1. 9	1. 6	2. 2	39. 9

* = number of developed spikelets per 10 cm of head length, ** = length-to-width ratio

Table 6. F_2 generation showing different morphotypes in crosses with Indian dwarf wheat in 2018

Selections and crossing combination	Height (cm)	Head density	λ grain	Grain weight/ wead (g)	1000-grain weight (g)
Sh-346-11-2 *T. sphaerococcum*	53. 4	24. 7	1. 4	0. 84	23. 5
Sh-359-11-1 *T. sphaerococcum*	50. 2	26. 7	1. 6	1. 26	29. 1
43-04-1 *T. aestivum*	79. 2	17. 9	2. 1	1. 83	38. 0
Sh-346-11-2/43-04-1	54. 3	22. 0	1. 7	1. 40	37. 7
Sh-359-11-1/43-04-1	65. 0	20. 5	1. 5	1. 17	33. 6

Powdery mildew is one of the most wide- spread and devastating wheat diseases. Epiphytotic spread of the infection in the Middle Volga Region may result in the loss of spring bread wheat up to 24% (Shevchenko1993). During the study period, bread wheat samples were found highly susceptible to the infection. Since the *T. sphaerococcum* samples obtained from Hindustan were susceptible to powdery mildew infection, the breeding for resistance to powdery mildew was very important.

T. sphaerococcum samples included VIR samples k-23769, k-33748, k-33750, k-33767, k-45738 and several lines derived from two different crosses with *T. sphaerococcum* and a standard control variety Kazakhstanskaya Rannespelaya were highly susceptible, displaying from 60 to 90% powdery mildew infection. Simbirtcit (k-64548), a regional standard variety showed 30-40% infection, whereas Tybalt (k-64897), a resistant variety showed immunity to powdery mildew at tillering stage and produced small necrotic spots on leaves at heading stage.

Creation of Indian dwarf wheat varieties, resistant to *Erysiphe graminis* was aimed using resistant genetic sources of *T. aestivum* (Vasilova et al. 2016). Since the infection races of fungus are becoming increasingly virulent in Volga region and the losses in wheat productivity is expected, the use of resistant materials is advocated.

Two approaches of breeding were followed using spring bread wheat with low levels of susceptibility to powdery mildew and varieties with slow increase of infection or carrying horizontal resistance (Table 7).

In the cross combinations one of the parents was a spring bread wheat variety with low levels of susceptibility to powdery mildew. Usage of LP-588-1-6 (k-65446, Germany) resulted in moderately resistant F_1hybrids, while in the case of Sitara variety with low levels of susceptibility to powdery mildew (Tatarstan, Russia) the hybrids were either very resistant or demonstrated intermediary inheritance in favour of the resistant parent. The cross combinations with the immune variety, Tybalt (k-64897, the Netherlands) resulted in first-generation hybrids without signs of infection or highly resistant hybrids. Such forms of inheritance suggest that it is possible to isolate forms with low levels of susceptibility to the infection.

Under this breeding project, hybridization between *T. aestivum* and *T. sphaerococcum* was started in 2011. The number of genotypes valuable for selection was incredibly small, with isolated lines only insignificantly better than the source forms in terms of agriculturally valuable traits. To increase the probability of the desired recombination, the hybridization volume was increased to 80–109 combinations including complex hybrid combinations and simple paired mating in 2017–2018.

Hybridization of Indian dwarf wheat and spring bread wheat does not cause problems: hybrid seed set and germination remains the same as that of combinations within the species, and there is no occurrence of unseeded (sterile) ears in F_1. However, the existing traditional selections with spring bread wheat in the third and fourth generations do not produce phenotypically constant forms. In such selections, for most crossing combinations in first- and second-year

Table 7. *E. graminis* infection of F_1 cross combinations of *T. sphaerococcum* with pathogen-resistant *T. aestivum*.

No.	Crossing combination	No. of plants examined	Descriptions of severity levels (0 to 4 scale)
1	Sitara/Sh-361-11	50	3 – moderately infected
2	Sitara/Sh-346-11-2	36	1 – very resistant
3	Sh -359-11-1/Sitara	27	4 – highly susceptible
4	k-33750 / Sitara	29	3 – moderately infected
5	Sh -346-11-2/LP -588-1-6	18	2 – moderately resistant
6	LP -588-1-6/Sh -359-11-1	49	2 – moderately resistant
7	Sh -359-11-1/Tybalt	37	0 – free from infection
8	Tybalt/Sh -359-11-1	36	1 – very resistant
9	Sitara	60	1 – very resistant
10	LP -588-1-6	60	11 – very resistant
11	Tybalt	60	0 – free from infection

nurseries, the formation process is still ongoing. We believe that it is more expedient to conduct selections in F_5 and after in order to achieve constant phenotypes. amount of powdery mildew infection was observed in Line Sh-359-11-5 which did not exceed 25%.

Table 8. Characteristics of *T. sphaerococcum* samples

Sample	Productivity (t/ha)		Vegetation period duration (days)		Degree of powdery mildew infection (%)			
					Tillering		Head emergence	
	2017	2018	2017	2018	2017	2018	2017	2018
Simbirtcit, st	4. 32	4. 03	92	77	30	30	45	30
k-45738 (source form)	1. 34	0. 73	90	81	90	70	95	70
Sh-359-11-1	2. 01	1. 75	95	80	75	25	50	15
Sh-359-11-2	2. 89	2. 14	92	76	80	60	50	75
Sh-359-11-5	3.77	2.82	94	80	25	25	15	15
Sh-359-11-6	3. 22	2. 80	94	79	75	25	45	40
S. E.	0. 34	0. 37						

Table 9. Characteristics of *T. sphaerococcum* prospective lines

Sample	1000-grain weight (g)		Grain unit (g/l)		λ, Grain	
	2017	2018	2017	2018	2017	2018
Simbircit, st	40. 7	38. 7	790	807	2. 12	2. 07
k-45738 (source form)	17. 4	15. 9	785	804	1. 55	1. 62
Sh-359-11-1	29. 7	32. 3	731	789	1. 38	1. 61
Sh-359-11-2	29. 2	30. 7	734	802	1. 42	1. 61
Sh-359-11-5	26. 1	29. 3	767	799	1. 44	1. 65
Sh-359-11-6	24. 2	27. 2	754	798	1. 43	1. 66
$LCD._{05}$	2. 4	2. 4	10	9	0. 11	0. 09

Given the short duration of selection improvement of *T. sphaerococcum,* the first prospective constant lines with a common genealogy of 350-10 (*T. aestivum*)/k-45738 (*T. sphaerococcum),* where 350-10 is a complex first-generation hybrid resistant to powdery mildew, have been obtained. The obtained sibs were tested in 2017 and 2018. It is apparent that the obtained lines show an advantage in productivity and powdery mildew resistance as compared to the Indian dwarf wheat sample (Table 8). The productivity of the obtained *T. sphaerococcum* lines is significantly greater than that of the parent k-45738 *T. sphaerococcum*. Line Sh-359-11-5 is the most productive, with average yields tripling those of the *T. sphaerococcum* source form. However, it is significantly less productive than the standard bread wheat variety, Simbirtcit, by 21% (Fig. 1). The least

Fig. 1. Promising, highly productive line Sh-359-11-5 grown at Chistpolsky in district Kazan, in 2020

All obtained lines except Sh-359-11-2 are characterized by a longer vegetative period than that of the standard variety. No significant progress in terms of earliness as compared to the *T. sphaerococcum* source form was recovered; however, it is mentioned that leaf infections resulted in the premature aging of k-45738 Indian dwarf wheat sample.

The increase of the 1000-grain weight leads to a certain decrease of grain unit (Table 9). Source form k-45738 has a smaller 1000-grain weight and higher grain unit

The selected *T. sphaerococcum* lines retained the spherical grain shape; the grain length-to-width ratio which is comparable to characteristics of *T. sphaerococcum,* and other specific traits have been preserved such as compact head, short wide erect leaves, short strong stem (41.8-54.3 cm), and resistance to the lodging.

The results of the study demonstrates that selection for improvement combined with retention of the positive traits of *T. sphaerococcum* is achievable. However, it appears difficult to get rid the species of its typical negative traits, especially low grain weight. Line Sh-359-11-5 was the most prospective as it showed significantly higher yields than its Indian draft wheat parent (k-45738). Other methodologies and approaches than the traditional selection crossing with soft wheat may turn out to be of advantage.

Authors' contribution

Conceptualization of research (DFA, NSL); Designing of the experiments (DFA, NZV); Contribution of experimental materials (DFA, DanFA, NZV); Execution of field/lab experiments and data collection (DFA, DanFA, NZV); Analysis of data and interpretation (DFA); Preparation of manuscript (DFA, NSL).

Declaration

The authors declare no conflict of interest.

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