

Article

Utilization of Iodent Germplasm in Breeding New High-Performing Maize Hybrids

Roxana Elena Călugăr ¹, Andrei Varga ^{1,*}, Carmen Daniela Vana ^{1,†}, Loredana Ancuța Ceclan ¹, Andras Fodor ^{1,2}, Alina Șimon ¹, Felicia Chețan ¹ and Alexandru Costin ²

¹ Agricultural Research and Development Station Turda, 401100 Turda, Romania; roxana.calugar@scdaturda.ro (R.E.C.); carmen.vana@scdaturda.ro (C.D.V.); anca.ceclan@scdaturda.ro (L.A.C.); andras.fodor@scdaturda.ro (A.F.); alina.simon@scdaturda.ro (A.Ș.); felicia.chetan@scdaturda.ro (F.C.)

² Department of Crops Sciences, University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca, Mănăstur Street 3–5, 400372 Cluj-Napoca, Romania; alexdan.costin@gmail.com

* Correspondence: andrei.varga@scdaturda.ro

† These authors contributed equally to this work.

Abstract

Maize (*Zea mays* L.) can be classified into several germplasm groups and crossing between these groups can produce hybrids with high heterosis. Iodent is one of the most widely used heterotic groups, both for creating new inbred lines and for developing high-performing hybrids. Thirteen inbred lines (nine Iodent and four Iodent mixed) were used as maternal parents to create new hybrids, which were tested during the 2020–2025 period at the Agricultural Research and Development Station Turda. Agronomic traits, including grain yield, the percentage of unlodged plants and dry matter content at harvest were evaluated as selection criteria to identify elite parental lines. Additionally, Principal Component Analysis (PCA) was performed as an exploratory multivariate analysis to investigate relationships among the maternal inbred lines based on grain yield, unlodged plants and dry matter. Hybrids derived from female line A452 outperformed the trial mean in all years studied, whereas those using line E390 as the female parent exceeded the average in five out of six years. PCA provided an exploratory visualization of the multivariate relationships among the evaluated maternal inbred lines.

Keywords: inbred line; heterotic group; line ×x tester

1. Introduction

Maize (*Zea mays*) is one of the primary crop plants worldwide, with both cultivated areas and yields having significant values. According to the Food and Agriculture Organization of the United Nations (FAOSTAT) data [1], in 2024, over 209 million ha were cultivated worldwide with this crop, being surpassed only by wheat. The most extensive areas cultivated with maize are found in China (44.7 million ha), the USA (33.5 million ha) and Brazil (21.1 million ha), with Romania ranking 20th with 2.1 million ha. At the European Union level, Romania has the largest maize area, followed by France and Poland. Regarding total production, however, the ranking is different: maize is the cereal with the highest total production globally, with the top yields recorded in the USA, while at the European Union level, Romania ranks third. In Romania, both in terms of cultivated areas and total production, maize ranks second after wheat. In recent decades, the areas

Academic Editor: Ai-Sheng Xiong

Received: 26 June 2026

Revised: 29 July 2026

Accepted: 30 July 2026

Published: 31 July 2026

Copyright: © 2026 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the [Creative Commons Attribution \(CC BY\)](https://creativecommons.org/licenses/by/4.0/) license.

cultivated with maize have represented between 26.7% (2023) and 38.4% (2004) of the total cultivated area in Romania [2]. In recent years, a reduction in the areas destined for maize has been observed, primarily due to drought and heat phenomena that have led to crop failure or extremely low yields.

Maize germplasm exhibits a rich diversity both phenotypically and genotypically. Depending on these differences, the germplasm resources were grouped into several heterotic groups, each characterized by specific traits. Single cross breeding accelerated the maize breeding progress while heterotic classification was given increased attention to better exploit the phenomenon of heterosis [3]. Heterotic groups are genetically distinct and when crossed, they produce hybrids with high heterosis [4]. Corn Belt Dent germplasm, one of the most widely used resources in the breeding programs, can be divided into three main heterotic groups: Stiff Stalk (SS), Non-Stiff Stalk (NSS) and Iodent, each having subgroups [3,5]. However, some sources indicate that the Non-Stiff Stalk group incorporates inbreds from various lines and origins, including the elite Lancaster Sure Crop lines, the Iodent group and other populations or synthetics [6,7]. Some authors suggest the classification of dent maize into Iowa Stiff Stalk Synthetic (BSSS) and non-BSSS heterotic groups [8], while others suggests grouping them into Reid Yellow Dent (includes BSSS), Lancaster and miscellaneous heterotic groups (i.e., inbred lines developed from crosses between the major heterotic groups) [9]. The Reid Yellow Dent, one of the most productive and hardiest corns ever developed, is the largest group and contributes to the genetic background for approximately 51% of US hybrids [10,11].

Modern clustering indicates two major heterotic groups: Stiff Stalk (SS) and Non-Stiff Stalk (NSS), which was formed by the merging and genetic homogenization of the ancestral Iodent and Lancaster [6]. Iodent, a main contributor to the Non-Stiff Stalk heterotic germplasm, originated from Pioneer Hi-Bred International germplasm in the 1940s [12]. This germplasm is characterized by hard kernels, rapid grain drying and exhibits good general combining ability with Stiff Stalk genotypes. A significant number of researchers have worked over time to improve these germplasm groups, developing Iodent maize inbred lines (PH207, PHP02, PHTD5, PH24E, PHR25, DK1274, DK213, DK216, DK234, DK237, DK555, DK714/195, DK744) [10,13,14].

In Europe, Iodent germplasm can be used successfully due to its shorter vegetative period and has also served as a source of earliness for improving Lancaster germplasm. The narrower genetic base of Iodent led to the introduction of other genetic backgrounds to enhance diversity; for example Lancaster germplasm was used to improve environmental resilience, leading to the formation of subgroups such as the Iodent-Oh43 Non-Stiff Stalk [6,15]. Iowa Stiff Stalk Synthetic, Lancaster Sure Crop, Iodent, European Flint as well as miscellaneous groups were identified in the southeastern and eastern Europe, and are widely used in breeding programs [16–18].

In Romania, the main public entities active in maize breeding activities, namely the National Agricultural Research and Development Institute Fundulea and the Agricultural Research and Development Station (ARDS) Turda, both hold an impressive collection of Lancaster, Iodent, European Flint and miscellaneous germplasm [19–21]. A large part of the inbred lines in the germplasm collection of the ARDS Turda belong to the Iodent group, one of the most widely used in crosses made to create new hybrids. The lines belonging to the Iodent group are crossed with either Lancaster, Flint or miscellaneous lines. Between 2020 and 2025, a series of hybrids created by crossing 13 inbred lines belonging to the Iodent or Iodent-miscellaneous group with new inbred lines (obtained in the selection field or other elite lines) were studied. The aim was both to identify the lines with a good general combining ability for further use in creating new hybrids or inbred lines, as well as to identify the best hybrid combinations.

2. Materials and Methods

2.1. Biological Material

Considering that the Iodent group is the most representative in the modern maize germplasm used in the breeding program at ARDS Turda, 13 elite lines (Table 1) were selected and used as the maternal parent in order to obtain new maize hybrids. These lines belong either to the Iodent group (nine inbreds) or combinations of Iodent with another groups (four inbreds). Each year, at least 10 different inbred lines were used as paternal parent (testers) (Table 2) in a line $\times$ tester cyclic crossing system. The maternal lines remained constant across all experimental years, whereas the paternal lines varied. Each maternal line was crossed with all paternal lines used in the experiment during that respective year. Thus, following the crosses, 156 hybrids were evaluated in both 2020 and 2021, 143 hybrids in each of the years 2022 and 2023 and 130 hybrids in each of the years 2024 and 2025, respectively.

Table 1. Maternal inbred lines used in crossings.

Maternal Line	Germplasm Group	GDD * (growing- BBCH 65)	GDD * (growing- BBCH 87)	Ear Average Length (cm)	Number of Kernel Rows	Predominant Grain Type	Grain Color	Cob Color
E293	Iodent	600	1100	13	16–18	Flint	Dark yellow	Red
C344	Iodent	697	1126	18	16	Semi-dent	Dark yellow	Red
E359	Iodent	643	1131	13	14–16	Semi-dent	Dark yellow	Red
A452	Iodent	683	1131	12	14–18	Semi-dent	Dark yellow	Red
A470	Iodent	681	1137	12	16–18	Semi-dent	Yellow	Red
A475	Iodent	620	1100	16	18–22	Dent	Dark yellow	Red
A477	Iodent	648	1137	16	18	Flint	Dark yellow	White
A478	Iodent	648	1150	12	16–18	Semi-dent	Dark yellow	Pink
A480	Iodent	648	1137	12	18–20	Semi-dent	Dark yellow	White
E389	Iodent + Lo3	620	1100	13	16–18	Dent	Dark yellow	Red
E390	Iodent + Lo3	620	1100	17	14–16	Flint	Dark yellow	Red
A447	Iodent + Oh43	657	1131	13	16–18	Dent	Dark yellow	Red
A483	Iodent + B73	700	1200	20	16–18	Dent	Dark yellow	Pink

* Growing Degree Days Index.

Table 2. Tester inbred lines used in crossings.

Paternal Line	Germplasm Group	Year Tested					
		2020	2021	2022	2023	2024	2025
B 2009	Euroflint (Lo3) + Iodent	x	x				
B 2074	Iodent + NSS (Oh43)	x	x				
B 2077	Euroflint + Iodent	x	x				
B 2087	NSS (Oh43) + Iodent	x	x				
B 2008	Iodent	x	x				
E 329	Lancaster (Mo 17)	x	x				
E 348	Iodent	x	x				
A 473	NSS (Oh 43)	x	x				
E292	Lancaster (Mo 17)	x	x	x	x		
E 385	BSSS (B73)	x	x	x	x		
B 2057	Lancaster + Iodent	x	x	x	x		
E 373	Lancaster (Mo 17 + C 103)	x	x	x	x		
F 308	NSS (Oh43) + Iodent			x	x		
B 330	Euroflint			x	x		

E 342	Lancaster	x	x				
E 381	Iodent	x	x				
E391	Lancaster + BSSS	x	x				
F 317	Iodent + NSS (Oh43)	x	x				
F 320	BSSS (B73)	x	x	x	x		
F 319	Iodent + BSSS (B73)			x	x		
F 312	Lancaster			x	x		
F 322	Iodent + Lancaster			x	x		
F 323	NSS (Oh 43) + Lancaster (Mo 17)			x	x		
F 324	NSS (Oh 43) + Lancaster (Mo 17 + C103) + Iodent			x	x		
F 325	Iodent			x	x		
F 327	NSS (Oh 43) + Lancaster (Mo 17 + C103)			x	x		
F 335	Iodent + NSS (Oh 43)			x	x		
No testers/year		12	12	11	11	10	10

The resulting hybrids were tested during the 2020–2025 period, in the ARDS Turda Maize breeding laboratory fields. The maternal inbred lines used in the present study are presented in Table 1.

The inbred lines used as the paternal parent (Table 2) varied over the six-year period ranging from two to four years, depending on the results. If a line used as a paternal parent does not yield satisfactory results, it is withdrawn from the breeding program. If it shows outstanding performance in only a single hybrid or a limited number of hybrids, only those hybrids will continue to be tested. Furthermore, new inbred lines are introduced annually into the breeding program for testing; thus, new lines began testing in the years 2022, 2023 or 2024.

2.2. Cultivation Technology

The hybrids were tested between 2020 and 2025 under the pedoclimatic conditions encountered in the ARDS Turda Maize breeding experimental fields, Cluj County, Romania (longitude 23°48' E, latitude 46°35' N).

The soils of the experimental site are vertical clay-iluvial chernozems, having an average pH of 6.2–6.8, approximately 0.2% total nitrogen, 0.7% carbonates and 3.5% humus [22].

A three-year rotation (soybeans–winter wheat–maize) is used in the experimental field. The soil was plowed in the autumn, while in the spring, a superficial pass was made with the combiner concurrent with the application of fertilizers (400 kg ha⁻¹ of NPK 27:13.5:0 from Azomureș, Târgu Mureș, Romania [23]).

Sowing was performed using the Monoseed DT seeder (Wintersteiger, Ried im Innkreis, Austria) [24] in the optimal period of the area, i.e. end of April–beginning of May. The sowing density was 70,000 plants ha⁻¹ (19 cm between plants, 0.7 m spaced rows, 5 m long rows). Data from two rows were analyzed (two marginal ones were excluded), resulting a 7 m² plot. The plots were arranged using the randomized block method, with three replications.

Weed control was performed using a pre-emergence and a post-emergence herbicide (pre-emergence 1.5 L ha⁻¹ of Tender 960 EC, by Syngenta Crop Protection AG, Basel, Switzerland and post-emergence 1.5 L ha⁻¹ of Laudis66OD, by BayerAG, Crop Science Division, Monheim am Rhein, Germany).

The total number plants and of lodged ones was counted from each plot, before harvest. The Wintersteiger Classic combine for experimental plots (Wintersteiger, Ried im Innkreis, Austria) [25] was used for harvest. The grain moisture was determined with the

analyzer included in the combine. The grain weight from each plot, related to the number of plants, was used to determine the yield ha^{-1} .

Grain yield per hectare was calculated by dividing the grain weight from a plot by the number of plants, then multiplying the result by the plant density. Then, it was adjusted to reference moisture content of 14%.

2.3. Statistical Analysis

Three variables were evaluated in this study: yield (kg ha^{-1}), unlodged plants (%) and dry matter (%). To determine differences among the 13 maternal parents, one-way ANOVA was applied when the assumption of normality was met. The results were presented as mean values followed by standard deviation (SD).

The value of each maternal line was estimated as a deviation to the mean of all hybrids involving that line from the mean of all hybrids tested in that year, using the line $\times$ tester test based on the formula [26,27]:

$$g_i = \bar{X}_i - \mu$$

where: g_i = maternal line i deviation, $\bar{X}_i$ = mean performance of maternal line i , across all testers (paternal inbred lines) in that specific year and μ = overall mean of all hybrids within the same year.

Principal Component Analysis (PCA) was performed as an exploratory multivariate technique to visualize the relationships among the maternal inbred lines based on three agronomic traits: grain yield (kg ha^{-1}), unlodged plants (UP, %) and dry matter at harvest (DM, %). The analysis was conducted using the mean values of each maternal inbred line calculated across the six experimental years (2020–2025). Prior to PCA, the variables were centered and standardized to unit variance to account for differences in measurement scales. Thus, each point in the PCA biplot represents one maternal inbred line described by its six-year average values for the three measured traits. PCA was used exclusively as an exploratory visualization tool and not for hypothesis testing or formal discrimination among breeding groups. The PCA visualizations were generated using the factoextra package in R [28], while all statistical analyses were carried out using R software (version 4.5.2) [29].

3. Results

3.1. Climatic Conditions

The meteorological conditions (Figure 1) in the six experimental years were very variable, with differences in average temperatures, the amount of precipitation recorded, as well as their uneven distribution, both within a year and between years. Mean temperatures across all experimental seasons consistently surpassed the 60-year historical climate normal preceding the study.

The moderate temperatures of 2020, with values close to the multiannual average, combined with increased rainfall, especially in June and July, created favorable conditions for maize development.

Starting in 2021, an increase in the number of days with maximum temperatures exceeding 32°C was observed during the maize anthesis period. That year, however, these high temperatures were associated with abundant rainfall, making it one of the best years for maize cultivation in the experimental area.

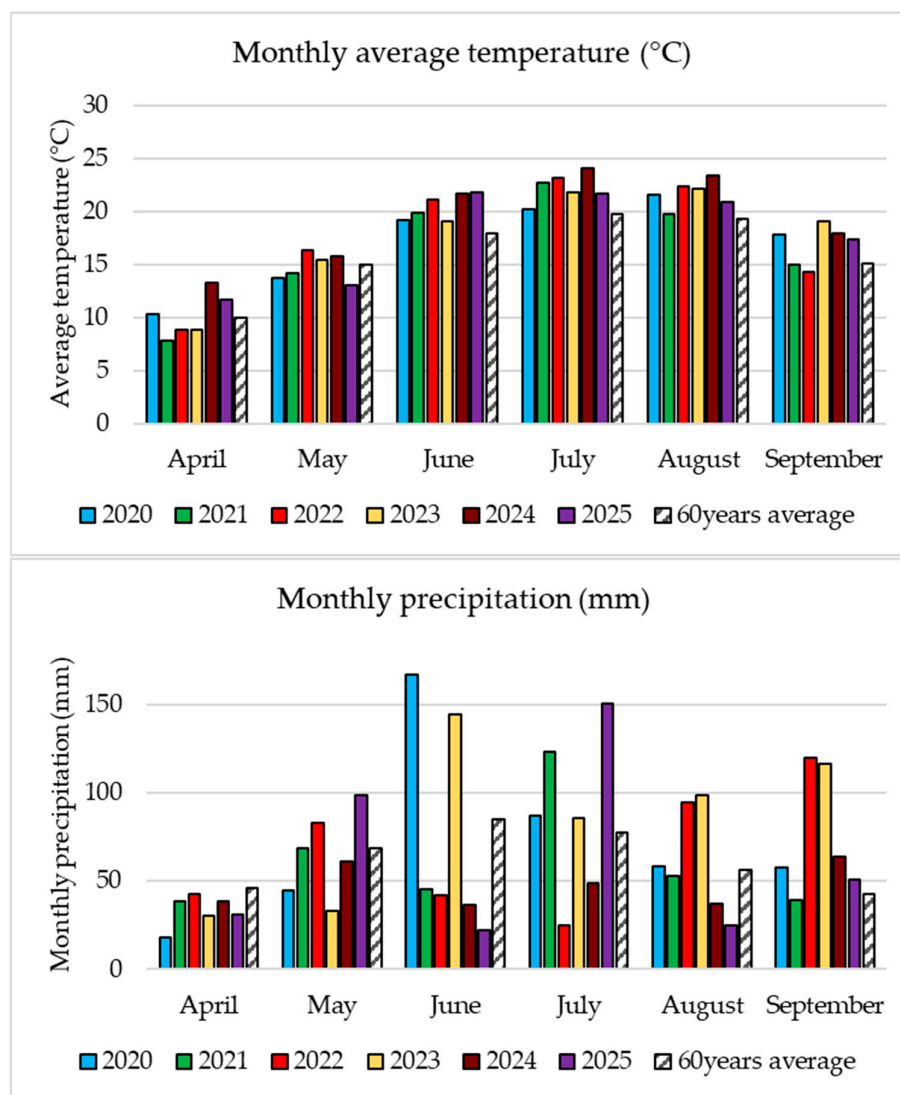


Figure 1. Meteorological conditions 2020–2025, Turda, Romania.

The year 2022 was characterized as arid during the maize growing season; high average temperatures, several heat waves, extreme maximum temperatures and a severe water deficit throughout the summer months negatively influenced crop development. The rainfall in August was recorded during the last days of the month and although its volume was high, it occurred after a prolonged period of drought, when the crop was already severely affected.

In 2023, low rainfall during the sowing period caused delayed and uneven crop emergence. In the summer, although temperatures were high with heat waves, abundant rainfall in June and July allowed for a certain recovery of the crop.

The highest temperatures were recorded in 2024, a year that was also described as the warmest in decades throughout the country. That year, a record temperature of 38.4 °C was also recorded, which, combined with a severe water deficit, made it one of the most unfavorable years for maize cultivation. In July, when maize flowers, the highest number of days with temperatures above 32 °C and even above 35 °C were recorded, associated with minimal or a total lack of rainfall.

In 2025, although the temperatures remained above the multiannual average and low rainfall in June indicated unfavorable conditions for the maize crop, abundant rainfall in July had a highly favorable influence on crop development, leading to high yields. Also,

that year, the number of days with extreme temperatures was much lower compared to previous years.

3.2. Maternal Line Effects on Yield, Unlodged Plants and Dry Matter

Yield levels fluctuated during the six-year trial, mainly because of variable weather. While 2025 and 2021 were among the best years for maize crops in recent decades [30,31], 2024 and 2022 were among the most unfavorable [32]. In 2020 and 2023, yields remained close to average levels. In a previous study [33] conducted in the same experimental field, which analyzed the same 35 hybrids, the mean yield was 10,121 kg ha⁻¹ in 2020, 10,895 kg ha⁻¹ in 2021, 6209 kg ha⁻¹ in 2022 and 7433 kg ha⁻¹ in 2023. In addition, in 2024, the mean of the yields obtained by the same hybrids was 5219 kg ha⁻¹, while in 2025, it was 11,600 kg ha⁻¹. However, we aim to identify genotypes that outperform the annual average, regardless of whether climatic conditions are favorable for maize cultivation.

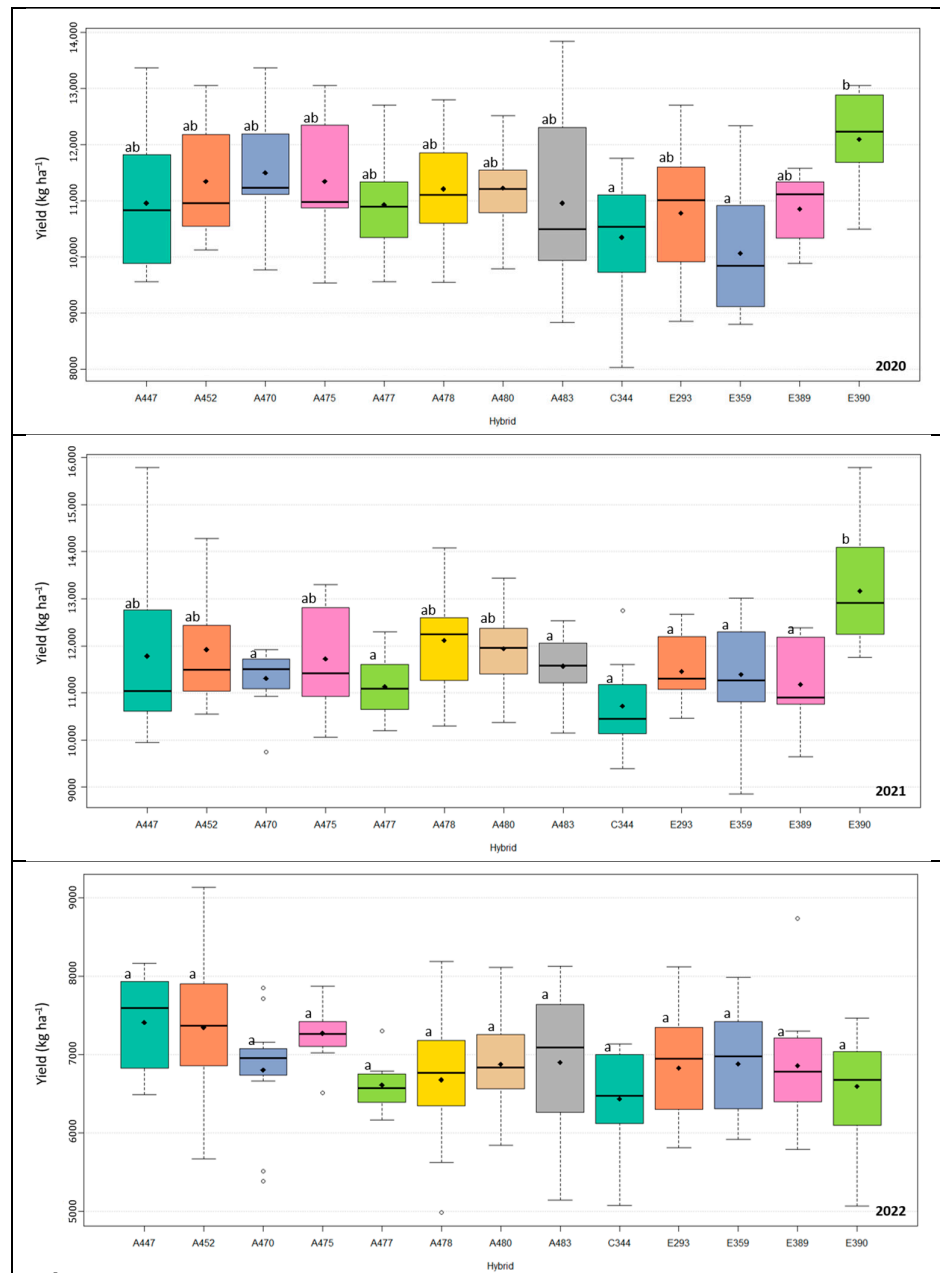
It was observed that in each of the six years analyzed, line A452 outperformed, on average, the other maternal lines tested in the cyclical crossing system. In the case of line E390, although a slight decrease was observed in the unfavorable year 2022, the yield differences in the favorable years (2020, 2021 and 2025) had the highest values across the entire experimental system (+1045, +1517 and +1180 kg ha⁻¹, respectively). A483 was noted for good average yields 2022, 2023 and 2024 (Table 3).

Table 3. Average yield (kg ha⁻¹).

Maternal Line		2020	2021	2022	2023	2024	2025
Experimental mean (kg/ha)		11,048	11,646	6883	9099	6000	12,198
E293	AY	10,781 ± 1184 ^{ab}	11,455 ± 789 ^b	6828 ± 738 ^a	8585 ± 837.6 ^a	5821 ± 778 ^{ab}	11,288 ± 753 ^b
	±mean	−267	−191	−55	−514	−179	−910
C344	AY	10,349 ± 1011 ^b	10,718 ± 889 ^b	6433 ± 628 ^a	9227 ± 742 ^a	5241 ± 942 ^b	11,828 ± 1322 ^{ab}
	±mean	−699	−928	−450	128	−759	−370
E359	AY	10,065 ± 1097 ^b	11,387 ± 1137 ^b	6881 ± 716 ^a	9056 ± 788 ^a	6259 ± 667 ^{ab}	11,707 ± 1460 ^{ab}
	±mean	−983	−259	−2	−43	+259	−491
A452	AY	11,347 ± 1008 ^{ab}	11,922 ± 1267 ^{ab}	7346 ± 968 ^a	9200 ± 696 ^a	6632 ± 577 ^a	12,471 ± 796 ^{ab}
	±mean	+299	+276	+463	+101	+632	+273
A470	AY	11,500 ± 1007 ^{ab}	11,310 ± 621 ^b	6803 ± 766 ^a	9319 ± 968 ^a	5877 ± 888 ^{ab}	12,655 ± 944 ^{ab}
	±mean	+452	−336	−80	+220	−123	+457
A475	AY	11,346 ± 1079 ^{ab}	11,724 ± 1183 ^{ab}	7270 ± 367 ^a	9302 ± 908 ^a	5522 ± 788 ^{ab}	11,783 ± 685 ^{ab}
	±mean	+298	+78	+387	+203	−478	−415
A477	AY	10,932 ± 942 ^{ab}	11,131 ± 642 ^b	6611 ± 343 ^a	8835 ± 710 ^a	5875 ± 1027 ^{ab}	12,183 ± 1828 ^{ab}
	±mean	−116	−515	−272	−264	−125	−15
A478	AY	11,213 ± 979 ^{ab}	12,117 ± 1186 ^{ab}	6678 ± 871 ^a	9294 ± 768 ^a	5835 ± 828 ^{ab}	11,931 ± 1584 ^{ab}
	±mean	+165	+471	−205	+195	−165	−267
A480	AY	11,226 ± 740 ^{ab}	11,938 ± 888 ^{ab}	6876 ± 640 ^a	9019 ± 1027 ^a	6018 ± 711 ^{ab}	12,816 ± 1014 ^{ab}
	±mean	+178	+292	−7	−80	+18	+618
E389	AY	10,854 ± 609 ^{ab}	11,178 ± 1124 ^b	6858 ± 810 ^a	8562 ± 858 ^a	6077 ± 532 ^{ab}	11,530 ± 947 ^{ab}
	±mean	−194	−468	−25	−537	+77	−668
E390	AY	12,093 ± 847 ^a	13,163 ± 1224 ^a	6591 ± 723 ^a	9412 ± 763 ^a	6167 ± 657 ^{ab}	13,378 ± 1100 ^a
	±mean	+1045	+1517	−292	+313	+167	+1180
A447	AY	10,958 ± 1205 ^{ab}	11,784 ± 1785 ^{ab}	7409 ± 657 ^a	8925 ± 1124 ^a	6018 ± 827 ^{ab}	12,888 ± 1509 ^{ab}
	±mean	−90	+138	+526	−174	+18	+690
A483	AY	10,957 ± 1655 ^{ab}	11,568 ± 660 ^b	6900 ± 952 ^a	9551 ± 700 ^a	6653 ± 837 ^a	12,115 ± 1635 ^{ab}
	±mean	−91	−78	+17	+452	+653	−83

AY = average yield; data as mean ± SD; a,b-superscript from post-hoc analysis.

Following the analysis of the yield distribution among the tested genotypes (Figure 2), the superiority of hybrids with the E390 line as the maternal parent is evident, with the majority achieving yields above the experimental average (except for 2022). In 2020 the yield of E390 hybrids ranged between 10,494 and 13,054 kg ha⁻¹ and between 11,752 and 15,785 kg ha⁻¹ in 2021, while in 2025 it was between 12,127 and 15,543 kg ha⁻¹. For hybrids derived from maternal line A477, a wider yield distribution occurs during favorable years; furthermore, values exceeding the mean indicate the presence of hybrids with superior yielding potential in the current study.



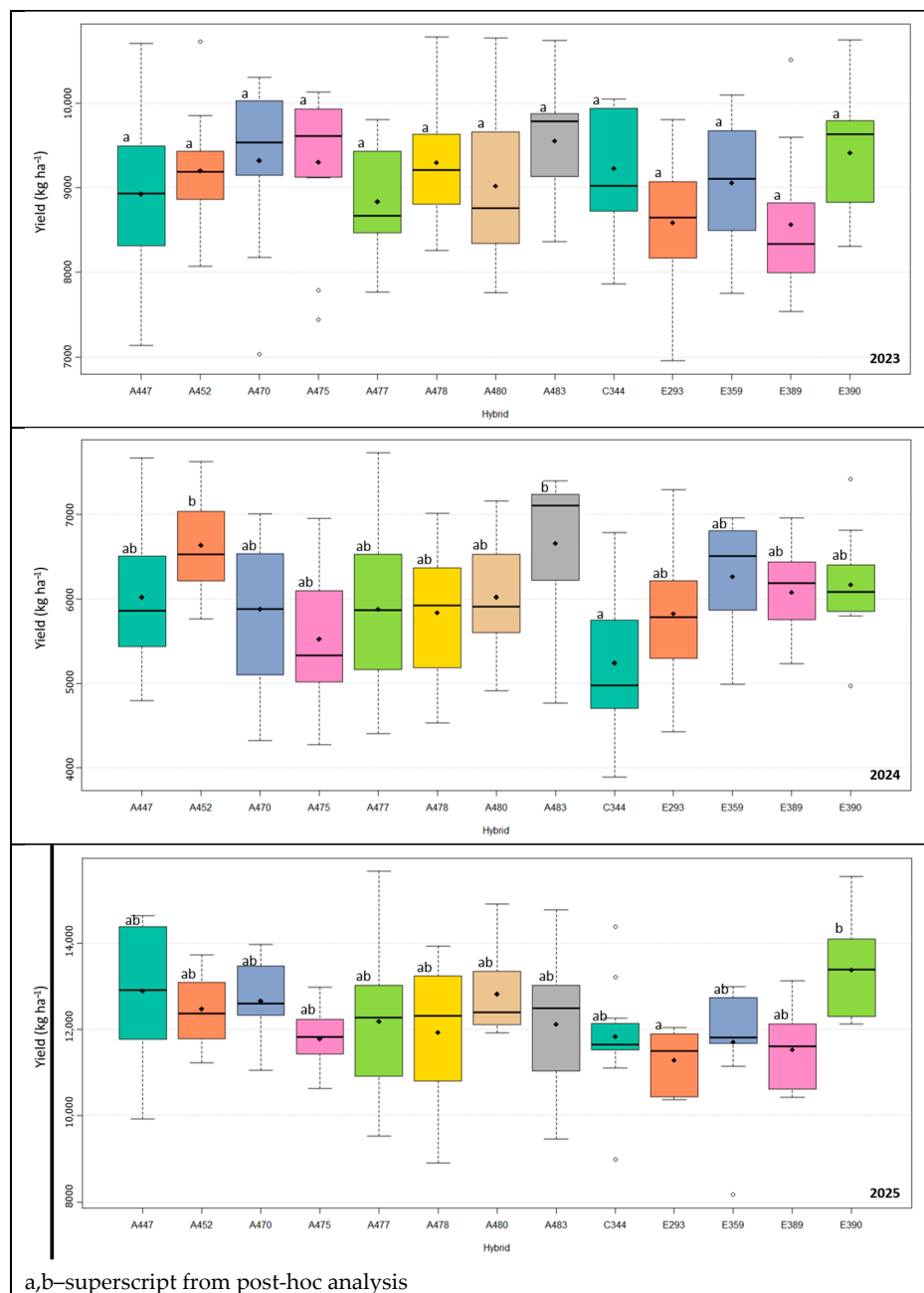


Figure 2. Yield value distribution among the tested hybrids.

One of the primary objectives of maize breeding is to develop hybrids with the lowest possible percentage of lodged plants at harvest time, this aspect being crucial for facilitating mechanized harvesting and reducing yield losses. Modern hybrids exhibit a high percentage of unlodged plants, with values close to 100%. Generally, the percentage of unlodged plants is higher in years favorable to maize cultivation. In 2023, heavy rainfall in August, occurring after a prolonged period of high temperatures, led to slight stalk susceptibility. Additionally, several inbred lines were identified that transmit a high percentage of unlodged plants to their offspring, such as E359, A475, A477 and A483 (Table 4).

Table 4. Average unlodged plants percent (%) at harvest.

Maternal Line		2020	2021	2022	2023	2024	2025
Experimental mean (%)		99.6	97.5	97.2	94.6	97.6	99.6
E293	UP	99.7 ± 0.4 ^a	96.8 ± 4.1 ^{ab}	96.3 ± 3.0 ^{ab}	94.3 ± 4.0 ^a	96.4 ± 1.7 ^b	99.5 ± 0.7 ^a
	±mean	0.1	−0.7	−0.9	−0.3	−1.2	−0.1
C344	UP	99.3 ± 0.9 ^b	97.3 ± 2.8 ^{ab}	95.3 ± 3.7 ^{ab}	94.7 ± 4.7 ^{ab}	97.4 ± 1.6 ^{ab}	99.7 ± 0.6 ^a
	±mean	−0.3	−0.3	−1.9	0.1	−0.2	0.1
E359	UP	99.8 ± 0.3 ^a	99.6 ± 0.7 ^a	98.4 ± 1.0 ^a	97.6 ± 1.6 ^{ab}	97.6 ± 1.5 ^{ab}	99.8 ± 0.6 ^a
	±mean	0.2	2.1	1.2	3.0	0.0	0.2
A452	UP	99.2 ± 1.0 ^b	94.3 ± 3.2 ^b	97.3 ± 2.2 ^{ab}	89.8 ± 4.8 ^{ab}	97.0 ± 1.3 ^{ab}	99.3 ± 1.2 ^a
	±mean	−0.4	−3.2	0.1	−4.8	−0.6	−0.3
A470	UP	99.6 ± 1.1 ^a	98.4 ± 1.7 ^{ab}	98.2 ± 1.8 ^a	94.9 ± 3.2 ^{ab}	97.8 ± 1.6 ^{ab}	99.8 ± 0.3 ^a
	±mean	0.0	0.9	1.0	0.3	0.2	0.2
A475	UP	99.4 ± 0.8 ^a	98.2 ± 1.5 ^{ab}	98.1 ± 1.4 ^a	94.2 ± 4.2 ^b	98.9 ± 1.6 ^a	99.4 ± 1.1 ^a
	±mean	−0.2	0.7	0.9	−0.4	1.3	−0.2
A477	UP	99.8 ± 0.3 ^a	98.5 ± 1.5 ^{ab}	98.6 ± 0.5 ^a	97.3 ± 1.9 ^a	99.1 ± 0.9 ^a	99.8 ± 0.3 ^a
	±mean	0.2	1.0	1.4	2.7	1.5	0.2
A478	UP	99.5 ± 0.6 ^b	97.5 ± 2.1 ^{ab}	94.7 ± 3.0 ^b	92.8 ± 6.0 ^{ab}	97.9 ± 2.2 ^{ab}	99.8 ± 0.4 ^a
	±mean	−0.1	0.0	−2.5	−1.8	0.2	0.2
A480	UP	99.9 ± 0.3 ^a	98.3 ± 1.6 ^{ab}	97.4 ± 1.6 ^{ab}	95.4 ± 2.9 ^{ab}	96.4 ± 3.1 ^{ab}	99.9 ± 0.2 ^a
	±mean	0.3	0.8	0.2	0.8	−1.2	0.3
E389	UP	99.9 ± 0.3 ^a	96.0 ± 4.6 ^{ab}	97.5 ± 2.1 ^{ab}	94.6 ± 4.6 ^{ab}	98.0 ± 1.6 ^{ab}	100 ± 0 ^a
	±mean	0.3	−1.5	0.3	0.0	0.4	0.4
E390	UP	99.4 ± 0.9 ^a	96.4 ± 3.0 ^{ab}	96.9 ± 1.9 ^{ab}	94.8 ± 3.9 ^{ab}	97.3 ± 1.4 ^{ab}	99.3 ± 0.7 ^a
	±mean	−0.2	−1.1	−0.3	0.2	−0.3	−0.3
A447	UP	99.9 ± 0.2 ^a	97.7 ± 2.1 ^{ab}	97.2 ± 1.5 ^{ab}	94.9 ± 3.0 ^{ab}	96.0 ± 5.3 ^{ab}	99.4 ± 1.3 ^a
	±mean	0.3	0.2	0.0	0.3	−1.6	−0.2
A483	UP	99.5 ± 0.5 ^b	98.3 ± 2.0 ^{ab}	97.8 ± 1.7 ^a	94.4 ± 3.9 ^{ab}	98.4 ± 1.4 ^{ab}	99.2 ± 1.8 ^a
	±mean	−0.1	0.8	0.6	−0.2	0.8	−0.4

UP = unlodged plants; data as mean ± SD; a,b—superscript from post-hoc analysis.

For better long-term storage and to reduce drying costs, high dry matter content at harvest is preferred. The high temperatures in August and September of 2023 and 2024 led to accelerated grain drying, resulting in a significantly higher dry matter percentage than in the other experimental years. C344, E359, A452, E389 and E390 can be used, as sources for the dry matter percentage at harvest (Table 5).

Table 5. Average dry matter at harvest (%).

Maternal Line		2020	2021	2022	2023	2024	2025
Experimental average (%)		81.3	78.0	80.9	85.4	86.9	82.3
E293	DM	80.9 ± 2.2 ^{ab}	79.6 ± 1.6 ^{ab}	81.5 ± 1.0 ^a	85.3 ± 1.6 ^{ab}	86.5 ± 1.1 ^a	83.3 ± 1.2 ^{ab}
	±mean	−0.4	1.6	0.8	−0.1	−0.4	0.9
C344	DM	81.9 ± 1.2 ^{ab}	79.3 ± 2.8 ^{ab}	81.4 ± 0.8 ^a	86.1 ± 1.1 ^a	87.0 ± 0.2 ^a	83.6 ± 1.4 ^{ab}
	±mean	0.6	1.3	0.7	0.4	0.1	1.2
E359	DM	81.8 ± 0.9 ^{ab}	80.0 ± 2.0 ^a	81.6 ± 0.7 ^a	85.8 ± 0.6 ^{ab}	86.9 ± 0.4 ^a	84.1 ± 1.4 ^a
	±mean	0.5	2.0	0.9	0.4	0	1.7
A452	DM	81.2 ± 1.5 ^{ab}	79.4 ± 1.8 ^{ab}	81.5 ± 0.7 ^a	86.1 ± 0.8 ^{ab}	86.7 ± 1.1 ^a	81.8 ± 1.6 ^{ab}
	±mean	−0.1	1.4	0.8	0.7	−0.2	−0.6

A470	DM	80.7 ± 1.7 ^{ab}	76.6 ± 2.9 ^{bc}	80.0 ± 1.8 ^b	84.8 ± 0.9 ^b	86.4 ± 0.9 ^a	82.5 ± 2.3 ^{ab}
	±mean	−0.6	−1.4	−0.7	−0.6	−0.5	0.1
A475	DM	80.6 ± 1.9 ^{ab}	77.3 ± 3.3 ^{abc}	80.5 ± 1.3 ^b	85.1 ± 1.1 ^{ab}	86.9 ± 0.7 ^a	83.0 ± 1.1 ^{ab}
	±mean	−0.7	−0.7	−0.2	−0.3	0.9	0.6
A477	DM	81.3 ± 1.5 ^{ab}	77.8 ± 1.4 ^{abc}	81.1 ± 0.6 ^{ab}	85.8 ± 0.8 ^{ab}	87.1 ± 0.2 ^a	81.1 ± 2.1 ^{ab}
	±mean	0	−0.3	0.4	0.4	0.2	−0.2
A478	DM	81.5 ± 1.4 ^{ab}	76.9 ± 1.8 ^{abc}	80.6 ± 1.2 ^{ab}	85.9 ± 0.5 ^{ab}	87.0 ± 0.6 ^a	81.3 ± 1.6 ^{ab}
	±mean	0.2	−1.1	−0.1	0.5	0.1	−1.1
A480	DM	80.5 ± 1.4 ^b	75.5 ± 2.5 ^c	80.3 ± 0.8 ^{ab}	84.4 ± 1.8 ^{ab}	86.7 ± 0.5 ^a	82.4 ± 2.1 ^{ab}
	±mean	−0.8	−2.5	−0.4	−1.0	−0.2	0
E389	DM	82.6 ± 0.5 ^{ab}	79.6 ± 1.7 ^{ab}	82.2 ± 0.6 ^a	85.7 ± 1.2 ^{ab}	86.5 ± 1.2 ^a	81.9 ± 2.5 ^{ab}
	±mean	1.3	1.6	1.5	0.3	−0.4	−0.5
E390	DM	82.7 ± 1.3 ^a	79.3 ± 1.8 ^{ab}	81.3 ± 1.0 ^a	85.8 ± 1.1 ^{ab}	86.9 ± 0.7 ^a	82.6 ± 1.5 ^{ab}
	±mean	1.4	1.3	0.6	0.4	0	0.2
A447	DM	81.0 ± 1.4 ^{ab}	77.3 ± 2.0 ^{abc}	80.6 ± 1.7 ^{ab}	84.5 ± 2.4 ^{ab}	87.1 ± 0.4 ^a	81.5 ± 2.3 ^{ab}
	±mean	−0.3	−0.7	−0.1	−0.9	0.2	−0.9
A483	DM	80.7 ± 1.9 ^{ab}	77.0 ± 2.3 ^{abc}	78.9 ± 2.4 ^b	85.2 ± 0.7 ^{ab}	86.8 ± 0.7 ^a	80.9 ± 1.8 ^b
	±mean	−0.6	−1.0	−1.8	−0.2	−0.1	−1.5

DM = dry matter % at harvest; data as mean ± SD; a,b, c—superscript from post-hoc analysis.

In general, all hybrids are adapted to the experimental region in terms of their growing season, allowing them to be harvested at moisture levels close to the standard 14% before the onset of early autumn frost.

3.3. Performance of Top-Ranking Hybrids

Of the 130–156 hybrids evaluated annually, the ten most productive hybrids were identified for each experimental year (Table 6). Notably, inbred line A447 was the maternal parent for top-ranking hybrids throughout the study period, namely one hybrid in 2020 and 2024, and two hybrids in each of the other years. This indicates not only the superior mean performance of the hybrids using this maternal line, but also the line's ability to yield highly productive hybrids. Another inbred line that stood out was E390, serving as a parental genotype for top-ten hybrids as follows: three in 2020, four in 2021, one each in 2023 and 2024 and three in 2025. Excellent performance was also recorded for lines A483 and A452, which served as maternal parents for several top-performing hybrids as follows: A483 featured two hybrids in 2020, four in 2024 and one each in 2022, 2023, and 2025; while A452 accounted for one hybrid in 2020, two in 2021 and 2024 and a total of four in 2023. Several high-yielding hybrids distinguished themselves by consistently ranking within the top tier across two experimental years, as follows: E390 × B2087 in 2020 and 2021, A480 × E342, A447 × F320, A483 × E381 and A480 × E342 in 2022 and 2023, and A483 × F325 in 2024 and 2025. These hybrids are currently undergoing multi-location testing.

Table 6. Top-ranking hybrids.

2020			2021		
Rank	Hybrid	Yield (ka ha ^{−1})	Rank	Hybrid	Yield (ka ha ^{−1})
1	A483 × E292	13,840	1	E390 × B2074	15,785
2	A447 × B2087	13,373	2	A447 × A473	15,785
3	A483 × B2074	13,373	3	A447 × B2057	14,333
4	A470 × E348	13,370	4	A452 × B2009	14,281
5	A452 × A473	13,056	5	E390 × E373	14,281
6	A475 × B2009	13,054	6	A452 × B2008	14,248
7	E390 × B2057	13,054	7	E390 × E329	14,101

8	E390 × B2087	12,989	8	A478 × B2009	14,075
9	E390 × E329	12,989	9	E390 × B2087	14,075
10	A478 × B2009	12,801	10	A478 × A473	13,938
2022			2023		
Rank	Hybrid	Yield (ka ha ⁻¹)	Rank	Hybrid	Yield (ka ha ⁻¹)
1	A452 × E373	9135	1	A478 × B2057	10,780
2	E389 × F320	8736	2	A480 × E342	10,765
3	A452 × E292	8220	3	E390 × F320	10,745
4	A478 × E342	8190	4	A483 × E381	10,740
5	A447 × F320	8170	5	A452 × E385	10,724
6	A447 × F317	8163	6	A447 × F320	10,707
7	A483 × E381	8128	7	E389 × E373	10,511
8	E293 × F320	8119	8	A447 × E342	10,453
9	A480 × E342	8111	9	A478 × E292	10,311
10	A452 × E381	8005	10	A470 × E342	10,301
2024			2025		
Rank	Hybrid	Yield (ka ha ⁻¹)	Rank	Hybrid	Yield (ka ha ⁻¹)
1	A477 × F312	7727	1	A477 × F324	15,662
2	A447 × F320	7669	2	E390 × F325	15,543
3	A452 × F320	7624	3	A480 × F319	14,900
4	E390 × F317	7413	4	A483 × F325	14,766
5	A483 × F317	7394	5	A447 × F327	14,636
6	A452 × F319	7341	6	A447 × F322	14,635
7	E293 × F317	7288	7	E390 × F335	14,412
8	A483 × F325	7260	8	A447 × F324	14,379
9	A483 × F327	7233	9	C344 × F323	14,376
10	A483 × F312	7200	10	E390 × F320	14,111

3.4. Principal Component Analysis for Yield, Unlodged Plants and Dry Matter

Principal Component Analysis (PCA) was used as an exploratory tool to visualize the multivariate relationships among the maternal inbred lines based on their six-year mean values for grain yield (kg ha⁻¹), unlodged plants (UP, %) and dry matter at harvest (DM, %). The first two principal components explained 82.39% of the total variance (PC1: 51.36%; PC2: 31.03%), indicating that most of the variability contained in the three measured traits was represented in the two-dimensional ordination (Figure 3).

The orientation of the variable vectors indicated that maternal lines located on the positive side of PC1 were generally associated with higher values of unlodged plants and dry matter, whereas those positioned on the negative side of PC1 were more closely associated with higher grain yield. Variation along PC2 further differentiated maternal lines associated with higher percentages of unlodged plants (upper part of the plot) from those characterized by relatively higher dry matter content (lower part).

Overall, the PCA biplot provides an exploratory visualization of the relationships among the measured agronomic traits and illustrates the multivariate variation among the evaluated maternal inbred lines. Because only three agronomic variables were included, the PCA should be interpreted as a descriptive visualization rather than evidence of genetic or breeding-group differentiation.

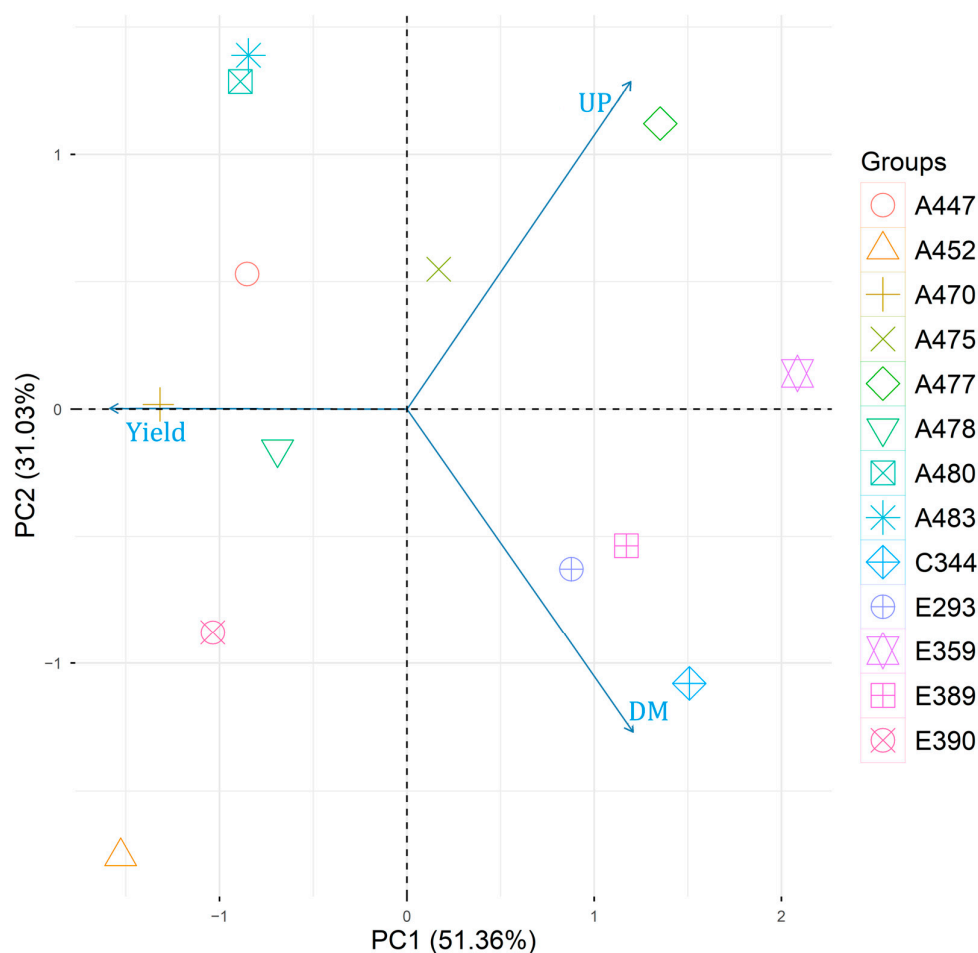


Figure 3. PCA of the 13 maternal inbred lines based on six-year mean values for grain yield, un-lodged plants (UP) and dry matter at harvest (DM). Each point represents one maternal inbred line.

4. Discussion

Maize, a highly diverse crop with major applications, is one of the most extensively studied cultivated plants. The diversity of this crop was influenced both by the transition from open-pollinated varieties to hybrids, and then by the transition from double-cross hybrids to three-way or single-cross hybrids [34]. To achieve the highest possible level of heterosis, it is desirable for the parental genotypes to be as genetically distant as possible; for this very reason, breeders have paid particular attention to classifying germplasm sources into heterotic groups [35,36]. In Europe, an evolution of heterotic groups has been observed: the differences between the germplasm groups increased, while the diversity within the groups decreased [6].

Some estimates indicate that approximately 75% of the germplasm used in Romania originates from the Corn Belt Dent [5], but these have been improved and adapted to the specifics of the growing area and introgressions of genes from other sources of germplasm have been observed [37].

In the case of the ARDS Turda, more than half of the inbred lines originate from Romania (own creations or exchanges with other research centers in the country), but a significant part of the germplasm collection originates in European countries (Republic of Moldova, France, Germany, Italy, Poland, etc.) or from the North American continent (USA or Canada) [38]. The use of foreign germplasm, as well as commercial hybrids in

selection programs, has led to the production of many inbred Iodent or miscellaneous lines (in which Iodent is predominant), their share currently being the majority. This aspect is also noticeable in terms of approved commercial hybrids, most of which have one of the parental lines belonging to the Iodent group, crossed with Lancaster, BSSS or mixed lines. Similar heterotic models have been noted by other researchers due to their productive superiority [39–42]. The Iodent germplasm group is often preferred as the maternal parent for producing commercial hybrids, particularly due to its excellent seed production capacity. Good results have been achieved in various crosses, such as Iodent $\times$ Lancaster (for mid-early hybrids with a good grain dry-down rate) [43], Iodent $\times$ BSSS (productive hybrids adaptable to diverse environmental conditions) [44–46] and Iodent $\times$ Euroflint (hybrids intended for cooler regions with a shorter growing season) [39,47]. A number of hybrids incorporating an Iodent line into their heterotic formula have been or still are successfully cultivated in various regions [10,14,48–50].

The steady rise in average temperatures in recent years [51,52], often associated with water deficits during critical growth stages or poor precipitation distribution throughout the maize growing season, necessitates a shift in breeding objectives. These goals must focus not only on increasing yield potential but also on enhancing adaptability to the stressful environmental conditions encountered in recent years. Another aspect of particular importance for the maize crops in the studied area is the probability of low temperatures in spring, in the first phases of vegetation requiring good tolerance to this stress. The growing season is also quite short in the Transylvanian region, with early autumn frosts being frequent [53], so hybrids with a shorter growing season are preferred, with the Iodent germplasm being successfully used for this purpose.

Inbred lines A452, E390, A447 and A483, identified in recent years for their high yield potential in various crosses, alongside other agronomic traits of interest, can serve as parental components for the hybrids evaluated in this study, as well as for developing new hybrids through crosses with lines currently undergoing the final stages of selection. These lines can also be utilized due to their high percentage of unlodged plants and their capacity for grain dry matter accumulation, a distinctive characteristic of Iodent germplasm [54]. Due to the traits of economic interest they transmit to their progeny, the four lines have undergone additional testing in recent years across a significant number of hybrid combinations; they currently serve as parental lines for registered hybrids or are undergoing testing for registration. Furthermore, these were used in various crosses or backcrosses to improve other inbred lines.

Hybrids developed at ARDS Turda undergo field testing in comparative observation trials, where various traits are recorded, including low-temperature tolerance during the early vegetative stage, seedling vigor, anthesis period, flowering-silking synchronization, physiological maturity, response to diseases, pests and climatic stress factors (e.g., soil drought, extreme heat and severe storms). Data are collected per plot regarding the number of fertile versus sterile plants, as well as lodging-resistant plants; following harvest, grain yield and dry matter content are evaluated. Hundreds of hybrids are assessed annually, after which the top performers are selected for an additional year of testing. Following this second year of evaluation, which monitors the same agronomic parameters, a subsequent selection isolates the superior hybrids for multi-location trials. A potential limitation of the study is that the 130–156 hybrids tested annually and examined in the present study represent a volume too substantial for multi-location trials, particularly if they fail to exhibit agronomic value within their environment of origin. Consequently, given that only the maternal lines remained constant across all experimental years and although identical testers were utilized with all thirteen maternal lines within a single year (line $\times$ tester mating design), the paternal lines were modified annually, resulting in new hybrid combinations each year. Because evaluations were restricted to a single location,

the present data do not permit a formal assessment of genotype-by-environment interaction or yield stability.

Some hybrid combinations tested in this study even exceeded the yields of the newest hybrids approved at the ARDS Turda, in the testing process, perspective genotypes are always compared with the latest creations. If the productive superiority of these hybrids has been noted over several years, they will be tested in several localities for a more in-depth testing of their productivity and adaptability to various environmental conditions and will then be sent for official testing at The State Institute for Testing and Registrations of Varieties. Nevertheless, two of the hybrids evaluated during the initial years of this study, Turda 380 and Turda 350, advanced to multi-location testing, subsequently achieving official registration in 2022 [42] and 2025, respectively. They are currently among the most widely cultivated hybrids within the research station's portfolio. Furthermore, the present study enabled the identification of promising inbred lines that serve as parental components for hybrids currently undergoing official registration testing.

5. Conclusions

A452 exhibited significant positive deviations from the trial mean throughout all six years of evaluation, whereas E390 demonstrated superior performance in five years and A447 in four. Consequently, these lines will be integrated into ongoing breeding programs and the high-yielding hybrids will undergo multi-location testing.

Based on their consistently superior yield performance over two consecutive years, a group of hybrids ($E390 \times B2087$, $A480 \times E342$, $A447 \times F320$, $A483 \times E381$, $A480 \times E342$, $A483 \times F325$) has been integrated into multi-location testing.

Two of the hybrids evaluated in the present study have been officially registered as Turda 380 and Turda 350 and are currently cultivated in Romania. Additionally, a series of other hybrids that excelled over the six-year study period are presently undergoing multi-location testing.

ARDS Turda possesses Iodent germplasm with strong potential for developing high-yielding hybrids; this germplasm can be successfully crossed with lines from the Lancaster, BSSS and Flint groups.

Author Contributions: Conceptualization, R.E.C. and A.V.; methodology, C.D.V.; software, A.C.; validation, R.E.C., A.V. and F.C.; formal analysis, A.Ş. and F.C.; investigation, A.F.; resources, L.A.C.; data curation, L.A.C.; writing—original draft preparation, R.E.C.; writing—review and editing, R.E.C. and C.D.V.; visualization, A.F. and A.C.; supervision, A.V.; project administration, R.E.C.; funding acquisition, R.E.C. and A.Ş. All authors have read and agreed to the published version of the manuscript.

Funding: The APC was funded by ADER 1.3.1 Cercetări privind îmbunătățirea/ameliorarea germoplasmei de porumb pentru creșterea randamentului de utilizarea apei și nutrienților din sistemul de fertilizare, from the Sectorial Plan of Ministry of Agriculture and Rural Development Romania, 2023–2026.

Data Availability Statement: The original contributions presented in this study are included in the article material. Further inquiries can be directed to the corresponding author.

Acknowledgments: The authors would like to thank the entire staff of the ARDS Turda maize breeding laboratory for their work in carrying out this study.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

ARDS	Agricultural Research and Development Station
UP	Unlodged plants

References

1. FAOSTAT. 2026. Available online: <https://www.fao.org/faostat/en/#data/QCL> (accessed on 2 March 2026).
2. Vîrva, I.S. *Evolutia Sectorului Vegetal in Agricultura Romaniei Dupa Anul 2000*; Editura Institutului Național de Statistică: Bucharest, Romania, 2025. <https://insse.ro/cms/ro/content/evolu%C8%9Bia-sectorului-vegetal>
3. Xue, Y.; Zhao, Y.; Zhang, Y.; Wang, R.; Li, X.; Liu, Z.; Wang, W.; Zhu, S.; Fan, Y.; Xu, L.; et al. Insights into the Genomic Divergence of Maize Heterotic Groups in China. *J. Integr. Plant Biol.* **2025**, *67*, 1467–1486. <https://doi.org/10.1111/jipb.13884>.
4. Adejumbi, I.I.; Mengesha, W.; Gedil, M.; Meseka, S.; Abubakar, A.M.; Bonkougou, O.T.; Ouattara, F.; Badu-Apraku, B.; Menkir, A.; Derera, J.; et al. Genomic-Assisted Refinement of Heterotic Groups in Short-Duration Maturing Tropical Yellow and Orange Maize Inbred Lines. *BMC Agric.* **2026**, *2*, 9. <https://doi.org/10.1186/s44399-026-00032-2>.
5. Smith, J.S.; Trevisan, W.; McCunn, A.; Huffman, W.E. Global Dependence on Corn Belt Dent Maize Germplasm: Challenges and Opportunities. *Crop Sci.* **2022**, *62*, 2039–2066. <https://doi.org/10.1002/csc2.20802>.
6. Kadoumi, R.; Heslot, N.; Henriot, F.; Murigneux, A.; Berton, M.; Moreau, L.; Charcosset, A. Evolution of Population Structure in a Commercial European Hybrid Dent Maize Breeding Program and Consequences on Genetic Diversity. *Theor. Appl. Genet.* **2025**, *138*, 233. <https://doi.org/10.1007/s00122-025-05008-5>.
7. Mikel, M.A. Genetic Composition of Contemporary U.S. Commercial Dent Corn Germplasm. *Crop Sci.* **2011**, *51*, 592–599. <https://doi.org/10.2135/cropsci2010.06.0332>.
8. Lu, H.; Bernardo, R. Molecular Marker Diversity among Current and Historical Maize Inbreds: *Theor. Appl. Genet.* **2001**, *103*, 613–617. <https://doi.org/10.1007/PL00002917>.
9. Gethi, J.G.; Labate, J.A.; Lamkey, K.R.; Smith, M.E.; Kresovich, S. SSR Variation in Important U.S. Maize Inbred Lines. *Crop Sci.* **2002**, *42*, 951–957. <https://doi.org/10.2135/cropsci2002.9510>.
10. Mikel, M.A.; Dudley, J.W. Evolution of North American Dent Corn from Public to Proprietary Germplasm. *Crop Sci.* **2006**, *46*, 1193–1205. <https://doi.org/10.2135/cropsci2005.10-0371>.
11. Troyer, A.F. Background of U.S. Hybrid Corn II: Breeding, Climate, and Food. *Crop Sci.* **2004**, *44*, 370–380. <https://doi.org/10.2135/cropsci2004.3700>.
12. Troyer, A.F. Background of U.S. Hybrid Corn. *Crop Sci.* **1999**, *39*, 601–626. <https://doi.org/10.2135/cropsci1999.0011183X003900020001xa>.
13. Hirsch, C.N.; Hirsch, C.D.; Brohammer, A.B.; Bowman, M.J.; Soifer, I.; Barad, O.; Shem-Tov, D.; Baruch, K.; Lu, F.; Hernandez, A.G.; et al. Draft Assembly of Elite Inbred Line PH207 Provides Insights into Genomic and Transcriptome Diversity in Maize. *Plant Cell* **2016**, *28*, 2700–2714. <https://doi.org/10.1105/tpc.16.00353>.
14. Dziubetskyi, B.V.; Cherchel, V.Y.; Abelmanov, O.V.; Semenova, V.V.; Tagantsova, M.M. Iodent Germplasm Source Material Selection in Development of Maize Hybrids for the Steppe Zone of Ukraine. *Ukr. J. Ecol.* **2020**, *10*, 76–84. https://doi.org/10.15421/2020_12.
15. White, M.R.; Mikel, M.A.; De Leon, N.; Kaeppler, S.M. Diversity and Heterotic Patterns in North American Proprietary Dent Maize Germplasm. *Crop Sci.* **2020**, *60*, 100–114. <https://doi.org/10.1002/csc2.20050>.
16. Borozan, P.; Musteata, S.; Spinu, V.; Spinu, A.; Donici, R. Results of Early Corn Breeding in the Republic of Moldova. In *Proceedings of the International Congress of Geneticists and Breeders of the Republic of Moldova*; Moldova State University: Chișinău, Moldova, 2025; pp. 148–154.
17. Mikić, S.; Kondić-Špika, A.; Brbaklić, L.; Stanisavljević, D.; Čeran, M.; Trkulja, D.; Mitrović, B. Molecular and Phenotypic Characterisation of Diverse Temperate Maize Inbred Lines in Southeast Europe. *Zemdirb.-Agric.* **2017**, *104*, 31–40. <https://doi.org/10.13080/z-a.2017.104.005>.
18. Galić, V.; Anđelković, V.; Kravić, N.; Grčić, N.; Ledenčan, T.; Jambrović, A.; Zdunić, Z.; Nicolas, S.; Charcosset, A.; Šatović, Z.; et al. Genetic Diversity and Selection Signatures in a Gene Bank Panel of Maize Inbred Lines from Southeast Europe Compared with Two West European Panels. *BMC Plant Biol.* **2023**, *23*, 315. <https://doi.org/10.1186/s12870-023-04336-2>.

19. Horhocea, D.; Martura, T.; Iordan, H.L.; Băduț, C.; Ciocăzanu, I. Aspects Regarding the Improvement and Diversification of Maize Germplasm at NARDI Fundulea. *Analele INCDA Fundulea* **2019**, *87*, 57–80. <https://www.incda-fundulea.ro/anale/anale87.html>
20. Străjeru, S. *Fondul Genetic Național de Porumb (Zea mays L. subsp. mays)*; Editura Pim: Iași, Romania, 2021.
21. Călugăr, R.E.; Varga, A.; Vana, C.D.; Ceclan, L.A.; Chețan, F.; Fodor, A.; Tritean, N. Using Flint Maize for Developing New Hybrids: A Case Study in Romania. *Agronomy* **2025**, *15*, 2215. <https://doi.org/10.3390/agronomy15092215>.
22. Pedological and Soil Chemistry Office Cluj. Available online: <https://ospacluj.ro/> (accessed on 2 April 2025).
23. AZOGrow NPK 27:13,5:0. Available online: <https://www.azomures.com/ingrasaminte-complexe-npk/azogrow/azogrow-npk271350> (accessed on 30 July 2025).
24. WINTERSTEIGER Seedmech GmbH Wintersteigerstrasse 14910 Ried Im Innkreis, Austria. Available online: <https://www.wintersteiger.com/seedmech/en/applications-technologies/planting> (accessed on 31 July 2026).
25. Plot Combines for Harvesting | WINTERSTEIGER. Available online: <https://www.wintersteiger.com/seedmech/en/products/harvesters/plot-combines> (accessed on 30 July 2025).
26. Sprague, G.F.; Tatum, L.A. General vs. Specific Combining Ability in Single Crosses of Corn¹. *Agron. J.* **1942**, *34*, 923–932. <https://doi.org/10.2134/agronj1942.00021962003400100008x>.
27. Griffing, B. Concept of General and Specific Combining Ability in Relation to Diallel Crossing Systems. *Aust. J. Biol. Sci.* **1956**, *9*, 463–493. <https://doi.org/10.1071/BI9560463>.
28. Kassambara, A.; Mundt, F. *Factoextra Extract and Visualize the Results of Multivariate Data Analyses. R Package Version 1.0.7. — References*; Scientific Research Publishing: Wuhan, China, 2020. Available online: <https://scirp.org/reference/referencespapers?referenceid=3067217> (accessed on 15 April 2026).
29. R Core Team. *R A Language and Environment for Statistical Computing. R Foundation for Statistical Computing — References*; Scientific Research Publishing: Wuhan, China, 2025. Available online: <https://www.scirp.org/reference/referencespapers?referenceid=3967248> (accessed on 15 April 2026).
30. Vîrva, I.-S.; Gheorghe, F.V.; Dima, I.; Brodeală, A.M.; Căruțașu, M.; Crăciun, V.; Dinu, M. *Producția Vegetală la Principalele Culturi în Anul 2025*; Institutul Național de Statistică: Bucharest, Romania, 2026.
31. Gheorghe, F.; Dima, I.; Clipcea, M.; Brodeală, A.M.; Căruțașu, M.; Crăciun, V.; Dinu, M. *Producția Vegetală la Principalele Culturi în Anul 2021*; Institutul Național de Statistică: Bucharest, Romania, 2022.
32. Barna, F.M.; Manescu, A.C. The Impact of Drought Risk on Maize Crop in Romania. *Sustainability* **2025**, *17*, 8870. <https://doi.org/10.3390/su17198870>.
33. Călugăr, R.E.; Varga, A.; Vana, C.D.; Ceclan, L.A.; Racz, I.; Chețan, F.; Șimon, A.; Popa, C.; Tritean, N.; Russu, F.; et al. Influence of Changing Weather on Old and New Maize Hybrids: A Case Study in Romania. *Plants* **2024**, *13*, 3322. <https://doi.org/10.3390/plants13233322>.
34. Reif, J.C.; Hamrit, S.; Heckenberger, M.; Schipprack, W.; Maurer, H.P.; Bohn, M.; Melchinger, A.E. Trends in Genetic Diversity among European Maize Cultivars and Their Parental Components during the Past 50 Years. *Theor. Appl. Genet.* **2005**, *111*, 838–845. <https://doi.org/10.1007/s00122-005-0004-5>.
35. Hou, G.; Yao, W.; Ku, L.; Ren, Z.; Zhang, Y.; Li, H.; Hu, J.; Wang, B.; Chen, Y.; Wu, L. Dissecting Maize Grain Yield Heterosis through Heterotic Group Differentiation and Dominance Effects. *J. Integr. Agric.* **2026**, in press. <https://doi.org/10.1016/j.jia.2026.07.003>.
36. Sun, J.; Yin, X.; Ma, Y.; Jiang, F.; Guo, R.; Shaw, R.K.; Ijaz, B.; Fan, X. Heterotic Group Classification and Heterosis Prediction in Recombinant Maize Inbred Lines. *J. Sci. Food Agric.* **2026**, *106*, 4017–4027. <https://doi.org/10.1002/jsfa.70490>.
37. Șuteu, D.; Băcilă, I.; Haș, V.; Haș, I.; Miclăuș, M. Romanian Maize (Zea Mays) Inbred Lines as a Source of Genetic Diversity in SE Europe, and Their Potential in Future Breeding Efforts. *PLoS ONE* **2013**, *8*, e85501. <https://doi.org/10.1371/journal.pone.0085501>.
38. Călugăr, R.E.; Vana, C.D.; Varga, A.; Ceclan, L.A.; Tritean, N.; Ghețe, A.B. Germplasm Collection—Valuable Resources of Variability for Plant and Ear Traits in Maize Breeding. *Not. Bot. Horti Agrobot.* **2023**, *51*, 13141. <https://doi.org/10.15835/nbha51213141>.
39. Musteața, S.; Borozan, P.; Spînu, A.; Spînu, V.; Donici, R. Identificarea Modelelor Heterotice Cu Performanțe Agronomice La Crearea Hibrizilor de Porumb Timpuriu. *Agric. Sci.* **2024**, *1*, 7–15. <https://doi.org/10.55505/sa.2024.1.01>.
40. Gee, M.; Khangura, R.S.; Tuinstra, M.R. Yield Impact of Source-Sink-Regulated Senescence in Hybrid Maize and Genetic Architecture in exPVP Inbreds. *Theor. Appl. Genet.* **2026**, *139*, 135. <https://doi.org/10.1007/s00122-026-05210-z>.
41. Haș, V.; Copândeian, A.; Tritean, N.; Varga, A.; Vana, C.; Călugăr, R.; Mureșanu, F.; Șopterean, L. Noi realizări în domeniul ameliorării porumbului la S.C.D.A. Turda. *Analele INCDA Fundulea* **2021**, *89*, 49–61.

42. Varga, A.; Haş, V.; Tritean, N.; Vana, C.; Călugăr, R.; Mureşanu, F.; Şopterean, L. Mid-Early new generation hybrid Turda 380 adapted to climate change in the center of the country. *Analele INCDA Fundulea* **2022**, *90*, 63–71. <https://www.incda-fundulea.ro/anale/anale90.html>
43. Tsoneva, K. Inheritance of moisture release rates in mid-early maize hybrids from the Iodent x Lancaster heterosis pattern. *Bulg. J. Crop Sci.* **2023**, *60*, 31–39.
44. Sang, Z.; Zhang, Z.; Yang, Y.; Li, Z.; Liu, X.; Xu, Y.; Li, W. Heterosis and Heterotic Patterns of Maize Germplasm Revealed by a Multiple-Hybrid Population under Well-Watered and Drought-Stressed Conditions. *J. Integr. Agric.* **2022**, *21*, 2477–2491. <https://doi.org/10.1016/j.jia.2022.07.006>.
45. Zhang, H.; Li, D.; Lamkey, K.R.; Stine, W.H.; Yu, J.; Stine, H.H. New Maize Inbred Development Method I: Inter-heterotic Group Composite and Tester Choice. *Crop Sci.* **2024**, *64*, 2170–2182. <https://doi.org/10.1002/csc2.21260>.
46. Has, V.; Has, I.; Copândeian, A.; Mureşanu, F.; Varga, A.; Sut, R.; Rotar, C.; Şopterean, L.; Grigore, G. Comportarea noilor hibrizi de porumb creaţi la SCDA Turda. *Analele INCDA Fundulea* **2014**, *82*, 99–110. <https://www.incda-fundulea.ro/anale/anale82.html>.
47. Musteaţă, S.; Borozan, P.; Statnic, M.; Spînu, A.; Spînu, V. Performanţele hibrizilor de porumb timpuriu realizaţi în diferite modele heterotice. In *Ştiinţa în Nordul Republicii Moldova: realizări, probleme, perspective*; USARB: Bălţi, Moldova, 2023.
48. Gribincea, V. Crearea şi evaluarea liniilor consangvinizate de porumb din germoplazma iodent. *Asp. Amelior. în Amelior. Plante-lor* **2018**, 30–40. https://ibn.idsi.md/ro/vizualizare_articol/93667
49. Borozan, P.; Musteata, S.; Institute of Crop Science “Porumbeni”, Republic of Moldova; Rusu, G.; Institute of Crop Science “Porumbeni”, Republic of Moldova Related Crosses as Seed Parents of Early Maize Hybrids. *Proceedings of the XIth International Congress of Geneticists and Breeders from the Republic of Moldova*; Scientific Association of Geneticists and Breeders of the Republic of Moldova, Institute of Genetics, Physiology and Plant Protection, Moldova State University: Chişinău, Moldova, 2021.
50. Musteata, S.; Borozan, P.; Spînu, A.; Spînu, V.; Donici, R. Evaluation of Single and Single Modified Early Maize Hybrids Developed in the Heterotic Model Iodent X BSSS-B37. *Agric. Sci.* **2025**, *1*, 14–23. <https://doi.org/10.55505/SA.2025.1.02>.
51. Şimon, A.; Cheţan, F.; Ceclan, A.; Popa, A.; Urdă, C.; Tritean, N.; Rezi, R.; Russu, F.; Negrea, A. Improving Soybean Quality Parameters by Sowing on Different Dates in Various Climatic Years. *Sci. Papers. Ser. A Agron.* **2025**, *68*, 631–639.
52. Şimon, A.; Cheţan, F.; Ceclan, A.; Urdă, C.; Popa, A.; Russu, F.; Tritean, N.; Varga, A.; Filip, E.; Aipătioaie, M. Stability of Yield and Quality Parameters in Maize Hybrids Cultivated at Different Sowing Dates. *Rom. Agric. Res.* **2025**, *42*, 267–274. <https://doi.org/10.59665/rar4223>.
53. Şimon, A.; Moraru, P.I.; Ceclan, A.; Russu, F.; Cheţan, F.; Bărdaş, M.; Popa, A.; Rusu, T.; Pop, A.I.; Bogdan, I. The Impact of Climatic Factors on the Development Stages of Maize Crop in the Transylvanian Plain. *Agronomy* **2023**, *13*, 1612. <https://doi.org/10.3390/agronomy13061612>.
54. Xu, Y.; Ning, X.; Rong, M.; Jiang, L.; Li, J.; Fei, J.; Yang, B.; Pan, Y.; Li, Z.; He, X. Genetic Evaluation of Iodent Hard Kernel Maize Inbred Lines. *Bangladesh J. Bot.* **2024**, *53*, 643–651. <https://doi.org/10.3329/bjb.v53i30.76671>.

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.