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## Corn growing problems

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# GENOTYPE AND ENVIRONMENT INFLUENCE ON THE RATE OF GRAIN MOISTURE LOSS IN CORN DURING RIPENING PERIOD

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Abstract

High grain moisture during harvesting is a factor that restrains the expansion of corn (*Zea mays* L.) crops in the Ural region. A decrease in the harvesting moisture content of seeds is achieved by corn breeding for early maturity (early flowering of the ear) and for accelerated moisture loss from grain in the pre-harvesting period. In our study, it was found for the first time that in the conditions of southern Russia under weather conditions that weakly limit moisture losses, the harvesting moisture of corn grain is determined by the rate of pre-harvesting moisture losses while in the Ural region where the weather conditions are periodically unfavorable the moisture losses are mainly due to the early maturity of the studied hybrids. This work aims to identify corn hybrids with an increased rate of moisture loss during grain ripening and to assess this trait under unfavorable hydrothermal conditions. The studies were carried out in 2016-2018 in two contrasting geographical sites, in the foothill zone of the North Caucasus (experimental field of the All-Russian Research Institute of Corn, the settlement Pyatigorskiy, Predgornii District of the Stavropol Territory) and in the northern forest-steppe of the Southern Urals (South Ural GAU, village Miasskoye, Krasnoarmeyskiy District, the Chelyabinsk Province). Six ultra-early corn hybrids (*Zea mays* L.) Nur, Ross 130 MV, Obsky 140 SV, Kubansky 141 SV, Mashuk 150 MV, Uralskiy 150 and early ripening Bilyar 160 hybrid were involved in the study. The field experiment was arranged in triplicate using a randomized field plot layout (28 $m^2$ plots with a full set of hybrids per plot). The recorded phenological phases were germination, ear flowering and physiological ripeness of grain detected by the corn kernel "black layer" as an indicator of physiological maturity. The corn grain moisture was measured gravimetrically from July 25 to September 11 in the North Caucasus and from August 15 to October 10 in the South Urals. Samples weighting not less than 70 g were dried at 150 °C to a constant weight (a SNOL 58/350 exicator, Elektrotechnika, AB, Republic of Lithuania; a CAS MW-II electronic Weighing Scale, CAS Corporation, Republic of Korea). For analysis, 10 ears of 1.2 to 1.8 kg were collected and completely threshed in three reps. Grain sampling was carried out with a 3-7-day interval providing 8 to 16 control points. Statistical hypotheses were tested by methods of variance, correlation and regression analysis. It was found that in the northern site, the calendar dates of flowering of the ear occurred in the beginning or end of the third decade of July, that is, 22-36 days later than in the south site. In the conditions of the North Caucasus, flowering occurred in the third decade of June—early July, the grain physiological ripeness was reached during the first week of August, that is, in ultra-early maturing hybrids, grain maturation and ripening occurred under favorable hydrothermal conditions. Consequently, environmental conditions did not limit the rate of moisture loss in grain, which provided reliable estimates of the differences between hybrids according to the trait. The research revealed significant differences in the rate of moisture loss both between the sites of trials and the hybrids. In the North Caucasian region, the rate of moisture loss in grain after reaching physiological ripeness varied for hybrids from 0.63 to 0.78 % per day with slight variation over the years. Under higher relative humidity and low air temperature the likelihood of which in the pre-harvest period is high for the Ural region, the rate of moisture loss decreased to 0.21-0.35 % per day, and under favorable hydrothermal conditions it reached only 0.52-0.72 % per day. It has been established that the harvest moisture content of corn grain is associated with two main characteristics of hybrids, i.e., the early maturity and the ability to quickly lose moisture at the final stages of ontogenesis. The contribution of each factor is due to the conditions of grain ripening. I.e., for the south of Russia, grain moisture is largely due to the ability of a hybrid to accelerate moisture losses. On the contrary, in the conditions of the Southern Urals, the early flowering of the ear is of primary importance. Differences between hybrids in the rate of moisture loss under these conditions appear irregularly and are often leveled by the influence of the environment. Therefore, for the northern zone of corn sowing, the corn breeding for its ability to rapidly lose moisture from grain makes sense only in combination with breeding for a short growing season which should be considered as a priority trait when creating adapted hybrids.

Keywords: corn, hybrids, ultra-early maturity, ontogenesis, vegetation period, grain moisture, moisture loss rate, Southern Urals, Northern Caucasus

One of the tendencies in developing corn sowing in Russia is the expansion of the sowing of this crop in the northern direction, including in the vast and diverse Ural region in terms of the complex of limiting factors. This process is held back by the high level of grain moisture during harvesting. The most severe restrictions on the maximum level of harvesting moisture content (25-30%) arise when harvesting grain with thermal drying, which is intended for long-term storage [1]. The efficiency of producing alternative types of feed from corn (preserved wet grain and high-energy silage) also depends on the moisture content in grain due to the close correlation between this parameter and the rest of the chemical composition of the caryopsis, including starch, the main target component for growing crops [2-5].

The main way to reduce grain moisture in the field conditions is the selection of early maturity corn. Depending on the growing area and the purpose of crops (for silage or grain), the hybrids adapted for the Urals should be characterized by numbers from 110 to 170 units FAO [6, 7]. The creation of hybrids with early flowering is a significant part of Russian programs for the selection of corn [8]. In world breeding, this direction develops locally, mainly to fill northern ecological niches [9-11]. Most foreign publications indicate high potential productivity [12-15], resistance to drought [2, 16-18], and resistance to cold [19, 20] as the main goals of corn breeding. It is noted that the final feature is indirectly related to the problem of reducing the harvest moisture content of grain, since it ensures the stable development of corn in the conditions of low temperatures.

When creating ultra-early samples of corn, recurrent selection for early flowering from industrial hybrids or hybrids, specially created for this purpose, as well as from local populations with high genetic diversity for various traits, can be used [10, 21, 22]. Isolated populations, donors of a wide range of economically useful traits, are of particular value [23]. Formed under the influence of long-term artificial and natural selection, they serve as potential sources of early maturity [24].

The modern development of early maturity selection ensures the guaranteed achievement of physiological ripeness by the corn grain practically up to 56° northern latitude. However, even in ultra-early hybrids of the FAO 130-150 ripening class, adapted for regions with scarce heat resources, the harvest moisture content of grain under the influence of hydrothermal conditions varies widely and acquires the values, at which thermal drying is associated with unreasonably high costs [25].

As a supplementary or alternative direction, providing the regulation of grain moisture content during the ripening period, the selection of corn for accelerated moisture loss in grain is considered [26-29]. The ability of corn grain to quickly yield moisture is a polygenic trait due to a complex of morphological and physiological characteristics of the genotype: endosperm type (odontoid, siliceous, or intermediate), grain size, the density of wrapping leaves of an ear, ear height above the soil surface, core thickness, and tolerance to suboptimal temperatures [29-32]. A high variation in the rate of moisture loss, from 0.5 to 1.3% per day, was noted both in industrial hybrids and in self-pollinated lines [33-36].

The process of reducing grain moisture in the pre-harvesting period takes place in two stages. Before the onset of physiological ripeness, it is due to the accumulation of organic matter in the endosperm and depends mainly on the air temperature. After physiological ripeness, moisture is lost due to physical evaporation, the rate of which is strongly inversely related to the relative humidity of the air and the amount of precipitation [31, 37, 38]. As a result of the complex interaction between the genotype and the environment, unstable dynamics of moisture loss are observed. Thus, under conditions that do not limit the physiological and physical processes of moisture loss, the intensity of moisture yield in specific samples is reproduced quite stably and varies slightly over the years [29, 31, 39]. However, an unfavorable hydrothermal background can neutralize the manifestation of the genetic characteristics of hybrids [40]. Excessive moisture during this period negatively affects the dynamics of grain moisture, even in hybrids with a potentially high capacity for moisture loss.

The difficulty in breeding corn for accelerated moisture loss in grain is that it is often associated with a decrease in the overall adaptability of plants to unfavorable environmental factors, in particular to water stress [29]. Nevertheless, the instability of the negative correlation between the harvesting moisture and grain yield is noted, which allows for positive selection for both traits and the creation of hybrids with a quick moisture loss without a decrease in the yield [37].

For the northern zone of corn cultivation, the effectiveness of the selection for the ability to accelerate moisture loss in grain has not been determined, and the likelihood of manifesting the genetic potential of hybrids for this trait in the Urals requires an experimental assessment against the background of fluctuations in hydrothermal conditions, which are typical for the region.

In this study, it was established for the first time that in the south of Russia, under weather conditions that weakly limit the moisture loss in corn grain, its harvest moisture was determined by the moisture loss rate in the pre-harvest period, while in the Ural region, given a periodically unfavorable weather background, it was mainly due to the early maturity of the studied hybrids.

The work aimed to identify corn hybrids with an increased rate of moisture loss during grain ripening and to assess the manifestation of this trait under unfavorable hydrothermal conditions.

*Materials and methods.* The studies were conducted in 2016-2018 in two contrasting geographical points (the foothill zone of the North Caucasus, the experimental field of the All-Russian Research Institute of Corn, Pyatigorskyi settlement, Predgorny District, the Stavropol Territory and in the northern forest-steppe of the Southern Urals, Southern Ural GAU, village Miasskoye, Krasnoarmeysky District, the Chelyabinsk Province) on six ultra-early corn hybrids (*Zea mays* L.) Nur, Ross 130 MV, Obsky 140 SV, Kubansky 141 SV, Mashuk 150 MV, Uralskiy 150, and early ripening Bilyar 160. The field trials were arranged in triplicate according to randomized design with 28 $m^2$ plots. Sowing dates in the North Caucasus were decade 3 of April, in the Southern Urals decade 2 of May. The actual plant density with manual formation was 70,000/ha. The phases of germination, flowering of the ear, and physiological ripeness of the grain were registered, the onset of which was judged by the appearance of a dark layer at the base of the caryopsis [30, 31]. The moisture content of grain in the North Caucasus was estimated from July 25 to September 11, in the Southern Urals from August 15 to October 10.

The moisture content of the grain was determined by the gravimetric method. The samples with a mass of at least 70 g were dried at a temperature of

150 °C (drying oven SNOL 58/350, Elektrotechnika, AB, Lithuania) to constant weight (it was determined using an electronic weighing scale CAS MW-II, CAS Corporation, Republic of Korea). For the analysis, 10 average ear samples weighing from 1.2 to 1.8 kg were taken and completely threshed in 3 repetitions. When choosing a method, the authors were guided by the criterion of the minimum measurement error. The periodic grain sampling was conducted with an interval of 3-7 days, which provided from 8 to 16 control points.

The statistical hypotheses were tested by the methods of variance, correlation and regression analyses. The reliability of the differences between the mean for the variants was assessed by Fisher's test (*F*) and the least significant difference (LSD). The moisture loss rate in grain was calculated as the linear regression coefficient ($b_i$) of grain moisture at the *i*-th observation dates. The significance of the correlation and regression coefficients was assessed by the magnitude of the errors of these parameters ($S_r$, $S_b$) and Student's *t*-test. The standard deviation (S) was used to assess the intragroup variation in the values of harvest moisture. The level of significance of the critical values of statistical parameters is $p = 0.05$. For the statistical analysis, we used the Data Analysis add-in of the Microsoft Excel 2016 spreadsheet processor.

*Results.* During the years of research, the average monthly air temperature in the North Caucasus exceeded the same indicator in the Southern Urals in May by 3-8 °C, in July and June by 3-7 °C, and in August and September by 5-9 °C (Table 1). Monthly precipitation totals in both areas varied within significant limits, but their minimum was observed in the Caucasus region in August and September. This annually led to a decrease in the relative humidity of the air by the end of the vegetation period. In the Urals, a more uniform distribution of precipitation over months was observed, which, at a low temperature, caused a steady increase in air humidity during the period of grain ripening. The noted differences provided a more favorable background for plant development, accumulation of dry matter in grain, and a decrease in its moisture content in the pre-harvest period in the North Caucasus.

**1. Weather conditions in the geographical areas of the study of corn (*Zea mays* L.) hybrids for moisture content in grain**

| Month | North Caucasus | | | Southern Urals | | |
|---|---|---|---|---|---|---|
| | 2016 | 2017 | 2018 | 2016 | 2017 | 2018 |
| | Average monthly air temperature, °C | | | | | |
| May | 17.9 | 13.8 | 17.9 | 12.0 | 10.7 | 9.8 |
| June | 22.3 | 18.8 | 21.6 | 16.5 | 16.2 | 14.6 |
| July | 25.8 | 23.1 | 24.5 | 18.8 | 18.0 | 20.2 |
| August | 27.3 | 22.4 | 21.3 | 18.3 | 17.4 | 15.9 |
| September | 18.7 | 18.5 | 19.5 | 11.2 | 9.7 | 11.3 |
| | Monthly precipitation, mm | | | | | |
| May | 93 | 218 | 80 | 16 | 60 | 40 |
| June | 134 | 61 | 79 | 78 | 113 | 60 |
| July | 46 | 56 | 65 | 40 | 91 | 37 |
| August | 0 | 25 | 39 | 56 | 26 | 95 |
| September | 9 | 8 | 20 | 38 | 16 | 19 |
| | Average monthly relative air humidity, % | | | | | |
| May | 50.9 | 50.8 | 52.0 | 50.6 | 51.3 | 60.6 |
| June | 52.8 | 54.6 | 56.4 | 64.3 | 61.2 | 64.7 |
| July | 64.1 | 62.6 | 61.0 | 69.6 | 69.0 | 73.2 |
| August | 62.7 | 59.2 | 59.4 | 72.8 | 71.2 | 83.4 |
| September | 58.8 | 57.4 | 58.8 | 73.7 | 71.9 | 74.1 |

In the North Caucasus region, full corn seedlings were observed 8-16 days after sowing, depending on the rate of soil warming, while in the Southern Urals after 21-23 days. In 2016-2017, the further development of plants up to the flowering phase of the ear took place against a relatively favorable temperature background, thus the duration of the period from the germination to this phase in both climatic zones was comparable (54-58 days). The exception was 2018, when, under a heat deficit under the conditions of the Urals, this period was 10 days longer on average. The early ripening hybrid Bilyar 160 was distinguished by the longest period from germination to flowering of the ear, the rest of the samples developed 3-4 days earlier and did not show significant differences in flowering dynamics within the ultra-early group. The calendar flowering dates in the northern research point occurred 18-40 days later than in the south of the country and fell on the third decade of July—early August (Table 2). In the conditions of the North Caucasus, flowering was observed in the third decade of June—early July. The grain reached physiological ripeness in the period from August 1 to 7, and the processes of maturation and filling of ultra-early hybrids took place under a favorable combination of air temperature and humidification. Consequently, the weather conditions in the south of the country did not limit the moisture loss rate in grain, which provided an objective assessment of the differences between hybrids according to the studied trait.

**2. Dates of ear flowering and physiological ripeness in corn (*Zea mays* L.) hybrids assessed by the moisture loss rate in grain in two geographical zones** (2016-2018)

| Hybrid | Southern Urals | | | North Caucasus | | |
|---|---|---|---|---|---|---|
| | 2016 | 2017 | 2018 | 2016 | 2017 | 2018 |
| Date of ear flowering | | | | | | |
| Obsky 140 SV | 20.07 | 28.07 | 07.08 | 27.06 | 03.07 | 30.06 |
| Kubansky 141 SV | 20.07 | 28.07 | 07.08 | 27.06 | 03.07 | 30.06 |
| Nur | 19.07 | 27.07 | 05.08 | 26.06 | 02.07 | 28.06 |
| Mashuk 150 MV | 20.07 | 28.07 | 06.08 | 27.06 | 01.07 | 28.06 |
| Ross 130 MV | 20.07 | 28.07 | 07.08 | 27.06 | 02.07 | 29.06 |
| Uralsky 150 | 19.07 | 27.07 | 08.08 | 27.06 | 03.07 | 31.06 |
| Bilyar 160 | 23.07 | 31.07 | 11.08 | 30.06 | 06.07 | 02.07 |
| Date of physiological ripeness of grain | | | | | | |
| Obsky 140 SV | 12.09 | 13.08 | 09.10 | 02.08 | 01.08 | 02.08 |
| Kubansky 141 SV | 12.09 | 14.08 | 09.10 | 04.08 | 02.08 | 02.08 |
| Nur | 11.09 | 13.08 | 10.10 | 04.08 | 01.08 | 02.08 |
| Mashuk 150 MV | 12.09 | 14.08 | 10.10 | 03.08 | 01.08 | 02.08 |
| Ross 130 MV | 11.09 | 13.08 | 10.10 | 04.08 | 02.08 | 03.08 |
| Uralskiy 150 | 12.09 | 14.08 | 11.10 | 04.08 | 03.08 | 03.08 |
| Bilyar 160 | 15.09 | 17.08 | – | 07.08 | 05.08 | 06.08 |

Note. A dash means that the hybrid has not reached the corresponding development phase.

In breeding, methods for determining moisture content that do not violate the integrity of the caryopsis are preferable, for example, using contact digital moisture meters [31]. Without limitations in the volume of the examined material, when choosing a method, the authors were guided by the criterion of the minimum measurement error with the number of control points from 8 to 16. The methods of similar studies based on 2-4 observation sites [29, 31], according to our opinion, replace the stochastic nature of the dependence with a functional one or unreasonably underestimate the variance of the regression.

It should be noted that by the time of the onset of physiological ripeness of the grain under specific vegetation conditions, no significant differences were found between the hybrids. According to Fisher's test, the fluctuations in grain moisture were statistically proven only for geographical points, while there was a tendency to its decrease in the south. Thus, in the conditions of the Southern Urals, grain moisture in 2016 varied from 37.4 to 41.7%, in 2017 from 39.2 to 42.0%, in 2018 from 38.5 to 41.9%; in the North Caucasus from 33.9 to 36.4%, from 36.3 to 39.6%, and from 33.9 to 36.8%, respectively.

The influence of environmental conditions on the moisture content in the corn grain when it reaches physiological ripeness is noted in various climatic zones. Thus, against the arid background of Canada, by the onset of this phase, the moisture content of grain decreases to 30% [31], in the Central Black Earth

Region of Russia to 35-38% [33, 40], in the conditions of the Southern Urals only to 40-42% [41]. The obtained data are within the range of these fluctuations.

Based on the results of analysis of variance of the data in the North Caucasus in 2016, four groups of hybrids were identified according to their moisture loss (Table 3). The first group includes the only hybrid Bilyar 160, which is characterized by the maximum dynamics of moisture loss; the second one comprised Uralskiy 150, Mashuk 150 MV, and Kubansky 141 SV with a medium rate of moisture loss; the third one was Ross 130 MV and Obsky 140 SV with moderate ability; the fourth one was the Nur hybrid, which was characterized by the minimum moisture loss rate.

**3. Characterization of corn (*Zea mays* L.) hybrids by the rate of moisture loss form grain** (% per day) **after reaching physiological ripeness** (North Caucasus, $b_i \pm S_b$, 2016-2018)

| Hybrid | Year | | | Averaged |
|---|---|---|---|---|
| | 2016 | 2017 | 2018 | |
| Nur | 0.58±0.03 | 0.73±0.05 | 0.69±0.05 | 0.67±0.03 |
| Ross 130 MV | 0.64±0.06 | 0.64±0.11 | 0.61±0.05 | 0.63±0.04 |
| Obsky 140 SV | 0.66±0.07 | 0.64±0.06 | 0.64±0.04 | 0.65±0.04 |
| Kubansky 141 SV | 0.71±0.09 | 0.74±0.06 | 0.69±0.05 | 0.71±0.03 |
| Mashuk 150 MV | 0.71±0.07 | 0.76±0.04 | 0.67±0.05 | 0.71±0.03 |
| Uralskiy 150 | 0.70±0.09 | 0.71±0.09 | 0.67±0.06 | 0.69±0.03 |
| Bilyar 160 | 0.81±0.11 | 0.81±0.05 | 0.72±0.07 | 0.78±0.05 |
| $LSD_{05}$ (hybrids) | 0.04 | 0.07 | 0.03 | 0.04 |
| $LSD_{05}$ (years) | – | – | – | $F_{observed} < F_{05}$ |
| $LSD_{05}$ (interaction) | – | – | – | $F_{observed.} < F_{05}$ |

N o t e. The dashes mean that when analyzing the results for some years, the LSD values were not calculated.

A similar distribution of samples was observed in 2017 and 2018, except that the Nur hybrid was included in the second group, showing an average moisture-yielding capacity. A fairly stable manifestation of the trait was established: for most hybrids, the differences in the moisture-yielding rate by years were insignificant and were not statistically proven by Fisher's test ($F_{observed} = 2.87 < F_{05} = 3.23$). This fact, as well as the obviously favorable hydrothermal background, against which the final processes of grain ripening took place, allow concluding that the differences between hybrids in terms of the moisture loss rate are mainly due to their genetic characteristics and reflect the results of selection for this trait. Similar conclusions are made by Reid et al. [31] and Wang et al. [32]. In the studies, conducted in the Primorye Territory [26] and North China [28] using mid-season and mid-late hybrids, daily moisture loss values of more than 1% were achieved, which is significantly higher than the maximum value obtained in the authors' studies (0.81%). With a high probability, these discrepancies can be explained not only by the growing conditions but also by the use of hybrids of different maturity classes [34].

Fundamentally different conclusions follow from similar observations, carried out in the forest-steppe of the Chelyabinsk Region. Under the conditions of this region, two stages of pre-harvesting moisture dynamics were observed. As it was already noted [37], in the first of them, which lasts from the beginning of grain formation to physiological ripeness, the moisture decrease rate is due to the intensity of accumulating organic matter in the endosperm and depends mainly on the air temperature. At the second stage (from physiological to full ripeness), moisture loss is inversely related to the relative humidity of the air and the amount of precipitation [31, 37]. At the second stage, the influence of external conditions on the moisture-yielding rate is mediated by the morphological features of the hybrids [29].

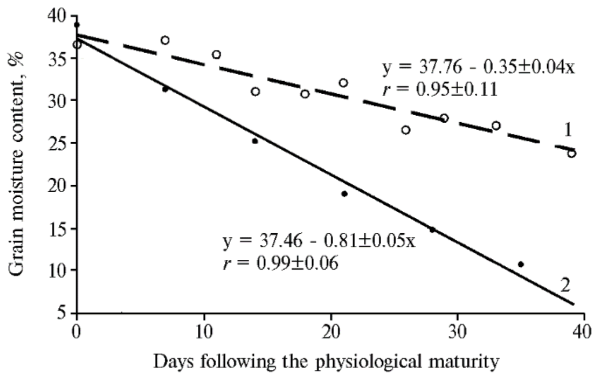


**Fig. 1. Grain moisture in a corn (*Zea mays* L.) hybrid Bilyar 160 depending on the time interval after the physiological ripeness occurred in two geographical zones:** 1 — Southern Urals, 2 — North Caucasus (2016).

As a consequence of the later flowering, the physiological ripeness of grain in the Ural region was reached in mid-late September (see Table 2), and a further decrease in moisture content was likely to occur against a background of low temperatures, high air humidity, and frequent precipitation. As a result, as established by the example of the hybrid Bilyar 160 in 2016, grain lost moisture more than 2 times slower than in the North Caucasus (Fig. 1). This may be associated not only with a slowdown in the current moisture yield but also with the sorption of moisture by grain due to precipitation [39].

**4. Characterization of corn (*Zea mays* L.) hybrids by the rate of moisture loss form grain** (% per day) **after reaching physiological ripeness** (Southern Urals, $b_i$±$S_b$, 2016-2018)

| Hybrid | Year | | | Averaged |
|---|---|---|---|---|
| | 2016 | 2017 | 2018 | |
| Nur | 0.23±0.02 | 0.55±0.09 | 0.18±0.03 | 0.32±0.20 |
| Ross 130 MV | 0.23±0.02 | 0.53±0.12 | 0.19±0.02 | 0.32±0.19 |
| Obsky 140 SV | 0.21±0.03 | 0.53±0.14 | 0.18±0.03 | 0.31±0.19 |
| Kubansky 141 SV | 0.22±0.02 | 0.52±0.06 | 0.21±0.04 | 0.32±0.18 |
| Mashuk 150 MV | 0.24±0.02 | 0.58±0.10 | 0.17±0.02 | 0.33±0.21 |
| Uralsky 150 | 0.24±0.03 | 0.58±0.06 | 0.19±0.04 | 0.34±0.21 |
| Bilyar 160 | 0.35±0.03 | 0.72±0.07 | No data | No data |
| $LSD_{05}$ (hybrids) | 0.06 | 0.07 | $F_{observed} < F_{05}$ | 0.03 |
| $LSD_{05}$ (years) | – | – | – | 0.02 |
| $LSD_{05}$ (interaction) | – | – | – | $F_{observed} < F_{05}$ |

N o t e. The dashes mean that when analyzing the results for some years, the LSD values were not calculated.

The distribution of hybrids according to the moisture-yielding rate was also different. By the method of two-way analysis of variance using Fisher's criterion, the reliability of the interaction was proved by the factors “geographic location” and “genotype”. That is, the differences between the hybrids in terms of moisture-yielding dynamics were due to the state of the external environment, which is indirectly confirmed by the data by Ghete et al. [27]. The main feature identified for the Ural region according to 2016 data was that only two groups of hybrids were reliably identified according to the target trait (Table 4). The first group with a high moisture loss rate (0.35%/day), as in the North Caucasus, was represented by one hybrid Bilyar 160. The rest of the samples were characterized by a relatively slow moisture loss (from 0.21 to 0.24%/day). The same distribution of hybrids was observed in 2017, despite the fact that the moisture-yielding rate was 2-2.5 times higher. In 2018, due to a significant shortage of heat during the vegetation period and late flowering, physiological ripeness was achieved by grain only by the end of the observation period, which did not allow revealing any peculiarities in the behavior of hybrids. For the hybrid Bilyar 160, the grain of which under these conditions did not reach physiological ripeness, the data on moisture loss in the last year of observations were not obtained.

The analysis of scientific publications confirms a significant variation in the moisture-yielding rate in corn grain due to the morphological features of the hybrids. Thus, in the studies by Wang et al. [28], Reid et al. [31], and Voronina et al. [33], the differences between breeding samples for this trait were 0.22-0.24%/day. Ghete et al. [27] report fluctuations in moisture loss in inbred lines from 0.6 to 2.2%/day. It is noted that these results were obtained in traditional grain corn growing zones (to the south of 50° northern latitude). For more northern regions, no experimental data were found on the considered problem in the scientific literature.

The results of our research allow concluding that the ability of corn hybrids to accelerate moisture loss in grain is quite fully manifested against a favorable hydrothermal background, while against the background of excessive moisture in combination with a low temperature, the manifestation of this trait is suppressed. Therefore, in the northern zone of corn cultivation, one should periodically expect a leveling of the harvest moisture content of grain in hybrids of the same ripeness group.

The only exception can be made only by some genotypes, sharply differing in terms of the discussed trait. However, even for these samples, under conditions of a general heat deficit, genetic features are manifested irregularly. Thus, in the authors' study, the ability of the hybrid Bilyar 160 to quickly yield moisture was most fully manifested in the form of a minimum moisture level only in 2016 (Table 5). The next two years were characterized by a more or less pronounced delay in the development of all hybrids. Under these conditions, against the background of the shortened period from reaching physiological ripeness to the end of the vegetation period, the early maturation of the hybrids played a more significant role, which ensured the minimum grain moisture in the hybrid Uralskiy 150.

**5. Grain moisture (%) at harvesting in corn (*Zea mays* L.) hybrids depending on vegetation conditions and a genotype** (two **geographical zones**, $M$±S, 2016-2018)

| Hybrid | North Caucasus | | | Southern Urals | | |
|---|---|---|---|---|---|---|
| | 2016 | 2017 | 2018 | 2016 | 2017 | 2018 |
| Нур | 19.6±0.8 | 17.9±2.4 | 14.6±1.3 | 26.9±0.6 | 34.4±1.9 | 41.3±2.6 |
| Росс 130 МВ | 18.5±1.3 | 16.4±2.1 | 15.1±1.7 | 26.9±0.7 | 32.2±1.6 | 41.4±3.7 |
| Обский 140 СВ | 17.8±1.7 | 18.2±2.6 | 14.9±2.3 | 25.6±1.0 | 33.3±1.8 | 41.7±2.1 |
| Кубанский 141 СВ | 17.9±0.5 | 17.1±2.0 | 14.3±2.5 | 25.4±0.3 | 33.8±2.1 | 39.8±2.2 |
| Машук 150 МВ | 17.6±0.9 | 17.8±3.2 | 14.8±2.3 | 26.3±0.5 | 34.4±1.6 | 41.9±3.4 |
| Уральский 150 | 16.1±1.1 | 16.2±2.8 | 12.8±2.4 | 25.2±0.9 | 31.4±2.2 | 38.5±2.8 |
| Биляр 160 | 15.5±1.6 | 17.5±1.6 | 14.4±2.1 | 23.7±0.9 | 34.9±1.2 | 43.5±4.3 |
| НСР$_{05}$ | 0.6 | $F_{факт.} < F_{05}$ | $F_{факт.} < F_{05}$ | 1.2 | 1.4 | 1.5 |

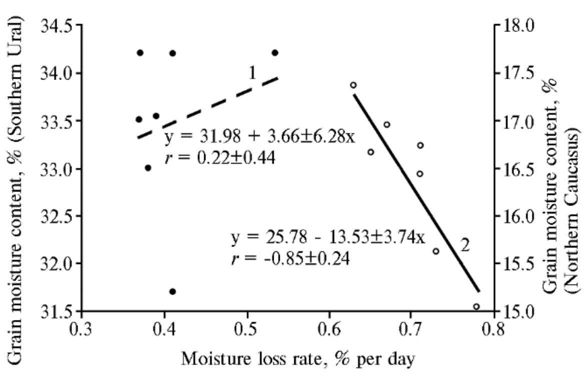


**Fig. 2. Corn (*Zea mays* L.) grain moisture at harvesting vs. the rate of moisture loss after reaching physiological ripeness in two geographical zones:** 1 — Southern Urals, 2 — North Caucasus (2016-2018).

An important consequence arising from the results of the conducted studies is the fundamentally different effect of the moisture loss rate on the harvest moisture content of grain in contrasting climatic conditions. As shown by the correlation and regression analysis, a close inverse dependence of the harvest moisture content of grain on the rate of moisture loss was observed only in the North Caucasus region (Fig. 2). These results confirm the conclusions by Wang et al. [28] for North China, Sala et al. [29] for Argentina and Reid et al. [31] for Canada.

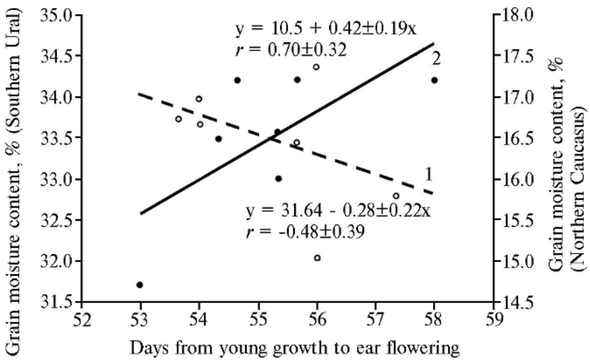


**Fig. 3. Corn (*Zea mays* L.) grain moisture at harvesting vs. time period from seedlings to ear flowering in two geographical zones:** 1 — Southern Urals, 2 — North Caucasus (2016-2018).

Under the conditions of the Southern Urals, this relationship was characterized as weak, and the main trait that depended on the moisture content of the grain during harvesting was the rapidity of the hybrids, defined as the duration of the period from germination to flowering of the ear (Fig. 3). In the North Caucasus, the dependence of humidity on the duration of the period "germination—ear flowering" was poorly expressed, with a statistically unproven significance of the correlation coefficient ($t_r < t_{05}$).

Thus, the harvest moisture content of grain of corn hybrids is associated with two main features: early maturity and the ability to rapidly lose moisture at the final stages of ontogenesis. The contribution of each of these traits is determined by the conditions of plant vegetation and grain ripening. For the south of Russia, characterized by a favorable hydrothermal background in the pre-harvesting period, grain moisture is largely due to the genetic ability of the hybrid to accelerate moisture yield. Under these conditions, the rate of moisture loss in grain after reaching physiological ripeness varies for hybrids on average from 0.63 to 0.78% per day. On the contrary, in the Urals, with high relative humidity and low air temperature in the pre-harvest period, early flowering of the ear is of primary importance. Against this background, the moisture yield rate decreases to 0.21-0.35% per day under unfavorable hydrothermal conditions and to 0.52-0.72% per day under favorable conditions, and the differences between hybrids appear irregularly and are often leveled by the influence of the environment. Consequently, for the northern zone of corn sowing, the selection of corn for its ability to rapidly lose moisture in grain makes sense only in combination with selection for a short vegetation period, which should be considered as a priority trait when creating adapted hybrids. According to the results of the authors' research, an ultra-early hybrid Uralskiy 150 can be recommended for cultivation in the Southern Urals, which is characterized by early flowering in combination with a moderate loss of grain moisture in the pre-harvesting period. The high moisture-yielding ability, established for the early ripening hybrid Bilyar 160 in the North Caucasus, does not provide a consistently low harvest moisture content of grain in the Ural region.

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