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Viability of seeds and adaptability of early-maping hybrids of corn in the conditions of the Southern Urals

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Abstract. **The purpose** is to study and identify the best high-yielding with rapid loss of grain moisture during ripening, ecologically plastic and stable corn hybrids adapted to the conditions of the Southern Urals. **Methods.** The studies were carried out in 2017–2020 in the North Caucasian and Ural regions of the Russian Federation at the earliest and optimal sowing dates, taking into account the temperature regime of the soil. Eight new early-ripening maize hybrids of the FSBSI ARRSI of corn breeding in 2016 were studied. Laboratory seed germination was determined at a temperature of +20 °C according to the method of V. S. Sotchenko and others and by cold germination in filter paper rolls after each year of storage. Field germination was determined by counting the number of seedlings after sowing. Plasticity and stability were calculated according to the method of S. F. Eberhart, W. F. Russel. **Results.** After four years storage of corn hybrids Nur and Mashuk 170 MV, the laboratory germination of seeds remained at the level of 98–99 % with cold germination. In the conditions of the Ural region, the hybrids Baikal and Mashuk 171 became ecologically plastic and productive, referring to high intensity forms. The hybrids with the lowest grainharvesting moisture for all the years of studying Bilyar 160 (27.0 %) and Ural'skiy 150 (27.5 %) were identified as adapted for growing for grain in the Ural region. **Scientific novelty**. For the first time, a variety test of new early-ripening maize hybrids bred by FSBSI ARRSI of corn was carried out in two ecological and geographical points. The results of the study of ecological plasticity, adaptability to natural and climatic conditions, yield, harvest moisture content of grain, preservation of the viability of seeds of hybrids during storage will make it possible to identify the most adaptive early-ripening hybrids according to a set of characteristics for the conditions of the Ural region.

Keywords: corn hybrids, grain yield, grain harvesting moisture, ecological plasticity, stability, plant height.

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Introduction

Modern hybrids of corn make it possible to significantly expand crops to the north of the border of its traditional cultivation and harvest grain up to 57° north latitude. In 2020, the area of corn cultivation for grain in Russia amounted to about 2.5 million hectares, for silage – 1.4 million hectares. Corn grain was harvested in amount of 13.9 million tons. Over the past 10 years, they have grown by 35.9 % or by 3.7 million tons. The corn grain harvest for grain in 2020 approached 5.1 t/ha. Yield growth over the past 10 years amounted to 17.1 % or 0.7 t/ha.

The main share of acreage under corn for grain is concentrated in the Southern and North Caucasian federal districts. Currently, the second Corn Belt has been formed in the Central Black Earth Region, and interest in this crop has also been noted in the northern corn-sowing zone, including the Ural-Siberian region. This is due to the rather high productivity potential of corn. In the conditions of the Chelyabinsk region, the average grain yield, provided with heat and moisture resources, ranges from 4.3–5.0 t/ha in the northern forest-steppe to 4.6–5.2 t/ha in the steppe zone [1; 2]. A significant expansion of sown areas for corn cultivated both for grain and for silage, requires a reasonable selection of hybrids for a particular zone and the development of elements of varietal agricultural technology that ensures the effective realization of their potential.

The question of the hybrids resistance to environmental factors that limit the formation of potential productivity is brought to the fore. This problem is especially relevant in areas with a sharp manifestation of adverse weather conditions. Thus, the Southern and Middle Urals are characterized by significant long-term and seasonal fluctuations in air and soil temperatures; therefore, resistance to cooling temperatures and suboptimal temperatures is among the adaptive traits of hybrids [3]. The cold resistance of corn is implemented through various mechanisms, in particular, through an increased level of unsaturated fatty acids in the embryo, a pool of "stress mRNA", a high content of prolamins and their intensive hydrolysis during seed germination, and other features of plant biochemistry and physiology [4; 5]. The listed traits vary widely in the corn gene pool, which provides the source material in the breeding process for cold resistance [6].

The second most important source of stress for corn plants is periodic aridity, the probability of which in the Ural region ranges from 25 to 40 % in the northern forest-steppe to 60–70 % in the steppe zone. Therefore, the drought resistance of hybrids is a necessary condition for the realization of the genetic corn potential. This feature also belongs to the widely varying ones and is realized due to the powerful initial growth of the root system, the high ability to retain moisture in the cells of the parenchyma, the increased concentration of chlorophyll "b", the stable rate of carboxylation, the ability to quickly switch to levels of transpiration of different intensity [7–9].

Taking into account the above, the study of the hybrids reaction to stress is a very topical issue [10]. At the same time, the traits that determine the corn adaptability to negative environmental factors are polygenic, which makes it difficult to directly assess them in the field [11]. Therefore, the task of studying the rate of reaction of genotypes (varieties) to changes in external conditions can be reduced to assessing their ecological plasticity and stability.

Ecological plasticity is understood as the ability of a genotype to form high yields, good quality under various conditions, and respond to improved cultivation technology. The most effective is the selection and evaluation of the source material in terms of adaptability parameters on ecobackgrounds. In this regard, it is of particular practical interest to study the timing of sowing in various ecological and geographical points, as backgrounds that contribute to the selection of forms that combine productivity and environmental stability. With the introduction of new corn hybrids with high productivity potential into production, the issue of stabilizing their yield became acute [12–14].

The purpose of this work is to study a set of early maturing and hybrids (FAO 150-185), to assess their ecological plasticity and stability of the manifestation of productive potential in two geographical points of research for further practical use.

Methods

We studied 8 corn hybrids of the FSBSI ARRSI of corn breeding FAO 150–185 of the 2016 harvest, which underwent complete seed preparation at the corn-sizing plant. The seeds were stored in a warehouse at the plant and were sown annually in 2017–2020 on the experimental fields of the ARRSI of corn in the settlement Pyatigorskiy, Predgornyy district, Stavropol region and in the South Ural SAU in the settlement Miasskoe, Krasnoarmeyskiy district, Chelyabinsk region, with two sowing dates (early and optimal in terms of the temperature regime of each region). An ecological test was carried out according to a single method on plots with an accounting area of 23.5 m^2 in three repetitions according to a single method [15]. Phenological observations were made, the yield was recorded with the determination of the harvesting moisture content in the grain, and plants height was measured. The laboratory germination of seeds after each year of storage was studied at +20 °C, as well as by the cold germination method (cold test) – 4 days at +10 °C and then 7 days at +20 °C [16]. Field germination was assessed in the field by counting the number of shoots that appeared.

The weather conditions during the years of the experiments at the points varied considerably. At the ARRSI of corn in 2017, the amount of precipitation in May was 218 mm, which was half of the precipitation during the growing season. The abundance of precipitation in May was accompanied by lower average daily air temperatures. From June to September, the average daily air temperature was close to the average long-term values. In 2018, the temperature background in May, June and July exceeded the long-term average by 3.3–3.7 °C, the amount of precipitation was lower than the long-term average values. Hot weather conditions in 2018 and a lack of precipitation during flowering and grain filling led to an increase in infertility in all studied hybrids. The weather conditions for the entire growing season of 2019 were quite favorable for the formation of a corn grain crop. In 2020, the average air temperature regime for the period May-September exceeded the long-term average by 2.3 °C. In April, June, July and September there was a lack of precipitation. In the first and second ten days of May and the first ten days of August, the amount of precipitation exceeded the long-term average by 26 and 36 mm, respectively.

In the South Ural SAU, the vegetation conditions of 2017 were generally characterized by an uneven distribution of heat and precipitation. The largest amount of precipitation (113 mm) fell in June, warm weather was established only from the third decade of July. In May and June 2018, the temperature background was below the long-term average by 1.4–1.8 °C. In July, there was a sharp increase in air temperature to an average of 20.2 °C and was accompanied by atmospheric drought. The greatest amount of precipitation fell in August against a typical temperature background. September is warm and dry. In 2019, the lack of heat was observed in the third decade of May – the first half of June, in addition, the entire growing season took place against the background of dry phenomena: the total precipitation deficit for May-September was 61 mm. The 2020 season as a whole was characterized by a long atmospheric drought. Effective precipitation began only on July 22nd. Thus, from the third decade of June to the second decade of July, corn plants experienced the most acute lack of moisture.

The soils of the experimental plot of the ARRSI of corn are ordinary calcareous thick heavy loamy chernozem, the South Ural SAU – ordinary medium-thick medium-humus heavy loamy chernozem with a humus content in the arable layer, respectively, 4.7 and 7.6 %.

The adaptive abilities of hybrids were determined according to the methods [17].

Results

The first sowing date at the ARRSI of corn fell at the end of the first – the beginning of the second decade of April, the second – at the end of the third decade of this month. In the South Ural SAU the sowing of the first period was carried out at the end of the third decade of April, the second – in the second decade of May (Table 1).

Seedlings appeared at the ARRSI of corn, respectively, at the end of the third decade of April and at the end of the first decade of May; in the South Ural SAU at the end of the second – the middle of the third decade of May and the second term – at the end of the third decade of May and the beginning of the first decade of June.

After each year of storage, the sowing qualities of seeds were studied. In 2020, after four years of storage, the laboratory germination of corn hybrids seeds of Nur and Mashuk 170 MV was 99 and 98 %, respectively, even with cold germination. In other hybrids, this figure was in the range of 56–87 %. When seeds were germinated at +20 °C, only hybrids Ural'skiy 150 (88 %) and Bilyar 160 (79 %) turned out to be substandard. Field germination of hybrids at the ARRSI of corn in the first sowing period varied from 70 to 92 %, in the second from 85 to 97 %; in the South Ural SAU, respectively, 58–76 and 84–93 %. The lowest rates of field germination in both points of the study were found in the hybrid Bilyar 160. High coefficients of variation in the sowing qualities of seeds were noted in early sowing and cold germination (Table 2).

Table 1

Dates of sowing and emergence of corn hybrids at two dates (FSBSI ARRSI of corn, South Ural State Agrarian University, 2017–2020)

Year	First sowing date		Second sowing date	
	Sowing	Germination	Sowing	Germination
	ARRSI of corn			
2017	04/12	04/30	04/28	05/08
2018	04/13	04/30	04/28	05/07
2019	04/08	05/03	04/29	05/11
2020	04/10	04/30	04/29	05/11
	South Ural State Agrarian University			
2017	04/26	05/17	05/16	06/01
2018	05/02	05/26	05/17	06/02
2019	04/30	05/18	05/15	05/30
2020	04/24	05/21	05/14	05/28

Table 2

Laboratory and field germination of corn hybrids seeds of the harvest of 2016 after 4 years of storage, % (FSBSI ARRSI of corn, South Ural SAU, 2020)

Hybrid	Laboratory germination, %		Field germination, %			
			ARRSI of corn		South Ural SAU	
	At +20 °C	Cold-test	First sowing date	Second sowing date	First sowing date	Second sowing date
Mashuk 150 MV	93	87	80	91	69	89
Nur	99	99	92	97	76	91
Bilyar 160	79	56	46	71	55	70
Ural'skiy 150	88	83	70	85	70	85
Mashuk 170 MV	99	98	85	96	67	93
Mashuk 171	94	84	82	94	71	89
Baykal	95	81	78	87	67	84
Mashuk 185 MV	93	81	82	90	58	86
Variation coefficient, %	7.0	15.9	18.1	9.4	10.4	8.3

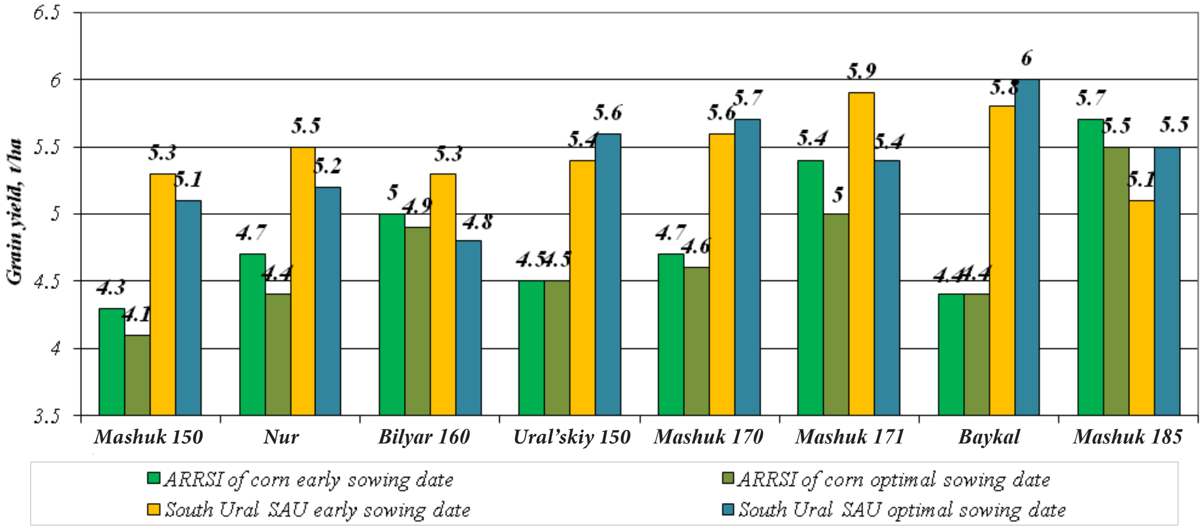

Fig. 1. The grain yield of corn hybrids at two test points at two sowing dates, t/ha, (FSBSI ARRSI of corn, South Ural SAU, on average for 2017–2020)

Table 3

Ecological plasticity and stability of corn hybrids (FSBSI ARRSI of corn, South Ural State Agrarian University, 2017–2020)

Hybrid	Plasticity, b_i				Stability, S_i^2			
	First sowing date		Second sowing date		First sowing date		Second sowing date	
	ARRSI of corn	South Ural SAU	ARRSI of corn	South Ural SAU	ARRSI of corn	South Ural SAU	ARRSI of corn	South Ural SAU
Mashuk 150 MV	0.15	0.84	0.72	0.56	0.16	0.72	0.19	0.07
Nur	0.87	0.83	0.37	1.16	0.29	0.12	0.29	0.55
Bilyar 160	0.96	1.29	1.27	0.78	0.13	0.01	0.03	0.64
Ural'skiy 150	1.22	0.91	0.97	1.12	0.32	0.15	0.003	0.24
Mashuk 170 MV	1.21	0.98	0.92	0.65	0.20	0.05	1.90	0.70
Mashuk 171	1.32	1.21	1.11	1.06	0.05	0.05	0.22	0.15
Baykal	1.55	1.18	1.22	1.22	0.07	0.06	0.09	0.78
Mashuk 185 MV	1.22	0.96	1.45	1.46	0.33	0.008	0.05	0.04

The grain yield of corn hybrids largely depends on climatic conditions by year and test point. For all early ripening hybrids (except for Mashuk 185 MV), a higher grain yield on average over four years was obtained in the South Ural SAU. The most productive were corn hybrids Mashuk 170 MV, Mashuk 171 and Baikal with a grain yield from 5.4 to 6.0 t/ha at 14 % moisture. Early ripe hybrids better realize their potential for grain yield in the northern regions. In addition, there is a tendency for the influence of sowing dates on the grain yield. For most early ripening hybrids, early terms are preferred (Fig. 1).

The plasticity and stability of hybrids genotypes were assessed by the grain yield, as the most expressive trait. The resulting yield of corn hybrids reflects the effect of growing conditions on the plant in the complex, and it can be considered the main criterion in assessing ecological plasticity and stability. To assess the plasticity of hybrids in terms of grain yield, the linear regression coefficient (b_i) was calculated. Those genotypes with $b_i < 1$ and a stability indicator (S_i^2) close to zero react weakly to improving external conditions (semi-intensive), but have fairly high yield stability. As follows from the calculation model of S. F. Eberhart, W. F. Russel (1966), the most valuable are those varieties in which $b_i > 1$, and S_i^2 tends to zero. Such hybrids are highly intensive. They are responsive to improving conditions and are characterized by stable yields. The combination of high plasticity and productivity is a particularly valuable quality of the hybrid. In our experience, among ecologically plastic forms, responsive to improving conditions, in which $b_i > 1$ in combination with a high average yield over the years, we can distinguish high-intensity hybrids: Bilyar 160, Mashuk 171 and Mashuk 185 MV (Fig. 1). Hybrids Ural'skiy 150, Mashuk 170 MV and Baykal have $b_i > 1$, in the context of all studied hybrids, a yield of 4.1–4.6 t/ha was obtained. (Table 3). Due to the fact that the regression coefficient of these hybrids is higher than one, they should be attributed to the intensive type, responding well to improved growing conditions. However, in years with unfavorable weather conditions, as well as

Table 4

Index of environmental conditions for the yield of hybrids (FSBSI ARRSI of corn, South Ural SAU, 2017–2020)

Locations	Years	Average grain yield, t/ha		Index of environmental conditions, I_j	
		First sowing date	Second sowing date	First sowing date	Second sowing date
ARRSI of corn	2017	4.90	4.77	0.03	0.09
	2018	4.26	3.82	–0.61	–0.86
	2019	4.88	5.02	0.01	0.34
	2020	5.45	5.11	0.58	0.43
South Ural SAU	2017	6.30	6.54	0.81	1.11
	2018	6.44	5.68	0.95	0.25
	2019	5.39	4.90	–0.10	–0.53
	2020	3.85	4.60	–1.64	–0.83

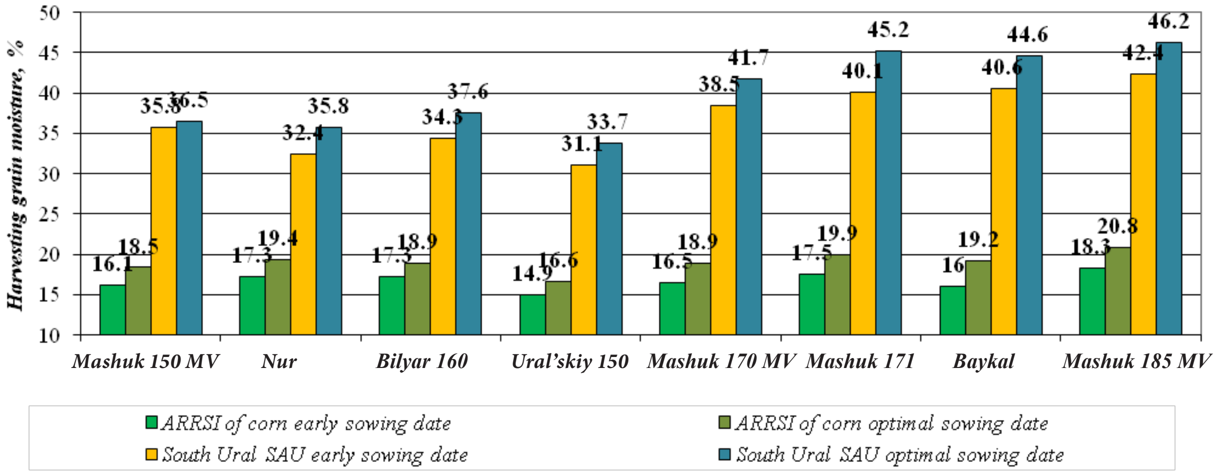

Fig. 2. Harvesting moisture content of corn hybrids, % (FSBSI ARRSI of corn, South Ural State Agrarian University, on average for 2017–2020)

on a low agricultural background, their productivity sharply decreases. Hybrids Mashuk 150 MV and Nur with low plasticity and grain yield are of no practical importance in the conditions of the south of Russia. They belong to extensive forms with low or reduced phenotypic stability.

Under the conditions of the Chelyabinsk region, the best ecologically plastic and productive, high-intensity hybrids became hybrids Baikal and Mashuk 171. Corn hybrids Nur, Ural'skiy 150, Mashuk 170 MV and Mashuk 185 MV with a linear regression coefficient $b_i > 1$ and an average grain yield of hybrids can be attributed to intensive phenotypically stable forms. Hybrids Mashuk 150 MV and Bilyar 160 are classified as extensive forms with low ecological plasticity.

The calculation of the indices of environmental conditions shows that in 2018, at the ARRSI of corn had relatively unfavorable conditions for realizing the potential of hybrids (I_j = –0.61…–0.86) at both sowing dates. In the South Ural SAU, similar conditions developed in 2019 (I_j = –0.1…–0.53) and 2020 (I_j = –1.64…–0.83) in the first and second sowing periods. This closely correlates with the low average grain yield for the entire set of hybrids (Table 4).

Harvesting grain moisture content of early ripening corn hybrids at the time of harvesting (1st decade of September) at the ARRSI of corn did not exceed 20.8 % on average for 4 years over the years of study. At the Institute of Agroecology, for the harvesting period (2nd decade of October), the harvesting grain moisture content for the same period did not fall below 31.1 % in the hybrid Ural'skiy 150. In other corn hybrids, the grain moisture content was higher (Fig. 2).

A detailed analysis of the grain moisture content of hybrids by years for the harvesting period is important for the South Ural region. The task is to identify hybrids that can achieve not only the physiological ripeness of the grain, but also the full one. Harvesting grain moisture in the first sowing period for the studied hybrids varied in 2017 within 30.4–41.3 %, in 2018 – 35.3–46.8 %, in 2019 – 30.6–41,2 %, in 2020 – 27.0–41.1 %; in the second sowing period, respectively: 33.7–44.7 %, 37.7–52.5 %, 32.2–49.7 %, 32.2–43.0 %. With regard to the harvesting grain moisture, the environmental conditions indices with negative values indicate favorable conditions for the moisture loss by the grain and, conversely, with positive ones, they indicate limited conditions that are unfavorable for grain ripening (Table 5).

An analysis of the index of environmental conditions indicates that in the South Ural region in 2018 the most unfavorable conditions for grain ripening developed both in the first and second sowing periods and in 2017 in the second sowing period (I_j = 3.04 and 6.68). Due to the lack of heat and late flowering in the early sowing period in 2018, only hybrids Nur, Mashuk 150 MV and Ural'skiy 150 reached physiological ripeness of grain at a moisture content of 35.3–36.5 %. The moisture content of other hybrids grain in the conditions of the Southern Urals was significantly higher and was in the range of 40.2–46.8 %.

The best conditions for grain maturation of hybrids developed in 2020 at both sowing dates (I_j = –4.27 and –1.01) and in the first sowing period in 2017 (I_j = –2.38). In 2020, in the corn hybrids Mashuk 150 MV, Nur, Bilyar 160 and Ural'skiy 150, grain moisture content did not exceed 33.2 % even in the second sowing period. The lowest values of this indicator for all the years of study were obtained in the hybrids Bilyar 160 (27.0 %) and Ural'skiy 150 (27.5 %).

The coefficient of variation in the plants height of corn hybrids by years at ARRSI of corn in the first sowing period was 6.4–8.3, in the second – 6.1–10.4; in the South Ural SAU, respectively – 7.0–14.5 and 7.2–14.0. The height of hybrid plants at ARRSI of corn for four years was 194–242 cm on average in the first sowing period and 190–234 cm in the second sowing period; in the South Ural SAU – 154-–195 cm and 165–204 cm, respectively (Fig. 3).

The plants height of all hybrids in the conditions of the Southern Urals at early sowing turned out to be 22–48 cm lower compared to the same period in the North Caucasus. At the optimal sowing time, this difference was less and amounted to 4–30 cm for hybrids. Only the height of the plants of the corn hybrid Bilyar 160 turned out to be almost the same (190 cm). The shortest hybrids were Mashuk 150 MV and Nur. Figure 3 clearly shows the trend of increasing the height of plants of hybrids on average over 4 years by 4–14 cm in the first sowing period compared to the second in the North Caucasus region and by 9–14 cm in the second sowing period compared to the first in the Ural region.

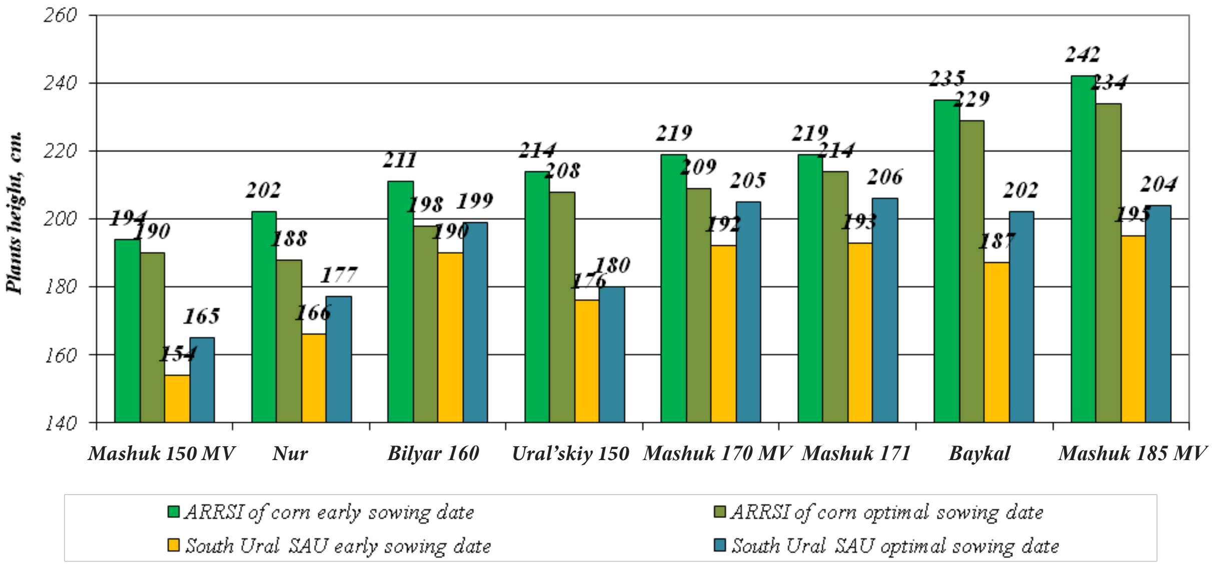

Fig. 3. Height of corn hybrids, cm (FSBSI ARRSI of corn, South Ural SAU, on average for 2017–2020)

Table. 5

Harvesting moisture content of corn hybrids, % (South Ural SAU, 2017–2020)

Hybrid	Harvesting moisture content of grain by years, %							
	First term				Second term			
	2017	2018	2019	2020	2017	2018	2019	2020
Mashuk 150 MV	31.6	36.5	34.4	30.8	33.7	40.8	38.7	33.0
Nur	30.4	35.8	33.7	29.9	33.7	38.9	37.6	33.2
Bilyar 160	36.1	40.2	34.1	27.0	39.7	43.4	36.3	31.2
Ural'skiy 150	31.2	35.3	30.6	27.5	33.8	37.7	32.2	31.2
Mashuk 170 MV	34.7	44.6	37.9	37.0	37.0	50.9	39.8	39.2
Mashuk 171	38.0	45.0	39.8	37.8	40.8	47.3	49.7	43.0
Baykal	41.3	43.1	40.3	37.6	44.7	44.8	47.9	41.0
Mashuk 185 MV	40.5	46.8	41.2	41.1	43.4	52.5	45.9	43.0
Environmental conditions index (I_j)	–2.38	3.04	–1.36	–4.27	0.49	6.68	–1.22	–1.01

Thus, the sowing seeds qualities are well preserved during storage of corn hybrids Nur and Mashuk 170 MV. Even after four years of storage, the laboratory germination of these seeds was at the level of 98–99 %. For almost all early-ripening hybrids, a higher grain yield on average over four years was obtained in the South Ural SAU. The most productive were corn hybrids Mashuk 170 MV, Mashuk 171 and Baykal with a grain yield of 5.4 to 6.0 t/ha at 14 % moisture. Under the conditions of the Chelyabinsk region, the hybrids Baykal and Mashuk 171 became the best ecologically plastic and high-intensity. Mashuk 150 MV and Bilyar 160 hybrids turned out to be extensive forms with low ecological plasticity. The lowest values of the "harvesting grain moisture" indicator, on average for all the years of study, were obtained in corn hybrids Bilyar 160 (27.0 %) and Ural'skiy 150 (27.5 %).

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Жизнеспособность семян и адаптивность раннеспелых гибридов кукурузы в условиях Южного Урала

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Аннотация. **Цель** – изучить и выделить лучшие высокоурожайные с быстрой потерей влаги зерном при созревании, экологически пластичные и стабильные гибриды кукурузы, адаптированные к условиям Южного Урала. **Методы.** Исследования проводились в 2017–2020 гг. в Северо-Кавказском и Уральском регионах РФ при максимально ранних и оптимальных сроках посева с учетом температурного режима почвы. Изучены восемь новых раннеспелых гибридов кукурузы селекции ФГБНУ ВНИИК урожая 2016 г. Лабораторную всхожесть семян определяли при температуре +20 °С по методике В. С. Сотченко и др. и методом холодного проращивания в рулонах фильтровальной бумаги после каждого года хранения. Полевую всхожесть определяли путем подсчета количества всходов после посева. Пластичность и стабильность рассчитывали по методике S. F. Eberhart, W. F. Russel. **Результаты.** После четырех лет хранения гибриды кукурузы Нур и Машук 170 МВ сохранили лабораторную всхожесть семян на уровне 98–99 % при холодном проращивании. Высокоурожайными, экологически пластичными и стабильными, относящимися к высокоинтенсивным, стали гибриды Байкал и Машук 171. Гибриды кукурузы Нур, Уральский 150, Машук 170 и Машук 185 МВ при коэффициенте линейной регрессии $b_i > 1$ и среднем урожае зерна отнесены к интенсивным фенотипически стабильным формам. В качестве адаптированных для выращивания на зерно в Уральском регионе рекомендуются гибриды Биляр 160 (27,0 %) и Уральский 150 (27,5 %) с самой низкой уборочной влажностью зерна за все годы изучения. **Научная новизна.** Впервые проведено сортоиспытание новых раннеспелых гибридов кукурузы селекции ФГБНУ ВНИИК в двух эколого-географических пунктах. Результаты изучения экологической пластичности, адаптивности к природно-климатическим условиям, урожайности, уборочной влажности зерна, сохранение жизнеспособности семян гибридов в процессе хранения позволит выделить наиболее адаптивные раннеспелые гибриды по комплексу признаков для условий Уральского региона.
Ключевые слова: гибриды кукурузы, урожай зерна, уборочная влажность зерна, экологическая пластичность, стабильность, высота растений.

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