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DEPENDENCE OF THE GRAIN FILLING INTENSITY AND MOISTURE-YIELDING ABILITY ON VALUABLE ECONOMIC FEATURES IN CORN

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Based on results on the dependence of the corn grain filling intensity and moisture-yielding ability of corn grain on morphological and economic characteristics, lines - sources were selected in each ripeness group. In the medium-early group, eight lines with high moisture-yielding ability and grain filling intensity were selected. In the medium-early group, the majority of lines were superior to the reference accession (UKh 52) in terms of performance (by 8-90%) and thousand grain weight (by 12-28%). In the medium-ripening group, 24 best lines were selected. In the medium-late group, 25 lines were selected due to rapid moisture release.

***Key words**: Zea mays, lines, morphological features, moisture-yielding ability, grain filling intensity*

Introduction. The problem of corn grain provision in Ukraine should be solved in several directions: by enhancing grain production via increased yields of hybrids and their adaptability to environmental stressors and by enlarging acreage and applying state-of-art cultivation technologies [1-3].

Reduction in harvest moisture content in corn grain is an important area in current corn breeding; it is capable of ensuring significant energy savings and, thereby, increasing production profitability and economic efficiency of corn cultivation [4].

Methods of genetic control of quantitative and qualitative traits and their adaptive potentials, determination of breeding value, and selection of sources and donors among accessions of the corn gene pool, which were developed at the Yuriev Plant Production Institute, can significantly raise the breeding efficiency [5].

In the agrobiological conditions of the forest-steppe and steppe zones of Ukraine generally, the crop can fulfill its yield potential. Climate changes in Ukraine have had a positive effect on the yields of late spring crops, in particular corn, the performance of which has increased on average by 1.0 t/ha over the past 24 years. A decrease of 7.0% in the harvest moisture content in grain was recorded in hybrids during this period. Morpho-physiological and heterosis models of intensive corn hybrids for various agro-climatic zones with programmed grain yields were developed and implemented; such hybrids have a set of valuable economic characteristics and can yield a lot (16-17 t/ha of grain). They are noticeable for intensive moisture release by grain during ripening and highly resistant to major diseases and pests. In addition, they are less energy-consuming due to better efficiency of using irrigation water and mineral fertilizers [6].

Reduction in grain moisture content is divided into two stages, which are related to the physiological processes of ripening in different ways. The first stage lasts until grain filling completion and the moisture content in grain decreases to 32-35%. The second stage is mainly related to the physical processes of drying of grain as a capillary-porous heterogeneous structure. Breeders usually try to reduce the first period, that is, to accelerate the moisture release, which is genetically determined at this stage [7]. It is believed that there are no clearly defined genetic factors that are responsible for the moisture release by grain after it reaches physiological ripeness and that this process is indirectly influenced by many morphological features (the number and density of sheaths of corn ears, cob diameter, orientation of the ear in space) and biochemical composition of grain (the ratio of floury to horny endosperm).

The moisture content in seeds decreases as the corresponding phases of corn plant development elapse. Before physiological ripeness, the moisture content in seeds decreases due to evaporation and accumulation of dry matter in seeds as a result of grain filling. After physiological ripeness (defined by the appearance of a black layer), moisture is released mainly due to evaporation of water from seeds. Water release by seeds in the field is linear in the moisture content range from 40% to 15-20%, after which the moisture egress almost stops. The exact level of moisture release specifically depends on hybrids and weather.

Under favorable weather conditions, all hybrids have similar levels of moisture release, but when weather conditions do not favor rapid water egress, hybrids that are able to release moisture fast have an advantage.

Several parameters that have the greatest influence on the field moisture-yielding ability have been defined. The relative contribution of one or another parameter to intensive moisture release changes over time and, as already indicated, is most noticeable under unfavorable weather conditions for water egress (cool, cloudy, and rainy weather and low temperatures after physiological ripeness).

It is noteworthy that the pericarp structure (tissue surrounding the embryo) is a very important characteristic for moisture-yielding ability. A thinner, in other words, easier to penetrate, pericarp more easily releases water. In addition, moisture release depends on the number of sheath leaves. The fewer sheath leaves the ear has, the more easily it releases water. Observations prove that recently bred hybrids have fewer sheath leaves than hybrids that were bred decades ago. The thickness of sheath leaves also affects moisture egress; it is usually more intensive in hybrids with thinner sheaths. The faster the sheath leaves of the ear die (dry out), the higher the moisture-yielding ability. Hybrids with loose sheaths have a higher moisture-yielding ability. The lean rate of ears after physiological ripeness also affects moisture egress. The faster ears lose their upward orientation, the faster they release moisture, in particular, if ears remain upward, they absorb autumn precipitation.

Another point is worth noting: grain does release water when kernels are attached to the cob. Grain releases moisture via evaporation. It was found that after physiological ripeness grain did not release water by draining it to the cob. After the tissue at the ear top dies (formation of the black layer), any connections between kernels and the cob cease.

Climatic conditions have the greatest influence on harvest moisture content in grain. Temperature, precipitation, and solar activity affect the speed of grain drying out. After seed filling is complete. weather has the greatest influence on the rate of moisture release in the field. On average, the sum of effective temperatures of 20-25^{o} is necessary for grain to lose 1% of moisture content. Thus, a number of factors affect moisture-yielding ability and farmers have to find a balance between the desire to harvest corn as dry as possible and losses from lodging because of late harvesting [8].

Hence, our purpose was to analyze the dependence of the corn grain filling intensity and moisture-yielding ability of corn grain on morphological and economic characteristics. In addition, our objective was to select lines - sources with intensive grain filling, rapid moisture release and combinations of these features.

Material and Methods. The study was carried out in the Laboratory of Introduction and Preservation of Plant Genetic Resources and the Laboratory of Corn Breeding and Seed Production of the Yuriev Plant Production Institute of NAAS in 2017-2019. The accessions were sown by the standard method in two-row plots of 9.8 m^2 in three replications. The reference accessions were placed after every 20 plots: early ripening - F2 line; medium-early – UKh 52; medium-ripening - DS 103, UKhS 126, and SO 125; medium-late - A 619, Kharkivska 215, and KhA 408.

During the growing period, the accessions were evaluated in the field 24 times for typicality and uniformity in terms of plant height and ear parameters. The following morphological characteristics were measured: plant height, leaf number per plant, length and number of branches per tassel, and stem and ear numbers per plant. The following valuable economic characteristics were determined: performance constituents (ear number per plant, ear length, number of kernel rows, number of kernels per row, and thousand grain weight), resistance to lodging, ear drooping, diseases, pests, etc.

The experiments were conducted in accordance with "Methodological Guidelines for Field and Laboratory Studies of Corn Genetic Resources" [9].

The filling intensity and grain drying rate were investigated in more details by specific morphological characteristics, viz. number of leaves above the ear, peduncle length, number of nodes per peduncle, number of sheath leaves, density of their adhesion to the cob (visual assessment), and their condition at the time of full ripenness of grain.

When we analyzed the intensity of grain filling, we evaluated the contributions of the morpho-biological characteristics (plant height above the ear, number of leaves above the ear, number of internodes per peduncle, etc.) to this parameter and its relationships with the economic characteristics, which determine the performance (ear length, number of rows, number of kernels per row, etc.). Corn lines with intensive grain filling and a set of valuable economic features were selected [10].

In the laboratory, the moisture content in grain was measured thermogravimetrically [11]. The grain moisture was determined four times for each line during its ripening period, every ten days in two replications, starting on day 30 after pollination. The average sample was taken from three ears. The moisture content in grain was also determined in the field using an AVD 6100 needle moisture meter for wood.

The meteorological conditions in 2017-2019 were characterized by a higher average monthly air temperature than the long-term average (by 5-17%). The wetting profile in 2017-2019 was marked by a particularly severe precipitation deficit, reaching 44-46% of the long-term average monthly amount. The meteorological factors (air temperature, precipitation) in 2017-2019 were generally unfavorable for the growth and development of corn plants.

All mathematical and statistical calculations were done in Microsoft Office Excel and Statistica 6.

Results and Discussion. We conducted a three-year experiment to determine the moisture content in grain of corn lines in the laboratory using the thermostat and scales and in the field using the AVD 6100 needle moisture meter. We compared the grain moisture content data and conducted correlation analysis to compare these two methods [12].

It was found that the results of the laboratory thermogravimetric method and the field method using the AVD 6100 needle moisture meter coincided by 90% (according to the coefficient of determination) on day 60. This allowed using the needle moisture meter to determine the moisture content in corn grain in the field, significantly accelerating the breeding process.

Medium-early and medium-ripening corn accessions were found to release water from grain more intensively, while there was no sharp decline in the grain moisture in the medium-late group.

The dynamics of moisture release by grain was studied for 100 corn lines of various ripeness groups in different periods of vegetation; lines with low moisture content were selected in each group, which makes it possible to select lines with good moisture-yielding ability [13].

Lines with the maximum yield of moisture per day were selected: six medium-early lines (LPL 79 A, UKhK 5, UChS 85, UKhK 590, UChS 85, SL 73-85-2 (Ukraine), CO 190 (Canada), and B 267 (Russia)), 24 medium-ripening lines (of them, 20 lines were bred in Ukraine; one line is from Russia (B 321), and three lines are from the USA (W 83, A 619, and B 143)), and 25 medium-late lines (20 Ukrainian lines (UKhK 472, KhLH 78, LNAU 18, OV 1248, UKh 804, and others), two Russian lines, 1 Kazakhstanian line, and 1 line from the USA) [12].

In 2017-2019, the lines were investigated during their growing periods and the limits of 22 traits were determined per the guide classifier of the *Zea mays* L. species [14].

It should be noted that there is a significant range of variability in each subspecies, allowing for identification of accessions with desired levels of a characteristic. The investigated characteristics of corn continuously vary, so while studying their variability, it is important to grade and determine the breeding values of classes for practical needs [16, 17].

Analyzing the dependences of the grain filling intensity, moisture release during ripening, and grain drying rate on morphological and economic characteristics of corn lines, we noted relationships of these parameters with the above-listed morphobiological and so-called "specific" characteristics (peduncle length, sheath number, density of sheath adhesion to the ear, grain consistency, etc.) as well as with the dynamics of the biochemical composition during kernel formation.

We selected lines with rapid grain drying and valuable economic features. The features affecting the moisture release rate are listed in Table 1.

Table 1

Morphological characteristics of the corn accessions, 2017-2019

Characteristic	Number of lines				
	Expression of characteristic, points				
	1	3	5	7	9
Sheath length	-	2	4	94	-
Number of sheath leaves	1	79	19	-	1
Peduncle length	6	42	53	-	-
Cob thickness	-	14	80	6	-
Cob consistency	-	33	42	25	-

Note: gradations of characteristics: 1 - very low, 3 - low, 5 - medium, 7 - high, 9 - very high.

Table 2

Characteristics of the best corn lines with rapid moisture release, 2017-2019

National Catalog ID	Line	Period from stigma emergence to gold ripeness, days	Plant performance, g	Kernel number per ear	Kernel number per row	Thousand kernel weight, g
Medium-early						
UB0104250	LPL 79 Ay	37*	28	420*	28	128
UB0101030	CO 190	32	25	270	27	212*
UB0101528	UKhK 5	32	28	336*	24	155
UB0108714	UChS 85	39*	28	252	18	186*
UB0108032	UKhK 590	34	41	209	19	200*
UB0100832	B 267	41*	50	256	32*	200*
Reference	**UKh 52**	**34**	**26**	**300**	**30**	**165**
Medium-ripening						
UB0108142	Kharkivska 720	36*	49	273	21	204*
UB0101199	S 35	32	76*	384	32*	279*
UB0108301	UKhS 108	40*	75*	392	28	254*
UB0111044	ZK 345	34	93*	408	34*	247*
UB0100299	W 83	39*	51	300	30	168*
Reference	**UKhS 126**	**34**	**58**	**540**	**30**	**156**
Medium-late						
UB0108247	AK 157	38	72*	518*	37	200*
UB0108027	UKhK 581	39	81*	544*	34	182*
UB0108936	UCh 278	39	96*	444	37	240*
UB0108581	DS 205/710 SV	42*	131*	592*	37	293*
UB0108130	UCh 291	35	73*	378	27	205*
Reference	**DS 103**	**39**	**53**	**492**	**41**	**162**

Note: * - lines that were superior to the corresponding reference accession.

It was found that the sheath was longer than the ear in 94 corn lines. Nineteen accessions had on average 5-10 sheath leaves. The peduncle length was medium in 53 lines. In 80 lines, the cob thickness was medium; the cob diameter was 2.1 - 2.5 cm. The cob was medium-dense in 42 lines.

The best corn lines were selected from each ripeness group by data on grain moisture content and intensity of moisture yield per day.

In the medium-early group, 8 best lines were selected. However, only 6 lines had good economic characteristics: LPL 79 Ay, UKhK 5, UChS 85, UKhK 590 (Ukraine), CO 190 (Canada), and B 267 (Russia). In UKhK 5 (Ukraine) and CO 190 (Canada), the period from stigma emergence to gold ripeness was 32 days; in UKhK 590 (Ukraine) – 34 days; in LPL 79 Ay (Ukraine) – 37 days; in UChS 85 (Ukraine) – 39 days; in B 267 (Russia) – 41 days (Table 2).

As can be seen from the Table 2, most of the medium-early lines were superior to the reference (UKh 52) by 8-90% in terms of performance and by 12-28% in terms of thousand kernel weight. Ukrainian lines, LPL 79 Ay and UKhk 5, had ears with lots of kernels (420 and 336, respectively). The largest number of kernels per row was recorded for B 267 (32; 30 in the reference accession).

Twenty-four best lines were selected in the medium-ripening group. Compared to the reference accession (UKhS 126), the following lines were noticeable for valuable economic characteristics: Kharkivska 720, UKhS 108, ZK 345 (Ukraine), S 35 (Poland), and W 83 (USA). The following lines were selected by Period from stigma emergence to gold ripeness: Kharkivska 720, UKhS 108 (Ukraine), and W 83 (USA); they exceeded the reference accession by 2.0-6.0 days. In terms of performance, UKhS 108 (Ukraine), S 35 (Poland), and ZK 345 (Ukraine) were superior to the reference accession (Table 2). S 35 (Poland), UKhS 108 (Ukraine), and ZK 345 (Ukraine) had the largest numbers of kernels per ear. ZK 345 (Ukraine) and S 35 (Poland) were superior to the reference accession in tems of the kernel number per row. The thousand kernel weight in all five lines was by 20–70% higher than that in the reference accession.

Twenty-five medium-late lines were selected due to rapid moisture release; AK 157, UKhK 581, UCh 278, DS 205/710 SV, and UCh 291 (Ukraine) were also characterized by valuable economic features. By period from stigma emergence to gold ripeness, UCh 291 (Ukraine) (35 days), AK 157 (Ukraine) (38 days), UKhK 581 (Ukraine) (39 days), UC 278 (Ukraine) (39 days), and DS 205/710 SV (Ukraine) (42 days) were distinguished. Five lines exceeded the reference accession (DS 103) by 30-140%, but the highest performance was observed in DS 205/710 SV line (Ukraine) (131 g of grain per plant).

As to the kernel number per ear, AK 157 (Ukraine), UKhK 581 (Ukraine), and DS 205/710 SV (Ukraine) exceed the reference accession by 5–20%. As to the kernel number per row in the medium-early group, the reference accession was inferior to B 267; in the medium-ripening group, S 35 and ZK 345 were better than the reference accession. The following lines were distinguished by thousand kernel weight: UKhK 581 (Ukraine), AK 157 (Ukraine), UCh 291 (Ukraine), UCh 278 (Ukraine), and DS 205/710 SV (Ukraine); their thousand kernel weights were by 12-80% higher than the reference value (in DS 103).

The largest numbers of kernels per row were noted in the following medium-late lines: AK 157, UCh 278, and DS 205/710 SV (Ukraine). A medium-late line, DS 205/710 SV (Ukraine), was distinguished due to several characteristics (kernel weight per plant, kernel number per ear, and thousand kernel weight).

Correlation analysis allows one to single out the most important features that need to be paid special attention to in the breeding and selection of genotypes with high adaptability [18].

Having studied inbred corn lines, we found a strong positive correlation between dry matter accumulation and performance ($r = 0.90$) and moderate positive correlations between dry matter accumulation and kernel number per ear ($r = 0.45$), between dry matter accumulation and plant height ($r = 0.40$), and between dry matter accumulation and ear attachment height ($r = 0.39$) (Table 3).

There was a strong positive correlation between plant growth intensity and plant height (r = 0.64) and moderate correlations between plant growth intensity and ear attachment height (r = 0.36) and between plant growth intensity and performance (r = 0.28).

Table 3

Correlation coefficients (r) between plant growth intensity, dry matter accumulation, and valuable economic characteristics in the inbred corn lines, 2017–2019

Characteristic pairs	Milky-waxy ripeness	Gold ripemess	Plant height	Ear attachment height	Kernel number per ear	Performance	Plant growth intensity	Dry matter accumulation
Milky-waxy ripeness	1.00							
Gold ripemess	-0.44	1.00						
Plant height	0.42	-0.35	1.00					
Ear attachment height	0.33	-0.24	0.81	1.00				
Kernel number per ear	0.07	-0.14	0.07	0.20	1.00			
Performance	0.38	-0.28	0.51	0.51	0.44	1.00		
Plant growth intensity	0.22	0.01	0.64	0.36	-0.15	0.28	1.00	
Dry matter accumulation	0.09	-0.12	0.40	0.39	0.45	0.90	0.31	1

Conclusions. The best lines were selected in each group of ripeness according to the intensity of moisture egress from grain and valuable economic characteristics. In the medium-early group, eight best lines were selected. However, only 6 lines had good economic characteristics: LPL 79 Ay, UKhK 5, UChS 85, UKhK 590, SO 190, and B 267. Most of the medium-early lines were superior to the reference accession, UKh 52, in terms of performance (by 8-90%) and thousand kernel weight (by 12 -28%). Ukrainian lines, LPL 79 Ay and UKhK 5, had lots of kernels per ear. In the medium-ripening group, 24 best lines were selected in comparison with UChS 126 (reference accession); of them, the following lines were characterized by valuable economic features: Kharkivska 720, UChS 108, ZK 345 (Ukraine), S 35 (Poland), and W 83 (USA). In the medium-late group, 25 lines were selected due to rapid moisture release; AK 157, UKhK 581, UCh 278, DS 205/710 SV, and UCh 291 (Ukraine) were also noticeable for valuable economic features.

There was a strong positive correlation between dry matter accumulation and performance (r = 0.90) and a moderate positive correlation between plant growth intensity and plant height (r = 0.64).

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Purpose. To analyze the dependence of the corn grain filling intensity and moisture-yielding ability of corn grain on morphological and economic characteristics in each ripeness group of corn lines.

Material and Methods. The study was carried out in the Laboratory of Introduction and Preservation of Plant Genetic Resources and the Laboratory of Corn Breeding and Seed Production of the Yuriev Plant Production Institute of NAAS in 2017-2019. The accessions were sown by the standard method in two-row plots of 9.8 m^2 in three replications. The reference accessions were placed after every 20 plots: early ripening - F2 line; medium-early – UKh 52; medium-ripening - DS 103, UKhS 126, and SO 125; medium-late - A 619, Kharkivska 215, and KhA 408. During the growing period, the accessions were evaluated in the field 24 times for typicality. In the laboratory, the grain moisture was determined thermogravimetrically four times for each line during its ripening period, every ten days, starting on day 30 after pollination. For

comparison, the moisture content in grain was also determined in the field using an AVD 6100 needle moisture meter for wood.

Results and Discussion. Lines with the maximum yield of moisture per day were selected: six medium-early lines (LPL 79 A, UKhK 5, UChS 85, UKhK 590, UChS 85, SL 73-85-2 (Ukraine), CO 190 (Canada), and B 267 (Russia)), 24 medium-ripening lines (of them, 20 lines were bred in Ukraine; one line is from Russia (B 321), and three lines are from the USA (W 83, A 619, and B 143)), and 25 medium-late lines (20 Ukrainian lines (UKhK 472, KhLH 78, LNAU 18, OV 1248, UKh 804, and others), two Russian lines, 1 Kazakhstanian line, and 1 line from the USA). We noted the dependences of the grain filling intensity, moisture release during ripening, and grain drying rate on morphobiological and so-called "specific" characteristics (peduncle length, sheath number, density of sheath adhesion to the ear, grain consistency). Corn lines with intensive grain filling and a set of valuable economic features were distinguished.

Having studied inbred corn lines, we found a strong positive correlation between dry matter accumulation and performance ($r = 0.90$) and moderate positive correlations between dry matter accumulation and kernel number per ear ($r = 0.45$), between dry matter accumulation and plant height ($r = 0.40$), and between dry matter accumulation and ear attachment height ($r = 0.39$).

Conclusions. The best lines were selected in each group of ripeness according to the intensity of moisture egress from grain and valuable economic characteristics. In the medium-early group, eight best lines were selected. However, only 6 lines had good economic characteristics. Most of the medium-early lines were superior to the reference accession, UKh 52, in terms of performance and thousand kernel weight. In the medium-ripening group, 24 best lines were selected in comparison with UChS 126 (reference accession).

***Key words**: Zea mays, lines, morphological features, moisture-yielding ability, grain filling intensity*

ЗАЛЕЖНІСТЬ ІНТЕНСИВНОСТІ НАЛИВУ ЗЕРНА ТА ВОЛОГОВІДДАЧІ ВІД ЦІННИХ ГОСПОДАРСЬКИХ ОЗНАК КУКУРУДЗИ

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Мета та завдання досліджень. Вивчити залежності інтенсивності наливу зерна кукурудзи та його вологовіддачі від морфологічних та господарських ознак в кожній групі стиглості ліній кукурудзи.

Матеріал і методи. Дослідження проводили у 2017-2019 роках, у лабораторії інтродукції та зберігання генетичних ресурсів рослин та в лабораторії селекції та насінництва кукурудзи Інституту рослинництва імені В. Я. Юр’єва НААН. Зразки висівалися стандартним методом на двухрядковій ділянці площею 9,8 м^2 в трьох повторностях. Через кожні 20 ділянок було розміщено стандарти: ранньостиглі – лінія F 2; середньорання – УХ 52; середньостиглі – ДС 103, УХС 126, СО 125; середньопізні – А 619, Харківська 215, ХА 408. Протягом вегетаційного періоду в польових умовах проведено 24 оцінки типовості зразка. Вологість зерна кожної лінії визначали в період достигання чотири рази, кожні десять діб, починаючи з тридцятої доби після запилення. Для порівняння результатів вміст вологи в зерні визначали польовим методом з використанням голчатого вологоміра для деревини АВД 6100.

Результати та обговорення. Виділено лінії з максимальною віддачею вологи за добу: в середньоранній групі стиглості виділено шість ліній – LPL 79 А, УХК 5, УХС 85, УХК 590, УХС 85, СЛ 73-85-2 (Україна), СО 190 (Канада); в середньостиглій групі стиглості – 24 лінії, з них 20 ліній української селекції, три з США (W 83, А 619 та В 143). У середньопізньої групи стиглості – 25 ліній з максимальною вологовіддачею, з України – 20 ліній (УХК 472, ХЛГ 78, ЛНАУ 18, ОВ 1248, УХ 804 та ін.), дві лінії російської селекції і по одній лінії з Казахстану та США. Встановлено залежність інтенсивності наливу зерна у ліній кукурудзи, його вологовіддачі при дозріванні та швидкості висихання зерна від морфологічних і так званих «специфічних» ознак (довжина плодоніжки, кількість обгорток, щільність їх прилягання до качана, консистенція зерна). Виділено лінії кукурудзи інтенсивним наливом зерна та комплексом цінних господарських ознак.

В результаті вивчення інбредних ліній кукурудзи встановлено високий позитивний зв'язок між інтенсивністю накопичення сухої речовини та продуктивністю ($r = 0,90$), середній позитивний зв'язок між інтенсивністю накопичення сухої речовини та озерненістю качана ($r = 0,45$), висотою рослини ($r = 0,40$) та висотою прикріплення качану ($r = 0,39$)

Висновки. За результатами досліджень в кожній групі стиглості відібрано кращі лінії за інтенсивністю вологовіддачі зерном та цінними господарськими ознаками. У середньоранній групі стиглості було виділено вісім кращих ліній, тільки шість ліній характеризувались високими господарськими ознаками. Серед ранньостиглої групи більшість ліній перевищили стандарт УХ 52 за продуктивністю і масою 1000 зерен. В середньостиглій групі у порівнянні зі стандартом УХС 126 було виділено 24 кращих ліній.

Ключові слова: *Zea mays, лінії, морфологічні ознаки, вологовіддача, інтенсивність наливу зерна*