Bioscience Biotechnology Research Communications Vol 14 No (4) Oct-Nov-Dec (2021)

Agricultural Communication

Investigations on the Source Material of Oat Seeds, *Avena sativa* through the Multidimensional Ranking Method in Natural Conditions of Yakutia, Siberia, Russia

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ABSTRACT
Eighty-three collection samples of oat seeds (Avena sativa L.) of various ecological, geographical, and breeding origins were studied in the conditions of Central Yakutia during 2017-2019 by the method of multidimensional ranking according to six economically valuable characteristics, namely, the duration of the growing season, grain yield, grain weight from the plant and panicles, the weight of 1.000 grains, and yielding tillering capacity. According to the results of the multidimensional ranking, the varieties were divided into three groups: the best, average, and worst. At that, from the data entered for 83 samples, the program determined priorities based on a combination of the duration of the growing season and yield. The group of best samples, based on a combination of economically valuable features, included 63% of samples from Europe, 30% from Russia, and 7% from Asia. The main share in the average group was made up of samples from Europe (63%), Russia (33%), and Asia (4%). The local zoned variety – Pokrovsky standard is included in the average group with a rank limit of 118.8. The worst group included the most samples from Europe (41%), Russia (26%), America (26%), Africa (3.7%), and Asia (3.7%). According to the precocity, 11 samples were identified that ripened earlier than the standard by 7-11 days. These are K-15062 (Omsk Region), K-15108 (USA), K-15111 (Colombia), K-15184 (Kemerovo Region), K-15191 (Slovakia), K-15357 (Norway), K-15375, K-15416, K-15418 (Germany), K-15392 (Sweden), and K-15408 (Belarus). Samples with high grain yield were included in the group of the best varieties. Among the selected varieties, cultivars K-15293 from Poland and K-15415 from Germany had the most stable yield over the years..

KEY WORDS: AGRONOMIC VALUABLE CHARACTERS, GRAIN YIELD, PRECOCITY, SEED OATS, SOURCE MATERIAL.

INTRODUCTION

Grain production for food and feed purposes remains one of the priority areas in agriculture and crop production. Oat crops in Yakutia occupy 57% of the total area (Sakha Yakutia Stat 2020). The demand and market attractiveness of oats as a universal use crop has been growing in recent years. The Oats acreage occupies fifth place in the world after wheat, rice, corn, and barley. Grain is used for animal feed, in human nutrition, as well as a food raw material (Arendt and Zannini 2013; Loskutov and Polonsky 2017). Continuous improvement of grain varieties is possible only if there is a gene pool, which is represented by a wide range of samples from the collection of the Vavilov Institute of Plant Genetic Resources (VIR) (Bespalova 2015; Dzyubenko 2015; Petrova 2020).

Article Information:*Corresponding Author: pelidia@yandex.ru
Received 17/10/2021 Accepted after revision 25/12/2021
Published: 31st December 2021 Pp- 1666-1672

Available at: https://bbrc.in/ DOI: http://dx.doi.org/10.21786/bbrc/14.4.44

At that, direct use of the gene pool is difficult, as a rule, due to the low adaptability of the material and the predominance of recombinants with low yields in the offspring, which were rejected at the first stages of the selection process (Friedrich et al. 2014; Singh and Kumar 2016). To create new varieties with a complex of valuable characteristics, high yield, and high quality of products in various environmental conditions, the well-studied source material was required (Petrova 2018). The ideal genotype should work well for many years both in one place (certain environmental conditions) and in a wide range of environments formed by external conditions in different geographic areas (Romagosa and Fox 1993; Petrova 2020).

The identification of new genetic factors that determined the high degree of manifestation of agronomic valuable characters in the selected samples of the collection will contribute to the creation of varieties with the required parameters (Randhawa et al. 2013; Petrova 2020). To successfully overcome objectively emerging barriers, it is necessary to systematically conduct selection work to find new genotypes with a complex of agronomic valuable characters, which largely depends on the correct selection of the source material and its diversity (Lubnin 2006). Therefore, the introduction of species and varietal diversity of oats of various geographical and selection origins in a specific natural and climatic zone is of great scientific and practical importance. This issue is most relevant in the extreme conditions of Central Yakutia. The analysis of the natural and climatic conditions of Central Yakutia shows that agriculture in this zone develops in peculiar and more extreme conditions than in other regions not only of Russia but also worldwide. The climate of Central Yakutia is sharply continental: low temperatures in winter (the absolute minimum is 640C) with weak winds sharply contrast with high air temperatures in summer (the absolute maximum is 380C) (Toropov et al. 2020).

Only 210 mm of precipitation falls per year, including during the summer period (Gavrilova 1973). The ranking of collection samples according to the combination of agronomic valuable characters was carried out using the Snedecor computer program (Sorokin 2004). Ranking of collectible varieties of oats according to the set of characteristics using the algorithm developed by Yuzhakov and Sorokin (2000) allowed dividing them into three groups: the best (the sum of the ranks equal to 144.0-149.2) average (137.0-117.1), and worst (107.3-26.0). Ranking allowed to order the factors according to the degree of increasing or decreasing their influence on the social phenomenon of interest to the researcher (Korobov 2005). According to Montel (1998), there have never been two completely identical opinions or one grain was similar to another. For data processing, a ranking operation was used, which consisted in the fact that the observed values of a random variable were arranged in ascending order (Montel 1998; Yuzhakov and Sorokin 2000; Korobov 2005; Toropov et al. 2020).

The purpose of the research was to identify valuable collection samples of seed oats (*Avena sativa* L.) adapted to the conditions of Yakutia, followed by the selection of promising (best) cultivars as parent forms for hybridization by the multidimensional ranking method.

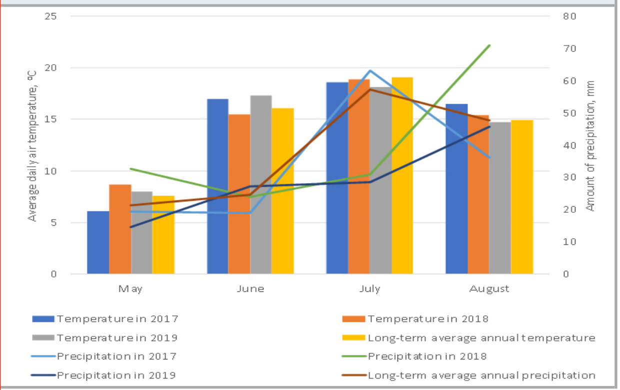
MATERIAL AND METHODS

The research was carried out during 2017-2019 in the Pokrovsky Division of the Yakut Research Institute of Agriculture in the territory of the Khangalassky ulus of the Republic of Sakha (Yakutia), located in the middle taiga zone. At that, 114 collection samples were studied, among which later the most promising 83 samples were selected from the VIR and foreign selections. The main portion of the collection (50.6%) was made up of samples from Europe. Varieties from Russia occupied 35%. From the foreign assortment, varieties from America (9.6%), Asia (3.6%), as well as Africa (1.2%) prevailed. The most fully studied characteristics were precocity (duration of the growing season), grain yield, grain weight from a plant, grain weight from a panicle, weight of 1.000 grains, and yielding tillering capacity of plants. According to the data of the weather station in the Pokrovsk town of the Khangalassky ulus, Republic of Sakha (Yakutia), during the years of research (2017-2019), the growing season was characterized by insufficient moisture.

The sum of active air temperatures above +100C from sowing to the ripening of oats varied from 1688 to 1801, the amount of precipitation ranged from 116.6 to 144.0 mm. The lowest precipitation was in 2019 (HI (Hydrothermal Index) =0.65), more humid weather was in 2017 and 2018 (HI= 0.77-0.81) (Fig. 1). In the first decade of May, (2017) average daily air temperatures were quite low equal to 3.3oC. The minimum temperature dropped to -2.8oC. The average monthly temperature in May was 6.1oC, which was lower than the average annual norm by 1.5oC. In general, 2017 was characterized by insufficiently humidified weather conditions. In June, when the vegetative mass of oats intensively increases (plants undergo the main phases, such as stem elongation, earing, formation of inflorescences), the moisture demand was greatest, however, the water supply of plants at elevated temperature conditions, lack of air humidity, and the dry hot wind was often insufficient.

Thus, 137 mm of precipitation fell from May to August, which was 0.9 times lower than the average annual norm (151 mm). The bulk of precipitation fell in July 63.1 mm, with an average annual norm of 57.3 mm. Current weather conditions led to an increase in the duration of the earing period – the wax ripeness of the samples. This resulted in a strong proliferation (sprouting), which greatly complicated the harvesting and reduced the quality of grain. June and July were warm – the average monthly air temperature was 17.8oC. The growing season of 2018, in general, can be characterized as quite favorable for oats growth and development. The average monthly temperature in May was 8.7oC, which was 1.1oC higher than the average annual norm. From May to August, precipitation amounted to 158 mm, which was 1.05 times higher than the average annual norm (151 mm).

Figure 1: Average daily air temperature and precipitation for 2017-2019



In May, precipitation for the month was 1.5 times higher than normal (33 mm versus 21 mm). Precipitation for July was 1.8 times below normal (31 mm with an average annual norm of 57 mm). In August, precipitation for the month was 1.5 times higher than normal (71 mm vs. 47 mm). The meteorological conditions of 2019 can be described as unfavorable for grain crops' growth and development. In May, precipitation for the month was 0.7 times lower than normal (21.3 mm versus 14.6 mm). The first and second decades of June were characterized by a severe drought, the amount of precipitation was 3.2 mm, which was 18.8 mm lower than normal. The third decade of June was rainy, the amount of precipitation exceeded the average annual norm by 3.1 mm. August was relatively cool. The monthly amount of precipitation was 45.7 mm, with a norm of 47.6 mm.

Table 1. Ranking of collectible varieties of oats by agronomic valuable characters (average for 2017-2019)

Group of the best objects		Group of the average objects		Group of the worst objects	
No. of the VIR catalog	Sum of ranks	No. of the VIR catalog	Sum of ranks	No. of the VIR catalog	Sum of ranks
15392	144.0	15287	137.0	15258	107.3
15357	143.7	15341	122.9	15390	119.8
15125	147.1	15348	148.7	15384	93.0
15336	168.7	15184	142.8	15376	112.1
15330	179.5	15278	130.9	15093	78.3
15342	137.6	15353	142.3	15249	106.4
15426	127.5	15335	149.4	15320	98.8
15380	159.1	15182	117.9	15428	92.0
15418	130.4	15420	129.2	15391	98.5
Nilola	160.7	15377	132.2	15064	105.2
15333	137.4	15279	129.2	15372	92.3
15180	146.8	15240	126.5	15111	86.5
15134	124.4	15425	121.3	15393	70.1
15186	118.7	15053	125.6	15394	60.2
15281	161.9	15412	95.2	15410	72.9
15293	153.2	15328	107.0	15267	88.5
15395	122.8	St Pokrovsky	118.8	15339	60.9
15291	143.0	15298	109.2	15264	80.1
15383	157.9	15417	64.3	15108	70.4
15415	143.8	15234	123.9	15006	64.2
15378	144.5	15069	94.9	15100	56.8
15421	144.2	15248	122.7	15062	43.7
15106	125.5	15416	110.4	15256	45.2
15294	134.3	15419	102.2	15121	38.9
15423	142.4	15301	105.4	15382	34.1
15275	150.0	15375	113.3	15408	34.9
15283	149.2	15338	117.1	15318	26.0

The agrochemical properties of the soil were determined using generally accepted methods in the laboratory of biochemistry and mass analysis of the Yakut Scientific Research Institute of Agriculture using the Infranid-61 infrared analyzer. The soil of the experimental plots was permafrost taiga-pale yellow, medium-loamy in mechanical composition with a humus content of 3-6% in the upper five-centimeter layer. With a depth, this indicator decreases to 1-1.5%. The mobile phosphorus content according to Egner-Rome was 10.43 mg/100 g of soil, the exchange potassium according to Maslova was 27.4 mg/100 g of soil. The reaction of the aqueous extract was alkaline throughout the profile, the area of 7.11-7.55, the hydrolytic acidity of the soil was 0.84-0.98 mg/eq. per 100 g of soil.

Table 2. Results of evaluation of collecting samples of oats by precocity

No. of VIR catalog	Variety	Vegetation period, days		
		average	±to standard	min-max
Standard	Pokrovsky	76		75-78
15111	Colombia	65	11	60-68
15062	Omsk region.	65	11	60-69
15418	Germany	67	9	63-74
15408	Belarus	67	9	60-73
15108	USA	68	8	65-71
15184	Kemerovo region	68	8	60-76
15357	Norway	68	8	65-71
15375	Germany	68	8	65-71
15191	Slovakia	69	7	66-74
15392	Sweden	69	7	67-73
15416	Germany	69	7	65-71

The type of salinity was sulfate-chloride (up to 49.1%). The composition of salts was dominated by sodium salts. Field experiments were based on one-factor experience, according to the generally accepted methods of field experience by I nthe previous studies (Dospekhov 1985).

Observations, estimates, and records of the harvest in collection nurseries were carried out according to the methodological guidelines for the study of the world collection of barley and oats (Methodological guidelines for the study of the world collection of barley and oats 1981) and the CMEA (Council for Mutual Economic Assistance) international classifier for Avena sativa L. genus. Mathematical data processing was carried out using an application software package developed by O.D. Sorokin (Sorokin 2004). The Pokrovsky variety was sown as a standard. In the experiment, manual sowing was used. The plot area of one square meter was placed on a complete fallow in a single repetition. The work was carried out taking into account the methodological guidelines of the VIR. After harvesting, the yield structure was analyzed.

RESULTS AND DISCUSSION

All six features were evaluated together, and the boundaries of the sum of ranks were determined, according to which the size of the group could be changed by the user towards decreasing from 1/3 of the total number of objects since three groups of ranks were determined, namely, the best, average, and worst (Sorokin). This was the peculiarity, novelty, and value of the statistical analysis of the multidimensional ranking of sown oats according to agronomic valuable characters. The cultivars that fall into the best group was used as parent forms for the selection of hybridization. The group of the best samples, based on the comprehensive agronomic valuable characters included 63% of samples from Europe, 30% from Russia, and 7% from Asia. The main portion in this group was made up of samples from Europe (63%), Russia (33%), and Asia (4%). Local zoned grade –Pokrovsky standard was included in the average group with a rank boundary of 118.8 (Table 1). The worst group had the most samples from Europe (41%), Russia (26%), the USA (26%), Africa (3.7%), and Asia (3.7%) (Dzyubenko 2015; Toropov et al. 2020).

One of the most important features that determine the degree of adaptability of a crop to specific growing conditions was precocity. The duration of the growing season was the most important biological characteristic that reflects the interaction of the genotype of the variety and the environment. Considering the growing season as the main moment in plant selection, Vavilov (1935) pointed out that it was associated with many properties that determine the resistance against frost, drought, diseases, pests, and improvement of grain quality. In case of drought and a short growing season, the best type of plant was the one that may not have very high yield potential but was most resistant in all respects to adverse environmental factors. At the same time, the tougher the environmental factors, the more the selection possibilities were narrowed. In the context of a short northern summer, precocious varieties are needed, while against the background of drought – drought-resistant ones (Vasiliev 2000; Ivanov and Ivanova 2012; Toropov et al. 2020).

Precocious forms were characterized by a lower productivity potential compared to medium-ripened ones (Sinitsyn 1970). The duration of the growing season over the years of research varied on average from 60-79 days or more. Thus, 11 cultivars were identified, which turned out to be the most precocious. These were cultivars K-15111 from Colombia and K-15062 from the Omsk Region (11 days), K-15418 from Germany and K-15408 from Belarus (9 days), K-15108 from the USA, K-15184 from the Kemerovo

Region, K-15357 from Norway, K-15375 from Germany (8 days), K-15191 from Slovakia, K-15392 from Sweden, and K-15416 from Germany (7 days) (Petrova 2020).

The duration of the main interphase periods of oats (sprouting – sweeping, and sweeping – ripening) varied depending on the variety. In July, oats were forming and filling grain. At this time, with sufficient moistening, a moderate temperature regime was extremely necessary. The analysis of the duration of the germination-earing period showed that the shortest period before earning in the collected samples was in 2019, on average, 27 and 33 days for various samples. The increased sum of temperatures (1801.2) in May, June, and July contributed to rapid ear formation. In (2017), the largest number of samples had an interphase period of ear formation – maturation lasting 48-53 days. The lowest indicator of the second period (45-47 days) is typical for precocious cultivars (Dzyubenko 2015; Toropov et al. 2020).

Table 3. Characteristics of varietal samples of spring oats, distinguished in collection Nurseries in terms of grain yield (average for 2017-2019)

No. of VIR catalog	Origin	Grain yield, g/m2	Grain weight per plant, g	Grain weight per panicle, g	Weight of 1,000 grains, g	Yielding tillering capacity, itm.	Growing season, days
Pokrovsky	Yakutia	180	3.5	1.9	32.9	2.4	76
15392	Sweden	325	4.5	1.6	36.6	3.8	69
15357	Norway	322	5.0	1.4	36.1	3.8	68
15125	Ukraine	288	4.2	1.8	38.4	3.5	72
15336	Altai Territory	271	2.9	2.0	46.4	3.7	76
15330	Ulyanovsk region	263	5.0	2.0	39.2	4.3	74
15342	Buryatia	286	4.5	1.6	34.1	3.4	73
15426	Germany	299	3.3	1.5	40.2	2.2	72
15380	Germany	264	5.2	1.9	40.0	3.3	72
15418	Germany	283	3.8	1.6	39.8	3.1	67
Nikola	Kazakhstan	261	4.5	2.0	37.3	3.5	75
15333	Ulyanovsk region	273	4.1	2.0	38.3	2.8	71
15180	Ulyanovsk region	264	4.5	1.8	35.5	3.9	70
15134	Czech	274	4.0	1.7	37.6	2.6	70
15186	Kirov region.	279	3.9	1.6	35.1	3.0	72
15281	Moscow region.	250.3	4.6	1.9	42.1	3.3	74
15293	Poland	251	4.4	1.5	37.5	3.8	76
15395	Sweden	267	3.3	2.0	35.4	2.3	72
15291	Poland	260	4.3	2.1	36.8	3.2	73
15383	Ukraine	244	4.4	2.1	37.9	3.2	76
15415	Germany	247	4.4	1.6	39.7	3.0	74
15378	Germany	246	4.4	1.6	42.3	3.3	73
15421	Germany	241	4.3	2.0	43.2	2.5	72
15106	Portugal	246	3.9	1.5	38.5	3.6	71
15294	Poland	243	2.9	1.7	38.2	2.0	77
15423	Germany	237	4.0	2.4	43.2	2.7	71
15275	Kirov region	228	4.9	1.6	32.3	4.6	74
15283	Tyumen region	223	5.6	1.6	37.5	3.6	74

Due to heavy rains in July, abundant tillering began and the duration of the ear formation – maturation phase lengthened. The zoned Pokrovsky variety was subject to less fluctuation in the duration of the growing season, showing stability in all years (Table 2). The selected samples was used as sources of precocity in the selection process when creating varieties that reliably ripen in the natural conditions of Yakutia (Loskutov and Polonsky 2017; Petrova 2020).

One of the most important characteristics of any variety was its yield (Korobov, 2005). It was quite difficult to combine high productivity and precocity in one genotype. According to the evaluation results obtained by the method of multidimensional ranking, 27 varieties were distinguished in terms of the highest grain yield. These are samples from Germany, the Ulyanovsk Region, the Altai Territory, the Moscow Region, the Novosibirsk Region, the Czech Republic, the Kirov Region, Poland, Ukraine, Portugal, the Tyumen Region, whose yield was 11-66% higher than the Pokrovsky variety standard. On average, over the years of research, the highest grain yield (299-325 g/m2) was shown by samples from Sweden (K-15392) and from Germany (K-15426), which is higher than the standard by 119 g/m2. The lowest yield (26-37 g/m2) was noted in cultivars from the USA (K-15417 and K-15093), Ukraine (K-15382), and Poland (K-15248, K-15294, K-15248). Among the selected cultivars, K-15293 from Poland and K-15415 from Germany had the most stable yield over the years (Petrova 2020; Toropov et al. 2020).

The grain weight from the plant varied from 1.7 g in the sample from the USA (K-15256) to 5.2 g in the variety from Germany (K-15380). The largest weight of grain from a plant of the best group was shown by samples from Norway (K-15357), the Ulyanovsk Region (K-15330), Germany (K-15380), and the Tyumen Region (K-15283). The weight of 1,000 grains of early-maturing oat samples varied from 25.2 to 42.0 g. On average, over the years of research, the largest grain (40-46 g) was formed by samples K-15426, K-15380, K-15378, K-15421, and K-15423 from Germany, K-15281 from the Moscow Region, and K-15336 from the Altai Territory.

The highest yielding tillering capacity was observed in a sample from Germany K-15418 (3.6 g). On average, during the three years of research, five cultivars were the most productive in terms of yielding tillering capacity: K-15240 from the UK (4.7 g), K-15275 from the Kirov Region (4.6 g), K-15330 from the Ulyanovsk Region (4.3 g), K-15248 from Poland (4.4 g), and K-15420 from Germany (4.2 g). In general, in terms of the best yielding tillering capacity, the following varietal types can be distinguished by the method of multidimensional ranking: precocious samples K-15357 from Norway, K-15281 from the Moscow Region, K-15418, K-15375, and K-15416 from Germany, K-15408 from Belarus, K-15111 from Colombia, K-15062 from the Omsk Region, K-15108 from the USA, K-15184 from the Kemerovo Region, K-15191 from Slovakia, and K-15392 from Sweden; cultivars, combining precocity and yield: K-15418 from Germany, K-15357 from Norway, and K-15392 from Sweden; cultivars with a high yield of grain and its main elements from the best group: K-15392, K-15395 from Sweden, K-15357 from Norway, K-15125, K-15383 from Ukraine, K-15336 from the Altai Territory, K-15330, K-15333, K-15180 from the Ulyanovsk Region, K-15342 from Buryatia, K-15378, K-15426, K-15380, K-15415, K-15418, K-15421, K-15423 from Germany, Nikola from Kazakhstan, K-15134 from the Czech Republic, K-15186, K-15275 from the Kirov Region, K-15281 from the Moscow Region, K-15291, K-15293, K-15294 from Poland, K-15106 from Portugal, and K-15283 from the Tyumen Region (Loskutov and Polonsky 2017; Petrova 2018; Petrova 2020).

CONCLUSION

The findings of the present study confirmed that one of the main indicators of the density of a productive stem is considered to be yielding tillering capacity. The productive stems formation is influenced by many factors. Employing the multidimensional ranking method in the analysis of grain yield and its structural elements allows identifying promising varieties of oats at the early stages of the selection process.

ACKNOWLEDGEMENTS

The study has been performed within the framework of a state assignment "Fundamentals of the creation of farming systems and agricultural technologies based on the preservation of the gene pool, selection of hybrids and varieties of a new generation of agricultural crops, their protection from harmful organisms, the preservation and reproduction of soil fertility in conditions of Cryolithozone of Yakutia" (registration number 0821-2019-0004).

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