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Cumulative improvement of base inbred maize line DK744 (*Zea maize* L.) related to Iodent germplasm

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Abstract

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The research was devoted to the development of new inbred lines of maize (*Zea mays* L.) of the Iodent heterotic group with economically valuable properties in accordance to modern requirements of the maize production and the modern breeding programs. There are research results for 2010–2020 which showed the cumulative improvement of the base line DK744 of Iodent germplasma in terms of morpho-biological traits, in particular, the combining ability on the grain yield indicator. The base maize line DK744 is one of the parental components of early ripening hybrids, such as Dniprovskyi 181SV, Pochaivskyi 190MV, Tesei, DN Palanok, Kvitnevyi 187MV, DZ Latorytsia and others. We identified a number of hybrids which dominated over standard hybrids and with the best traits. Among them, there were an early ripening hybrid Pochaivskyi 190MV and a mid-early – DN Khortytsia which dominated in terms of grain yield and grain moisture content at harvesting, and ecological stability. The obtained lines are widely used in the selection of hybrids adapted to different zones of Ukraine.

Keywords: maize; selection; line; testcross; yield; grain moisture content; combining ability

Introduction

In recent years, climate changes have significantly affected the duration of the growing season, production volumes and crops quality (Sirotenko & Pavlova, 2012). According to research for 1991–2018 in the Northern zone of the Steppe of Ukraine, global warming caused a prolongation of the period with a temperature ≥ 5°C (biological minimum of early spring crop development) by 11–16 days, while increasing the sum of effective temperatures ≥ 10°C (Chaban et al., 2020). It was noted that the average annual air temperature during of active growth season of early grain crops (April–June) and late spring crops (May–August) increased by 0.8 and 1.1°C. Accordingly, against the background of increasing the thermal resources, an increase in yield of main field crops: winter cereals – by 36%, spring barley – by 24%, maize – by 11%, sunflower – by 30% was observed. This was confirmed by studies, which showed that despite the intensification of droughts, there was a steady increase in yield of maize hybrids from 5.69 (1995–1999) to 7.14 t/ha (2016–2020) and a decrease in grain moisture content at harvesting from 22.4% to 16.1%, respectively (Cherchel et al., 2020a). Climate change in Ukraine has positively effected on maize yield due to increased adaptability of the crop and renewal of its hybrid composition with higher productivity potential.

Maize is very sensitive to drought. The maize productivity fluctuations are explained by less resistance to stress air temperatures, especially in the second half of the growing season. There are several ways to solve the problem: first – to avoid drought, and second – to develop drought resistant genotypes (Troyer, 1983; Kerechky et al., 1994; Mustyatsa, 2005; Aslam et al., 2015). Nowadays, priorities are shifting towards less resource-intensive maize biotypes; the dates of sowing and harvesting are shifting to earlier ones to complete the critical stages of their growth season before the beginning of droughts (Aslam et al., 2015; Cherchel et al., 2020a).

In the Northern Steppe of Ukraine, it is recommended to grow maize hybrids of different maturity groups in the following ratio: early ripening – 25%; mid-early – 30%; mid-ripening – 30% and mid-late ripening – 15% (Gadzalo et al., 2021). This is caused not only by the economic factors (low grain moisture content at harvesting), but also the progress in selection of drought-resistant early and mid-early forms, and the ability of precocious genotypes to partially avoid heat stress due to accelerated development and earlier accumulation of dry matter. (Cherchel et al., 2020b).

Modern maize selection is based on the several basic genetic plasmas, such as Reid, Lancaster, Iodent, Lacaune, etc., which combine well with each other when crossing. The pedigree of hybrids, which entered in the State Register of Plant Varieties Suitable for Dissemination in Ukraine (hereafter State Register) and studied in the competitive variety trial by the Istitute of Grain Crops NAAS Ukraine (IGC), was analysed and revealed a high use frequency of Iodent germplasma in FAO 200-450 groups, where it is part of 47.8–83.9% of hybrids (Dziubetskyi & Cherchel, 2002). In addition, heterotic models are mostly based on Iodent, Lancaster, Reid germplasmas (Cherchel et al., 2020b). A number of scientists report on the expediency of using these germplasmas in breeding practice (Cherchel & Oleshko, 1997; Dziubetskyi et al., 1997, 2013; Dziubetskyi & Ilchenko, 2000; Mustyatsa et al., 2001; Troyer, 2009).

A series of long-term studies were launched to solve the problem of adapting the initial material to the Steppe conditions. They revealed that Lancaster germplasma lines were the most plastic in terms of selection. Significant problems had arisen at the development of Iodent and Reid germplasma lines with stable and high combining ability in terms of grain yield and balanced phenotypic traits. It was noted that the use of cyclical cumulative selection was effective for their solution (Cherchel et al., 2020b).

There is a necessity to develop a new initial material is due to the feasibility of further expanding the use of Iodent germplasma in breeding programs. The new initial material must have a number of valuable breeding properties, including an increased drought and heat resistance, tolerance to major diseases, ability to form a full-fledged yield with simultaneous flowering of female and male inflorescences, high seed yield, and etc.

The purpose of the reaserch is the cumulative improvement of the base maize line DK744 (Iodent germplasma) on breeding traits.

Materials and Methods

The research was based on the mid-early DK744 line entered in the State Register, which is one of the parental components of early ripening hybrids, such as Dniprovskyi 181SV, Pochaivskyi 190MV, Tesei, DN Palanok, Kvitnevyi 187MV, DZ Latorytsia and others. DK744 line has fairly high seed productivity, intensive loss of grain moisture content during ripening, resistance to most diseases and pests; at the same time, it has a low seed yield due to the shape of the kernel, low drought and heat resistance, and open tip of ear.

Initial material was presented by line groups obtained with self-pollination of DK744xUH6, DK744xDK6498, DK744xDK3113, DK744xDK360, and DK744xDK3610 (conditionally – DK7446, DK4464, DK7443, DK4436, DK4410) hybrids. The DK744 line was used as a maternal component in all hybrids, and a control to test new lines. Iodent germplasma lines (UH6, DK6498, DK3113, DK360, and DK3610) balanced on the main economically valuable features were used to develop a new initial material. Testers of various alternative germplasmas were used to evaluate inbred material on combining ability. The standards for testcrosses were early ripening Pochaivskyi 190MV hybrid and mid-early DN Khortytsia hybrid.

When developing lines, a standard method based on inbreeding and selection of desired plants in all subsequent generations of self-pollination was used until the necessary line homogeneity was reached. An assessment of each generation of self-pollinated families for general and specific combining ability was simultaneously carried out. (Jumbo et al., 2011; Mustyatsa et al., 2014; Dziubetskyi et al., 2020).

The breeding program provided the self-pollination of 150 F1 plants of the initial population and culling plants and ears on undesirable traits. The following year, 25–30 plants from each self-pollinated ear were grown on a plot. Up to 10 plants were self-pollinated at each plot, and the best of them were selected according to the planned program. For the third year, kernels from 3–5 ears of each selected families were sown. Later, 3–5 desired plants were self-pollinated. The best families and 3–5 ears of them were selected. In subsequent generations, it was performed self-pollination, culling of undesirable families and intrafamily selection of plants on breeding and value traits, and testing per family with testers of alternative genetic plasmas. At the last stages, testing experimental hybrids of constant lines in a control nursery and their assessment on economically valuable indicators were carried out.

Significantly large amount of culling inbred families allowed us to focus on more valuable initial material and develop a competitive genotype. Troyer points to the high efficiency of selection at culling 60–75% of self-pollinated families at S_2–S_4 stage, and the ability reducing the experimental area to 30% (Troyer, 2000).

The research was conducted in 2010-2020 at the State Enterprise Dnipro Experimental Farm of the State Enterprise Institute of Grain Crops of NAAS according to the (Lebid et al., 2008). Sowing was carried out in the second half of April. The size of the plots is 4.9 m², the replication is three times. Plant density – 50 thousand plants per hectare.

Over the years of the study, weather conditions were different; most of them were characterized by optimal temperature and sufficient precipitates for growth and development of maize. It should be noted that 2010, 2014–2016 years were drier, and 2012 was stressful. In 2012, abnormally high temperatures were observed in July, averaging 25.5°C at a norm of 21.3°C.

The distribution of precipitation by months was uneven. A significant amount of them fell in the form of hail shower and were unproductive, in addition, led to lodging and damage to plants that negatively affected the level of grain yield (Cherchel, 2018). The highest amount of precipitation was recorded in 2014 – 442.7 mm, the minimum in 2013 – 193.1 mm, a long-term average – 272.0 mm.

Statistical processing of research data was performed according to the methods by Lakin, and Atramentova – Utievska (Lakin, 1990; Atramentova & Utievska, 2007, 2014). The parameters of the combining ability of maize lines were calculated according to the recommendations (Turbin et al., 1966; Volf & Litun, 1980; Dremliuk & Gerasimenko, 1992). Data processing and systematization, and mathematical calculation were carried out with a personal computer by the special applications: Microsoft Word 2010 та Microsoft Excel 2010.

Results and Discussion

During 2010–2017, self-pollinated lines were obtained in the selection nursery by the standard method, which were conditionally assigned to DK7446, DK4464, DK7443, DK4436, DK4410 groups. In 2018–2020, the combining ability of selected lines under crossing with testers of alternative genetic plasmas was determined.

After the selection and assessment of the complex of breeding traits, self-pollinated lines with basic indicators exceeded or equal to the DK744 standard line were identified (Table 1). In particular, the average period from sprout emergence to silking stage was within 55–58 days, plant height was 135–180 cm with an ear insertion height of 35–55 cm, take into account that these standard indicators were 55 days, 150 and 40 cm, respectively. As a rule, all new lines exceeded the standard in terms of elements of yield structure: the number of ears per plant (by 3.6–35.7%), the number of kernel rows (by 12.5–25.0%), the number of kernels in a row (by 5.9–47.0%), and thousand kernel weight was almost equivalent. Resistance to lodging and major diseases was also high.

During 2018–2020, testcrosses of all groups of Iodent germplasma lines were studied in the control nursery ac-

Table 1. Characteristics of the best self-pollinated lines, average for 2018-2020

Self-pollinated line	The emergence-silking period, day	Height of plant, cm	Ear insertion height, cm	Number of ears per plant, pcs	Cob colour	Kernel consistency	Kernel number in row, pcs	Number of kernel rows, pcs	Thousand kernel weigh, g
DK7446 23-11	57	150	40	1.30	red	d*	17	18	242
DK7446 63-32	57	145	40	1.40	red	d	21	16	227
DK7446 63-33	57	140	40	1.25	red	d	24	16	218
DK7446 63-34	57	135	35	1.32	red	d	23	16	212
DK4464 62-11	55	160	50	1.19	red	d	25	16	322
DK4464 62-13	55	155	40	1.16	red	d	24	16	264
DK4464 62-21	55	140	35	1.25	red	d	19	16	250
DK4464 62-22	55	145	40	1.29	red	d	17	16	255
DK7443 41-32	56	145	45	1.52	red	d	21	20	228
DK7443 41-34	56	145	45	1.41	red	d	22	16	224
DK7443 53-12	55	140	40	1.47	red	d	19	16	222
DK4436 12-21	57	170	50	1.21	red	d	18	16	220
DK4436 31-11	58	155	50	1.18	red	d	19	18	290
DK4436 31-21	56	150	50	1.18	red	d	23	18	235
DK4410 21-22	56	155	40	1.23	red	d	18	16	232
DK4410 54-12	58	180	55	1.17	red	d	19	16	233
DK744	55	150	40	1.12	red	d	17	16	226

Note: d* – dent kernel

cording to the main indicators. It should be noted that their grain yield significantly varied depending on the conditions of the year, at the maximum level (9.81 t/ha) in 2019 and the minimum (6.80 t/ha) in 2018 (Table 2). The lower yield of testcrosses in 2018 is due to the high average monthly temperature in August (23.5°C) and the lack of precipitation during this period. It is known that the weather conditions in August to some extent affect the plant productivity formation, and determinate such characteristics as ear length, grain fullness, thousand kernel weight, grain moisture content at harvest, etc. (Cherchel, 2018).

Over the years of research, the highest average yield was observed in testcrosses of group lines of DK4436 – 8.23 t/ha and DK4410 – 8.19 t/ha. For the testcross lines of the other groups, it was smaller: 8.03 t/ha (DK7446, DK 4464) and 8.09 t/ha (DK7443). In 2018, all testcrosses of the lines provided grain yield on the level or higher of the DK744 line testcrosses (6.82 t/ha); in 2019, their grain yield was higher by 0.53–1.02 t/ha, and in 2020 – by 0.87–1.15 t/ha. They also exceeded the mid-early hybrid (standard) DN Khortytsia in 2018 and 2019. In 2020, grain yield of the hybrids of DK7446 group was less by an average of 0.09 t/ha, and other groups were at its level or slightly higher (7.58 t/ha and 7.56 t/ha, respectively). However, this group provided the greatest differentiation of testcrosses, which is showed by the variation coefficient in 2018 and 2019; and some hybrids had the highest grain yield in the experiment (7.68 and 9.81 t/ha, respectively).

Large focus in the selection of grain-type maize hybrids is paid to grain moisture content at harvesting due to significant energy costs for its post-harvest processing. This indicator determines the profitability of grain production (Cherchel et al., 2020a; Kyrpa et al., 2020), as well as affected to the quality of harvesting by combine (Chistiakov, 2013).

In the years of research, this indicator for all groups of lines and standards was close to the base moisture content (14%) or

Table 2. Grain yield of testcrosses depending on the environmental condition of research years, t/ha

Year	Indicator	Groups of lines							
		DK7446	DK4464	DK7443	DK4436	DK4410	DK744	Pochaivskyi 190MV	DN Khortytsia
	N, pcs	13	16	18	7	16	–	–	–
2018	$\bar{x}\pm s(\bar{x})$	6.80±0.1	7.01±0.1	7.04±0.1	7.17±0.1	6.80±0.1	6.82	6.89	6.33
	Lim	5.94-7.68	6.43-7.51	6.65-7.56	6.53-7.60	6.09-7.23			
	V, %	7.7	5.0	3.9	5.5	4.9			
2019	$\bar{x}\pm s(\bar{x})$	9.81±0.2	9.50±0.1	9.50±0.1	9.97±0.1	9.99±0.1	8.97	7.74	9.19
	Lim	8.53-11.04	8.41-10.32	8.78-10.19	9.11-10.37	8.80-10.83			
	V, %	7.7	5.8	4.2	4.4	5.2			
2020	$\bar{x}\pm s(\bar{x})$	7.49±0.2	7.58±0.1	7.72±0.1	7.56±0.1	7.77±0.1	6.62	5.72	7.58
	Lim	6.32-8.41	6.84-8.30	6.09-8.70	7.05-7.98	7.26-8.71			
	V, %	9.4	6.0	8.3	4.7	6.1			
Average		8.03	8.03	8.09	8.23	8.19	7.47	6.78	7.70

Table 3. Grain moisture content at harvesting testcrosses depending on the environmental condition of research years, %

Year	Indicator	Groups of lines							
		DK7446	DK4464	DK7443	DK4436	DK4410	DK744	Pochaivskyi 190MV	DN Khortytsia
	N, pcs	13	16	18	7	16			
2018	$\bar{x}\pm s(\bar{x})$	14.7±0.3	14.3±0.2	14.7±0.1	14.6±0.2	15.5±0.2	15.4	16.4	15.7
	Lim	12.5-16.6	13.2-15.6	14.2-15.9	13.5-15.5	14.0-17.0			
	V, %	5.8	5.6	3.5	4.7	5.2			
2019	$\bar{x}\pm s(\bar{x})$	12.7±0.4	12.9±0.4	13.9±0.4	12.4±0.4	12.9±0.3	11.1	8.8	12.1
	Lim	10.1-15.5	10.7-15.2	9.3-16.5	10.0-13.4	10.4-14.7			
	V, %	12.3	12.4	12.6	9.5	10.6			
2020	$\bar{x}\pm s(\bar{x})$	7.2±0.3	7.4±0.2	7.8±0.3	7.3±0.4	7.1±0.2	7.8	7.9	7.8
	Lim	5.3-9.5	5.0-8.7	5.4-9.9	6.2-8.9	5.7-9.1			
	V, %	18.6	14.9	16.4	15.5	15.2			
Average		11.5	11.5	12.1	11.4	11.8	11.4	11.0	11.8

much lower than it. In 2018, the grain moisture content of testcrosses averaged from 14.3 to 15.5%, this indicator was slightly lower (from 12.4 to 13.9%) in 2019, and the average values of this indicator ranged from 7.1 to 7.8% in 2020 (Table 3).

The low grain moisture content of testcrosses was primarily caused by their precocity and weather conditions, in particular, in 2020 it was due to high average air temperatures in August and September (above the long-term annual average of 1.5°C and 4.0°C, respectively) and lack of precipitation in the period when drying grain (Cherchel, 2018).

In 2018, the testcrosses of DK4410 lines had wettest grain at harvesting, in 2019–2020 – DK7443. The variation coefficient was characterized by an inverse value to the average annual, and increased with decreasing absolute values. Selection of samples with high rates of water yielding capacity was impossible due to low assessment values.

Positive results in the selection of high-yielding hybrids can be achieved when the parental forms have high combining ability (Hallauer et al., 2010), which can be detected by two indicators: the average value of heterosis in all hybrid combinations, and deviations from this value in a particular combination. The first value characterizes the general combining ability (GCA), and the second – the specific combining ability (SCA) of the lines (Federer & Spraque, 1947; Mustyatsa et al., 1991).

For a clearer assessment of testcrosses by indicators of GCA effects, the lines were divided into conditional classes relative to the average in the trial: 1 – assessmens of GCA effects significantly exceeded it; 2 – insignificantly differ from it; 3 – significantly lower.

The combining ability analysis of the line according to grain yield in our trials showed that the lines of DK7446 – DK7446 23-11, DK7446 63-32, DK7446 63-33, DK7446 63-34 groups had the smallest class sum (3) and stable positive assessments of GCA effects during all three years of research, and lines of DK7446 14-12, DK7446 41-12, DK7446 63-11, on the contrary, had the negative indicators of GCA effects (Table 4). The GCA effects of the other lines were unstable.

The specific combinating ability variances of lines over the years of research ranged from 0.01 to 2.02. High SCA variances were noted in DK7446 23-12 line in 2019 (0.98) and in 2020 (2.02) that indicated significant yield fluctuations of its testcrosses. The rest of the lines had low variances of specific combining ability. This indicates that they can provide a practically identical level of yield in all crosses.

It is noted that 76.9% of DK7446 group lines had the average value of GCA effect assessments higher than the DK744 standard line.

In the DK4464 group, 37.5% of lines had a positive value of GCA effects, 18.75% – negative and 43.75% – unstable value over the years (Table 5). DK4464 62-11 and DK4464 62-13 lines were characterized by high stable assessments of GCA effects (0.16; 0.87; 0.65 and 0.51; 0.23; 0.72, according to research years). 31.25% of lines were noted negative values of GCA effects for two years out of three, and 12.5% of lines had positive values of GCA effects for two years and negative values for one year (DK4464 15-21 and DK4464 42-12 lines). GCA effects in term of grain yield of the standard line DK744 were negative in all years of research and

Table 4. GCA effects and SCA variances by grain yield for DK7446 group lines, t/ha

Line	2018		2019		2020		Class sum
	GCA effects	SCA variances	GCA effects	SCA variances	GCA effects	SCA variances	
DK7446 11-13	-0.25^{3*}	0.31	-0.26^{3}	0.06	0.74^{1}	0.01	7
DK7446 14-12	-0.65^{3}	0.02	-0.34^{3}	0.15	-0.91^{3}	0.01	9
DK7446 23-11	0.19^{1*}	0.19	0.85^{1}	0.11	0.20^{1}	0.09	3
DK7446 23-12	0.21^{1}	0.01	-0.30^{3}	0.98	0.62^{1}	2.02	5
DK7446 23-21	0.51^{1}	0.10	-0.60^{3}	0.11	-0.53^{3}	0.25	7
DK7446 41-12	-0.34^{3}	0.07	-1.00^{3}	0.01	-0.93^{3}	0.07	9
DK7446 43-12	-0.55^{3}	0.39	0.87^{1}	0.12	-0.95^{3}	0.01	7
DK7446 63-11	-0.57^{3}	0.19	-0.59^{3}	0.81	-0.02^{2}	0.01	8
DK7446 63-12	0.03^{2*}	0.01	-0.85^{3}	0.08	0.25^{1}	0.32	6
DK7446 63-13	-0.03^{2}	0.01	0.45^{1}	0.13	0.40^{1}	0.15	4
DK7446 63-32	0.36^{1}	0.01	0.26^{1}	0.01	0.38^{1}	0.35	3
DK7446 63-33	0.75^{1}	0.01	1.24^{1}	0.13	0.82^{1}	0.01	3
DK7446 63-34	0.31^{1}	0.01	0.96^{1}	0.12	0.71^{1}	0.01	3
DK744	0.03^{2}	0.16	-0.69^{3}	0.36	-0.78^{3}	0.01	8
$LSD_{0.05}$	0.13	0.13	0.10	0.10	0.10	0.10	

Note: 1*, 2 *, 3 * – GCA assessment class significantly lower than of 56.3% of lines in this group. The greatest value among them is DK4464 13-11, DK4464 15-21, DK4464 62-11, DK4464 62-13, DK4464 62-21, DK4464 62-22 lines with the class sum of 3 and 4.

It should be noted that DK4464 62-11 line had the lowest class sum (3) by GCA effects and combined high assessments of GCA and SCA effects. According to Krivosheev & Ignatiev, 2011, such genotypes are valuable in the selection of hybrids for different climatic zones.

Negative assessments of the GCA effects were mostly noted among the lines of the DK7443 group (Table 6). Testcrosses of DK7443 41-23, DK7443 43-23 lines were sensitive to growing conditions. Their assessments of the GCA effects by the grain yield (-0.03; 0.08; 0.65 and -0.09; 0.02; 0.30, according to years) changed from negative in 2018 to positive in 2019–2020. DK7443 43-24 line, on the contrary, in the first two years of the research had positive assessments of the GCA effects, but in 2020 significantly reduced them. Hybrids, which were developed with the help of lines with unstable GCA effects, are more recommended to favorable growth conditions. Only three lines of this group (DK7443 41-32, DK7443 41-34, DK7443 53-12) were characterized by positive GCA assessments and a minimum class sum (3) by GCA effects. They have the greatest value in the selection of high-yield hybrids.

Low SCA variances were observed in most lines of the DK7443 group, and only a small number of lines had high SCA values with low GCA effects for two consecutive years (DK7443 43-24, DK7443 53-11, DK7443 53-13 lines). The high SCA variances indicate significant fluctuations in testcross yield obtained with their participation (Mustyatsa et al., 1991).

At assessment of the DK4436 group lines, DK4436 12-21, DK4436 31-11, DK4436 31-21 lines were extracted on the bases of the positive GCA effects on combination ability by grain yield (Table 7). Negative assesments of GCA effects in all years of research were obtained for the standard line DK744 and DK4436 12-11, DK4436 12-31 lines (class sum on GCA effects – 9, 9 and 8), unstable assesments over the years – for DK4436 12-12 and DK4436 12-22 lines (class sum – 5). Lines with low negative indicators on combination ability should not be included in the further breeding process.

In the DK4410 group, the highest level of adaptability to environments among the studied lines was showed by DK4410 21-22, DK4410 54-12 with the lowest class sum (3) (Table 8). The DK4410 42-11, DK4410 54-21 lines had negative assessments of GCA effects over all years of research (class sum – 9), which gives grounds to consider them unpromising in further use.

The DK4410 11-12, DK4410 21-12, DK4410 54-11, DK4410 54-13 lines had positive assessment of GCA effects in 2018 and 2020, and negative – in 2019. It is indicated that their testcrosses have the yield instability and can be used only in certain conditions.

Table 5. GCA effects and SCA variances by grain yield for DK4464 group lines, t/ha

Line	2018		2019		2020		Class sum
	GCA effects	SCA variances	GCA effects	SCA variances	GCA effects	SCA variances	
DK4464 13-11	0.13^{1*}	0.01	0.18^{1}	0.17	0.13^{1}	0.24	3
DK4464 15-21	0.18^{1}	0.19	0.73^{1}	0.03	-0.01^{2}	0.35	4
DK4464 15-22	-0.30^{3*}	0.44	-0.51^{3}	0.05	-0.07^{2}	0.31	8
DK4464 42-11	-0.25^{3}	0.05	0.41^{1}	0.22	-0.42^{3}	0.01	7
DK4464 42-12	0.21^{1}	0.01	-0.47^{3}	0.32	0.76^{1}	0.87	5
DK4464 51-11	-0.10^{2*}	0.01	0.46^{1}	0.35	-0.10^{2}	0.79	5
DK4464 62-11	0.16^{1}	0.59	0.87^{1}	0.13	0.65^{1}	0.71	3
DK4464 62-12	0.46^{1}	0.12	0.07^{2}	0.08	0.09^{2}	0.75	5
DK4464 62-13	0.51^{1}	0.06	0.23^{1}	5.81	0.72^{1}	0.16	3
DK4464 62-21	0.25^{1}	0.01	0.21^{1}	0.56	0.15^{1}	0.26	3
DK4464 62-22	0.19^{1}	0.07	0.23^{1}	0.02	0.49^{1}	0.59	3
DK4464 81-11	0.13^{1}	0.02	-0.91^{3}	0.17	-0.36^{3}	0.39	7
DK4464 83-11	-0.41^{3}	0.03	0.04^{2}	0.28	-0.60^{3}	0.40	8
DK4464 83-12	-0.33^{3}	0.01	-0.48^{3}	0.81	-0.22^{3}	0.02	9
DK4464 83-13	-0.19^{3}	0.11	0.25^{1}	0.33	-0.14^{3}	0.13	7
DK4464 83-21	-0.39^{3}	0.01	-0.84^{3}	0.54	-0.38^{3}	0.30	9
DK744	-0.25^{3}	0.01	-0.47^{3}	0.37	-0.69^{3}	0.05	9
$LSD_{0.05}$	0.10	0.06	0.10	0.02	0.10	0.10	

Note: 1*, 2 *, 3 * – GCA assessment class

Selection on the bases of high combining ability by grain yield, and assessment of valuable agronomic indicators among the study line groups allowed to identify testcrosses, which significantly exceeded the best standard hybrid DN Khortytsia on term of grain yield by 0.61–1.34 t/ha at less or close to it moisture content (Table 9).

The general assessment of inbred lines allowed to identify the best groups by an indicator set. In particular, among the lines of DK7446 and DK4464 groups, we extracted 4 samples, while in the DK4410 group – only 2. The average grain yield of the first two groups was the lowest. Thus, intrafamilial diversity may be a priority in the selection on specific combining ability.

It should be noted that a grain yield of the experimental hybrids was higher by 0.84-1.57 t/ha than the testcrosses of the standard line DK744, that confirms the high efficiency of the selection. This is confirmed by the fact that the DK7443 line was one of the parental components of DN Straid and DN Pulsatsiia hybrids entered in the State Register of Plant Varieties of Ukraine. Another 6 lines are the parental forms of pilot hybrids, and are also used in the selection of new lines of subsequent cycles.

Table 6. GCA effects and SCA variances by grain yield for DK7443 group lines, t/ha

Line	2018		2019		2020		Class sum
	GCA effects	SCA variances	GCA effects	SCA variances	GCA effects	SCA variances	
DK7443 12-11	-0.38[3]	0.03	-0.43[3]	0.48	-1.24[3]	0.21	9
DK7443 41-21	-0.05[2]	0.01	-0.34[3]	0.13	-0.38[3]	1.18	8
DK7443 41-22	-0.44[3]	0.02	-0.43[3]	0.15	0.14[1]	1.21	7
DK7443 41-23	-0.03[2]	0.03	0.08[1]	0.08	0.65[1]	0.01	4
DK7443 41-31	0.55[1]	0.05	-0.09[3]	0.15	-0.34[3]	0.08	7
DK7443 41-32	0.32[1]	0.10	0.64[1]	0.09	0.31[1]	0.30	3
DK7443 41-33	0.01[2]	0.01	-0.12[3]	0.99	-0.55[3]	0.24	8
DK7443 41-34	0.43[1]	0.01	0.58[1]	0.25	0.69[1]	0.24	3
DK7443 41-35	-0.03[2]	0.01	0.22[1]	0.12	-0.15[3]	0.68	6
DK7443 43-21	0.06[1]	0.27	-0.15[3]	0.26	-0.01[2]	0.19	6
DK7443 43-23	-0.09[3]	0.01	0.02[2]	0.02	0.30[1]	0.79	6
DK7443 43-24	0.04[2]	0.14	0.18[1]	0.35	-0.06[2]	0.41	5
DK7443 43-25	-0.18[3]	0.01	0.05[1]	0.05	-0.34[3]	0.20	7
DK7443 43-32	0.08[1]	0.03	0.02[2]	0.12	0.58[1]	0.23	4
DK7443 43-33	-0.14[3]	0.14	-0.07[3]	0.05	0.57[1]	0.11	7
DK7443 53-11	-0.18[3]	0.78	-0.01[2]	0.21	-0.14[3]	1.26	8
DK7443 53-12	0.41[1]	0.03	0.45[1]	0.22	0.79[1]	0.02	3
DK7443 53-13	-0.17[3]	0.06	-0.22[3]	1.92	-0.11[3]	0.58	9
DK744	-0.21[3]	0.12	-0.38[3]	0.53	-0.71[3]	0.11	9
$LSD_{0.05}$	0.05	0.05	0.02	0.02	0.06	0.06	

Note: 1*, 2 *, 3 * – GCA assessment class

Table 7. GCA effects and SCA variances by grain yield for DK4436 group lines, t/ha

Line	2018		2019		2020		Class sum
	GCA effects	SCA variances	GCA effects	SCA variances	GCA effects	SCA variances	
DK4436 12-11	-0.48[3]	0.29	-0.62[3]	0.05	-0.39[3]	0.04	9
DK4436 12-12	0.18[1]	0.01	0.22[1]	0.22	-0.21[3]	0.02	5
DK4436 12-21	0.32[1]	0.17	0.24[1]	0.14	0.49[1]	0.10	3
DK4436 12-22	0.13[1]	0.24	-0.22[3]	0.15	0.38[1]	0.33	5
DK4436 12-31	-0.29[3]	0.01	-0.01[2]	0.41	-0.15[3]	0.02	8
DK4436 31-11	0.24[1]	0.08	0.56[1]	0.34	0.27[1]	0.06	3
DK4436 31-21	0.06[1]	0.01	0.54[1]	0.07	0.35[1]	0.05	3
DK744	-0.16[3]	0.35	-0.71[3]	0.45	-0.74[3]	0.01	9
$LSD_{0.05}$	0.02	0.02	0.01	0.01	0.02	0.02	

Note: 1* , 2 * , 3 * – GCA assessment class

Table 8. GCA effects and SCA variances by grain yield for DK4410 group lines, t/ha

Line	2018		2019		2020		Class sum
	GCA	SCA	GCA	SCA	GCA	SCA	
DK4410 11-11	-0.14^{3}	0.08	0.59^{1}	0.46	1.09^{1}	0.43	5
DK4410 11-12	-0.23^{3}	0.20	0.06^{1}	0.01	-0.79^{3}	0.33	7
DK4410 11-21	0.46^{1}	0.04	-0.13^{3}	0.19	-0.46^{3}	0.11	7
DK4410 11-22	0.28^{1}	0.07	-0.97^{3}	1.13	-0.82^{3}	0.16	7
DK4410 12-11	0.32^{1}	0.15	0.49^{1}	0.55	-0.46^{3}	0.12	5
DK4410 11-12	0.12^{1}	0.11	-0.67^{3}	0.24	1.24^{1}	0.17	5
DK4410 21-12	0.09^{1}	0.16	-0.04^{3}	0.22	0.87^{1}	0.22	5
DK4410 21-22	0.33^{1}	0.07	0.83^{1}	0.75	0.46^{1}	0.39	3
DK4410 41-12	-0.51^{3}	0.19	0.21^{1}	0.58	-0.49^{3}	0.25	7
DK4410 41-21	-0.46^{3}	0.04	0.62^{1}	0.19	-0.43^{3}	0.15	7
DK4410 42-11	-0.58^{3}	0.25	-0.06^{3}	0.12	-1.13^{3}	0.05	9
DK4410 52-11	-0.09^{3}	0.05	0.62^{1}	0.46	-0.54^{3}	0.06	7
DK4410 54-11	0.14^{1}	0.03	-0.22^{3}	0.29	0.59^{1}	0.16	5
DK4410 54-12	0.33^{1}	0.07	0.27^{1}	0.01	1.42^{1}	1.22	3
DK4410 54-13	0.17^{1}	0.05	-0.25^{3}	0.17	1.32^{1}	0.43	5
DK4410 54-21	-0.14^{3}	0.06	-0.47^{3}	0.01	-0.54^{3}	0.97	9
DK744	-0.09^{3}	0.03	-0.88^{3}	0.42	-1.33^{3}	0.42	9
LSD $_{0.05}$	0.02	0.02	0.01	0.01	0.14	0.02	

Note: 1*, 2 *, 3 * – GCA assessment class

Table 9. Average grain yield (t/ha) and moisture content (%) of testcrosses of the best lines, 2018-2020

Testcrosses of lines	2018		2019		2020		Average	
	t/ha*	%**	t/ha	%	t/ha	%	t/ha	%
DK7446 63-33	7.68	14.5	11.04	11.8	8.41	6.4	9.04	10.9
DK7443 53-12	7.53	14.4	10.19	9.3	8.70	6.6	8.81	10.1
DK7443 41-34	7.42	14.5	10.17	13.5	8.51	8.5	8.70	12.2
DK4410 54-12	7.10	14.0	10.24	10.9	8.71	5.9	8.68	10.3
DK4410 21-22	7.10	15.4	10.83	12.8	7.86	6.1	8.60	11.4
DK7446 63-34	7.18	14.7	10.49	13.0	8.12	6.7	8.60	11.5
DK4436 12-21	7.60	14.8	10.15	13.4	7.98	6.4	8.58	11.5
DK4464 62-11	7.17	15.0	10.32	13.9	8.19	6.9	8.56	11.9
DK4436 31-11	7.48	13.6	10.37	12.0	7.71	6.5	8.52	10.7
DK4464 62-13	7.51	14.2	9.73	11.0	8.27	8.6	8.50	11.3
DK7443 41-32	7.33	14.6	10.16	14.2	8.00	7.9	8.50	12.3
DK4436 31-21	7.13	14.6	10.36	10.0	7.81	6.7	8.43	10.4
DK7446 23-11	6.95	14.7	10.65	11.7	7.58	9.4	8.40	11.9
DK7446 63-32	7.22	14.6	9.97	12.7	7.83	7.6	8.34	11.6
DK4464 62-22	7.26	13.2	9.73	11.4	7.99	5.0	8.33	9.9
DK4464 62-21	7.35	13.9	9.70	10.7	7.87	7.2	8.31	10.6
DK744	6.82	15.4	8.97	11.1	6.62	7.8	7.47	11.4
Pochaivskyi 190MV	6.89	16.4	7.74	8.8	5.72	7.9	6.78	11.0
DN Khortytsia	6.33	15.7	9.19	12.1	7.58	7.8	7.70	11.8
LSD $_{0.05}$	0.08	0.15	0.12	0.32	0.11	0.26		

Note: * – grain yield, ** – grain moisture content

Conclusions

At the selection by the standard method, a number of lines with the best trait set compared to the initial form were obtained. Their testcrosses dominated over DK744 testcrosses on grain yield by 0.84–1.57 t/ha with grain moisture content less than or close to them. The obtained lines became the basis of the renew base collection of precocious Iodent germplasma lines, and they are widely used in the synthesis of drought- and heat-resistant hybrids with wide adaptive potential and capability to form stable and high yields with low grain moisture content at harvesting.

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