

IDENTIFICATION OF SELF-POLLINATED MAIZE LINES BY THE RATES OF DRY MATTER ACCUMULATION AND GRAIN MOISTURE-YIELDING ABILITY AND COMPLEX OF VALUABLE ECONOMIC TRAITS

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Topicality. For Ukrainian agricultural production, it is extremely important to obtain consistently high yields of maize grain. Development of high-yielding hybrids requires a diversity of source material, namely self-pollinated lines with the following key requirements of breeders: increased grain and seed productivity, high donor properties, genetic protection against abiotic and biotic factors, and good adaptability to weather and agronomic conditions. **Purpose.** The study of maize lines of different maturity groups, which have a significant range of genotypic variability in interphase periods, indicating the possibility of selecting lines with high rate of accumulation of dry matter in maize grain and with high rate of grain moisture-yielding ability. **Methods.** The experiments were conducted in accordance with the "Methodological recommendations for field and laboratory study of maize genetic resources". During the evaluation of the source material for grain filling intensity, the influence of morphological and biological traits (plant height and number of leaves above the ear, number of internodes on the ear pedicel, etc.) on this trait, its relationship with economic traits that determine the level of productivity (ear length, number of grain rows, number of grains per row, etc.) was determined. **Results.** The maize lines UKhK 545, UKhK 549, UKhK 467, UKhI 71, ZK 345, ZK 266, UKhK 5, IG 34/4, UP 149, UKhI 66, UKhK 605, Kharkivska 125 MV, AK 145 (Ukraine) with intensive grain filling and a complex of valuable economic traits were identified. The results of the correlation analysis of maize grain moisture content determined by the laboratory thermostat-weighing method and the field method with the needle moisture meter AVD 6100 coincided by 90% on the 60th day after pollination, so in 2019 we determined the moisture content of maize grain only by the field method for comparison with the previous two years. **Conclusions.** We have studied 100 maize self-pollinated lines of different subspecies composition, maturity group and geographical origin from 11 countries. The results of our study showed that determination of maize grain moisture content in the field is available with the needle moisture tester AVD 6100, which significantly accelerates the breeding process, allows us to observe the dynamics of grain moisture-yielding ability at different stages of grain ripeness, starting from milk ripeness, while keeping the ear on the plant.

Keywords: maize, line, yield, productivity, dry matter accumulation, intensive moisture-yielding ability

Introduction. Maize is characterised by adaptability to different growing conditions. The high adaptability of maize is explained by the genotypic diversity of its subspecies [1–4].

The length of the growing season is one of the essential quantitative traits. The duration of the maize growing season plays a major role in breeding practice, especially for research in the eastern Forest-Steppe of Ukraine.

The growing season is the time required for the full development of a plant, ending with the formation of seeds [5]. Researchers distinguish two main periods: the formation of vegetative organs (roots, stems, leaves) and the formation of generative organs (inflorescences, fruits and seeds) [6].

The growth and development of maize is

influenced by a complex of external environmental factors: temperature, moisture, daylight hours, and plant nutrients. At the same time, each stage of development has its own optimal combination of environmental factors [7].

The success of any breeding programme is determined by the source material with the trait examined, which has a phenotypic manifestation only in an indirect environment. Numerous studies have been devoted to genotypic and paratypic (nonheritable) variability with the aim of introducing them into breeding programmes to improve certain traits [7–10].

The study of grain productivity and quality traits of the National Collection specimens revealed the ranges of their phenotypic, genotypic and environmental variation.

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It was determined that the most variable traits are productivity, number of kernels per ear, 1000 grain weight, oil content, for which phenotypic and genotypic coefficients of variation are high and average. A high coefficient of environmental variation (19.4 %) was also noted for the productivity trait, while for other traits it did not exceed 10 %. High genotypic variability was found in the studied specimen, which covered most of the traits according to the "Classifier-guide of the species *Zea mays* L." [11].

Materials and Methods. In 2017–2019, field and laboratory research was conducted to

study the economically valuable traits of maize lines. The material for the study of filling intensity and intensive moisture-yielding ability of grain was selected from 100 self-pollinated lines of different subspecies composition, maturity group and geographical origin.

The origin of the lines is represented by 11 countries, namely: Ukraine – 81 lines, Russia – four, USA – five, Canada – two, Croatia – two, Germany, Czech Republic, France, Poland, Kazakhstan and Slovakia – one line each. These maize lines are registered by the National Centre for Plant Genetic Resources of Ukraine (Fig.1).

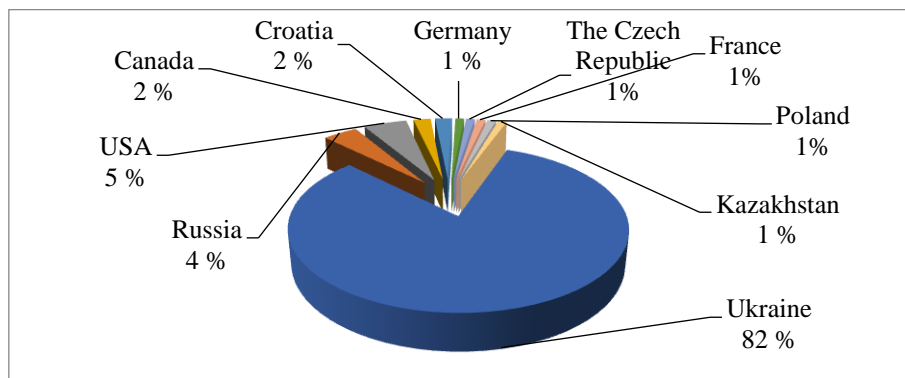


Fig. 1. Distribution of maize source material by geographical origin

The specimens were sown using the standard method on a two-row plot of 9.8 m² in three replications. Standards were placed every 20 plots: early ripening line F 2; mid-early line UKh 52; mid-ripening lines DS 103, UKhS 126, SO 125; mid-late lines A 619, Kharkivska 215, KhA 408.

During the growing season, the typicality of the specimen, its alignment in plant height, and ear parameters were assessed in the field conditions. Morphological traits were determined as follows: plant height, number of leaves per plant, length and number of branches per tassel, number of stems and ears per plant; and economically valuable traits: number of ears per plant, ear length, number of kernel rows per ear, number of kernels per row, 1000 kernels weight), resistance to lodging, ear dropping, disease and pest damage.

The experiments were conducted in accordance with the "Methodological recommendations for field and laboratory study of maize genetic resources" [12].

A detailed study of the filling intensity and grain drying rate was carried out according

to specific traits, such as number of leaves above the ear, ear pedicel length, number of internodes on a pedicle, number of husk layers, husk thickness, consistence of ear husks at the stage of full grain ripeness.

In assessing the source material, the influence of morphological and biological traits (plant height, number of leaves above the ear, number of internodes on the ear pedicel, etc.) on the grain filling intensity and its relationship with economic traits that determine the level of productivity (ear length, number of grain rows, number of kernels per row, etc.) was determined. The maize lines with intensive grain filling and a complex of valuable economic traits were identified [13].

In laboratory conditions, the moisture content of the grain was estimated by the thermostat-weight method [14]. During the grain ripening period, the moisture content of each line was determined four times, every ten days in two replicates, starting from the thirtieth day after pollination. The average specimen was formed from three ears. The moisture content in grain was determined by the field method using a

needle wood moisture tester AVD 6100 to compare the results.

In the study of maize lines, the relationship of grain drying rate with both the above morphological and biological traits and specific traits (pedicel length, number of ear husks, husk thickness, grain consistency, etc.), as well as with the dynamics of biochemical composition during grain formation was determined. Lines characterised by fast grain drying and valuable economic traits were selected.

In 2017–2019, the average monthly air temperature was 5–17 % higher than the long-term average. During this period, the humidity regime was marked by a severe precipitation deficit, which was 44–46 % of the long-term average monthly norm. According to the set of

meteorological factors (air temperature, precipitation), 2017–2019 were generally unfavourable for the maize growth and development.

All mathematical and statistical calculations were carried out using the data analysis package Microsoft Office Excel and the Statistica 6 software.

Results and Discussion. For three years, the studied maize lines were systematised by maturity groups and subspecies composition. The lines were distributed as follows: mid-early group included one dent line, four flint, and five semi-dent lines; mid-ripening group included 11 dent, 11 flint, and 23 semi-dent subspecies lines; and mid-late group included 13 dent, 10 flint, and 22 semi-dent lines (Table 1).

The lines studied belong to three maturity

Table 1. Distribution of maize specimens by maturity groups and subspecies composition in 2017–2019

Subspecies	Number of line, pcs.	Maturity groups, pcs.		
		mid-early	mid-ripening	mid-late
Dent maize	25	1	11	13
Flint maize	25	4	11	10
Semi-dent maize	50	5	23	22
Total	100	10	45	45

groups, and therefore we compared them in different interstage periods of maize. The mid-early maturity group in the experiment is represented by 10 lines. On average, over the three years, emergence of seedlings occurred 11 days after sowing. The period from seedling emergence to stigma emergence lasted an average of 50 days. The period from stigma emergence to wax ripeness varied from 32 to 53 days. The duration of plant development from waxy to full ripeness was within 7–24 days. The growth rate in this group averaged 2.7 cm/day.

The mid-ripening group included 45 self-pollinated lines. The emergence of seedlings occurred, on average, on the 10th day. The period from seedlings to stigma emergence was 56 days; the period from stigma emergence to wax ripeness lasted 32–51 days, and the period from wax ripeness to full ripeness lasted 11 days on average, but varied from 3 to 27 days. The growth rate of maize plants was 2.7 cm/day.

The mid-late maturity group also included 45 lines. On average, the emergence of seedlings was observed at the 10th day. The period from seedlings to stigma emergence lasted 61 days, the period from stigma emergence to waxy ripeness lasted 43 days, and the period

from waxy ripeness to full grain ripeness averaged 11 days, but in 2017 it lasted up to 10 days, in 2018 – up to 19 days, and in 2019 – up to 17 days. On average, over the three years, the growth rate of maize plants was 2.7 cm/day (Table 2).

Thus, the results of the research (2017–2019) showed that the earlier emergence of seedlings was observed in 2019 (on the 8–9th days) compared to 2017 and 2018, due to the sufficient supply of spring soil moisture. In 2018, the shortest period from the stigma emergence to the waxy ripeness was 37–39 days.

On average, for three years, in the period from the stigma emergence to waxy ripeness of grain, most lines with intensive grain drying (10–12 days) was observed in the mid-ripening group, while drying in the mid-late group occurred on 10–11th day in 2017 and 2019.

The combining ability of the source material is a crucial component of heterotic breeding [15, 16]. It is known that the components of genotypic dispersion are subject to significant environmental variability, which makes it impossible to accurately determine the parameters of general (GCA) and specific (SCA) combining ability [17, 18].

Table 2. Characteristics of maize lines of different maturity groups by interstage periods, 2017–2019

Maturity group	Number of specimens, pcs.	Level of trait manifestation	Period, days												Plant growth rate, cm/day		
			seedling emergence			seedling – stigma emergence			stigma emergence – waxy ripeness			waxy ripeness – full ripeness					
			years														
			2017	2018	2019	2017	2018	2019	2017	2018	2019	2017	2018	2019	2017	2018	2019
Mid-early	10	max	13	12	10	54	60	47	50	43	53	24	19	16	3.8	2.7	4.5
		min	11	10	8	45	51	40	35	32	42	7	7	9	2.0	1.8	2.4
		average	12	11	9	50	55	45	39	37	47	18	13	12	2.8	2.2	3.2
Mid-ripening	45	max	13	12	10	66	71	63	52	46	55	28	34	19	3.4	3.3	3.9
		min	11	10	8	47	53	45	28	31	37	3	2	3	1.9	1.6	2.3
		average	12	11	8	58	59	52	41	37	45	13	11	10	2.7	2.5	3.1
Mid-late	45	max	14	12	11	71	77	70	52	47	52	20	36	17	3.2	3.6	4.3
		min	11	10	8	51	52	41	33	33	37	4	3	5	1.8	1.8	2.1
		average	12	11	8	62	64	56	44	39	45	10	19	11	2.6	2.6	2.9

It was found that maize lines of different maturity groups have a significant range of genotypic variability in interstage periods. In 2019, the seedlings of all lines emerged earlier than in previous years. For the mid-early group, the periods from seedlings to stigma emergence and from stigma emergence to wax ripeness were at the same level in 2017 and 2018. In 2019, the average growth rate was 3.2 cm/day.

Similar results were observed for the mid-ripening and mid-late maturity groups of the lines.

The duration of period from sowing to seedling emergence was stable over the years. In subsequent periods, we identified lines with both the minimum and the maximum duration of the period, allowing us to develop lines with high rate of dry matter accumulation in maize grain and high moisture-yielding ability [14, 19].

The range of trait limits for the interstage periods from seedling emergence to full grain ripeness (53.9 %) and from waxy to full grain ripeness (24.7 %) is particularly noteworthy.

Scientists V. H. Gonzalez, E. A. Lee, L. N. Lukens, C. J. Swanton, found that the relationship between floret number and dry matter accumulation in plants varies depending on stress in the early development stages of maize (*Zea mays* L.). Our studies have confirmed the relationship between the number of florets, plant dry matter accumulation and stress at the beginning of the growing season [20].

Studying the parameters of morphological traits of maize lines, we observed a high coefficient of variation in the initial plant growth rate (23.3 %), ear insertion height (24.0 %) and number of branches per tassel (48.6 %) (Table 3).

Table 3. Parameters of morphological traits for maize lines, 2017–2019

Limits	Traits					
	Intensity of early growth, point	Plant height, cm	Ear insertion height, cm	Number of leaves, pcs.	Tassel length, cm	Number of branches per tassel, pcs.
Average	5	156	51	18	32	12
Min	3	108	23	12	22	3
Max	8	203	76	22	43	28
Coefficient of variation, %	23.3	12.3	24.0	11.4	13.6	48.6

The intensity of dry matter accumulation in grain depended on both phenological

stages and the formation of ear productivity and some of its components that is indicated

by the coefficient of variation: 1000 grain weight (17.0 %), ear grain content (20.2 %),

number of kernels per row (14.6 %), number of ear rows (24.0 %) (Table 4).

Table 4. Limits of productivity traits for maize lines, 2017–2019

Limit	Trait									
	Ear length, cm	Ear diameter, cm	Number of grain rows per ear, pcs.	Number of kernels per ear row, pcs.	Ear grain content, pcs.	Grain weight per plant, g	1000 grain weight, g	Number of ear per plant, pcs.	Plant growth rate, cm/day	Intensity of dry matter accumulation, g/day
Average	14	3.6	15	31	451	78	201	1.2	3.2	2.4
Min	10	2.9	10	19	260	35	125	0.9	2.4	1.6
Max	22	4.4	33	39	601	125	275	1.8	3.3	3.1
Coefficient of variation, %	15.9	10.3	24.0	14.6	20.2	29.0	17.0	12.8	11.2	27.3

For three years, we have determined the moisture content of maize lines in the laboratory condition using the thermostat-weight method and in the field trials using the needle moisture tester AVD 6100, and have conducted a correlation analysis to compare these two methods [14].

According to the results of mathematical

processing of the data of 2017, it was found that the correlation coefficient on the 30th day after pollination was $r = 0.55$, on the 40th day $r = 0.78$, on the 50th day $r = 0.89$, on the 60th day $r = 0.88$. Also in 2018, the correlation coefficient was $r = 0.43$ on day 30, $r = 0.77$ on day 40, $r = 0.92$ on day 50, and $r = 0.95$ on day 60 (Table 5).

Table 5. Correlation coefficient of grain moisture content by thermostat-weight method and moisture tester AVD 6100, 2017–2018

Sampling period (days after pollination)	Method	30		40		50		60	
		TWM *	MT **	TWM	MT	TWM	MT	TWM	MT
<i>I</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>	<i>6</i>	<i>7</i>	<i>8</i>	<i>9</i>	<i>10</i>
2017									
30	TWM	1.00	–	–	–	–	–	–	–
	MT	0.55	1.00	–	–	–	–	–	–
40	TWM	0.85	0.38	1.00	–	–	–	–	–
	MT	0.51	0.52	0.79	1.00	–	–	–	–
50	TWM	0.72	0.33	0.79	0.60	1.00	–	–	–
	MT	0.49	0.46	0.65	0.71	0.89	1.00	–	–
60	TWM	0.62	0.30	0.73	0.53	0.74	0.61	1.00	–
	MT	0.55	0.38	0.73	0.69	0.75	0.75	0.88	1.00
2018									
30	TWM	1.00	–	–	–	–	–	–	–
	MT	0.43	1.00	–	–	–	–	–	–
40	TWM	0.43	0.42	1.00	–	–	–	–	–
	MT	0.43	0.47	0.77	1.00	–	–	–	–
50	TWM	0.53	0.33	0.51	0.52	1.00	–	–	–
	MT	0.47	0.38	0.47	0.61	0.92	1.00	–	–
60	TWM	0.48	0.24	0.50	0.49	0.73	0.68	1.00	–
	MT	0.43	0.29	0.54	0.53	0.74	0.72	0.95	1.00

Note: * – Thermostat-weight method (TWM), ** – Moisture tester AVD 6100 (MT).

Thus, it was found that the results of measurements at the 60th day by the laboratory thermostat-weight method and the field method using the needle moisture tester AVD 6100 coincided by 90 % (by the coefficient of determination).

The application of a needle moisture tester to determine the moisture content of maize grain in the field conditions greatly facilitates and accelerates the breeding work. This method reduces the labour intensity of evaluating maize specimens, does not damage the grain, and makes it possible to monitor the filling rate and moisture-yielding ability of maize grain.

The results of the correlation analysis allow us to determine the moisture content of maize grain in 2019 only by the field method and compare them with the data of the last two years.

It was found that the moisture content of maize grain in 2019 on the 30th day after pollination was: in mid-early lines – 45.9 %, which is 1.2 % higher than in 2018 and 0.7 % higher than in 2017; in mid-ripening lines – 45.3 %, which is 2.1 % less than in 2018, but by 1.1% higher than in 2017; in mid-late lines, the highest rate was 50.2 % in 2018, which is 0.3 % and 3.2 % higher than in 2017 and 2019, respectively (Table 6).

Table 6. Grain moisture content of maize lines of different maturity groups during grain filling, 2017–2019

Sampling period (days after pollination)	Grain moisture content, %								
	Mid-early			Mid-ripening			Mid-late		
	2017	2018	2019	2017	2018	2019	2017	2018	2019
30	45.2	44.7	45.9	44.3	47.4	45.3	49.4	50.2	47.0
40	32.2	33.2	36.2	35.8	34.4	33.7	40.8	35.9	35.3
50	25.7	16.4	27.4	26.9	20.7	23.0	30.1	26.5	25.4
60	13.9	15.0	19.7	17.8	17.1	14.1	23.5	22.8	16.1

Conclusions. We have studied 100 self-pollinated lines of different subspecies composition, maturity group and geographical origin.

Studying the parameters of morphological traits of maize lines, we observed a high coefficient of variation in the initial plant growth rate (23.3 %), ear insertion height (24.0 %) and number of branches per tassel (48.6 %).

It was found that the results of measurements at the 60th day by the laboratory thermostat-weight method and the field method using the needle moisture tester AVD 6100 coincided by 90 % (by the coefficient of determination). The application of a needle moisture tester to determine the moisture content of maize grain in the field conditions greatly facilitates and accelerates the breeding work.

Over three years, during the period from stigma emergence to waxy ripeness of grain, most lines with intensive grain drying (10–12 days) belonged to the mid-ripening group, while in the mid-late lines drying was observed

at 10–11 days in 2017 and 2019.

The intensity of dry matter accumulation in grain depended on both phenological stages and the formation of ear productivity and some of its components that is indicated by the coefficient of variation: 1000 grain weight (17.0 %), ear grain content (20.2 %), number of kernels per row (14.6 %), number of ear rows (24.0 %).

When sampling on the 60th day, the lowest grain moisture content was observed in the lines of the mid-early maturity group (15 % in 2018) and in the lines of the mid-ripening group (14 % in 2019), and the highest grain moisture content was observed in the specimens of the mid-late maturity group at all stages of sampling in 2017–2018. Variation of grain moisture content during ripening in maize lines of different maturity groups showed that each group has genotypes with low grain moisture content. Therefore, the selection of lines with high moisture-yielding ability of grain within each maturity group is simplified.

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Актуальність. Для сільськогосподарського виробництва України надзвичайно актуальним є одержання стабільно високих врожаїв зерна кукурудзи. Для створення високоврожайних гібридів потрібно мати різноманітний вихідний матеріал, а саме самозапилені лінії, які відповідають основним вимогам селекціонерів: підвищена зернова та насіннева продуктивність, високі донорські властивості, генетичний захист від абіотичних та біотичних чинників, добра пристосованість до погодних та агротехнічних умов. **Мета роботи.** Вивчення ліній кукурудзи різних груп стиглості, які мають значний розмах генотипової мінливості за міжфазними періодами, що вказує на можливість виділення ліній з швидким накопиченням сухих речовин у зерні кукурудзи і виділення зразків з швидкою вологовіддачею зерна. **Методи.** Досліди було проведено у відповідності з «Методичними рекомендаціями польового та лабораторного вивчення генетичних ресурсів кукурудзи». При оцінці вихідного матеріалу за інтенсивністю наливу зерна було визначено вплив морфо-біологічних ознак (висота рослини та кількість листків над качаном, кількість міжвузлів на ніжці качана та ін.) на дану ознаку, її взаємозв'язок з господарськими ознаками, що визначають рівень продуктивності (довжина качана, кількість рядів, кількість зерен в ряду та ін.). **Результати.** Виділено лінії кукурудзи УХК 545, УХК 549, УХК 467, УХІ 71, ЗК 345, ЗК 266, УХК 5, ІГ 34/4, УП 149, УХІ 66, УХК 605, Харківська 125 МВ, АК 145 (Україна) з інтенсивним наливом зерна та комплексом цінних господарських ознак. Результати кореляційного аналізу між термостатно-ваговим методом та польовим з використанням голчатого вологоміра АВД 6100 для визначення вологості зерна кукурудзи співпали на 60 добу на 90 %, що дало нам можливість у 2019 році проводити дослідження лише польовим методом для визначення вологості зерна кукурудзи та порівняти їх з двома минулими роками. **Висновки.** Досліджено 100 самозапиленних ліній кукурудзи різних за підвидовим складом, групою стиглості та географічним походженням. Лінії представлені з 11 країн світу. Установлено, що результати лабораторного термостатно-вагового та польового методів з використанням голчастого вологоміра АВД 6100 співпали (за коефіцієнтом детермінації) на 60 добу на 90 %, і дозволили використовувати голчастий вологомір для визначення вологості зерна кукурудзи в польових умовах, що значно прискорює селекційний процес, дозволяє виконувати аналіз динаміки вологовіддачі зерна на різних стадіях стиглості зерна, починаючи з молочної стиглості, а також проводити досліди в полі, залишаючи качан на рослині.

Ключові слова: кукурудза, лінія, урожайність, продуктивність, накопичення сухої речовини, інтенсивна вологовіддача