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# THE IMPACT OF CLIMATE CHANGE AND GENETIC PROGRESS ON PERFORMANCE OF OLD AND RECENT RELEASED MAIZE HYBRIDS CREATED AT THE ARDS TURDA

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## ABSTRACT

**Climate change effects on maize performance have been already detectable during the last twenty years in many parts of the world. This study aims to assess the relationship between climatic factors and maize yield, grain moisture at harvest and resistance of plants to broken and stalk lodging, with reference to maize hybrids created at the Agricultural Research and Development Station Turda (ARDS), in the centre area of Romania. The purpose of this study was to detect trends in the yield ability of 35 maize hybrids (18 historical and 17 recently released) and the possible association with weather trends. A significant increase in temperature both during vegetative growth and grain filling was observed, while rainfall presented a decrease in the critical period of flowering and grain-filling, during the last two decades (2000-2020), with large year to year variations. During the analyzed period, yields of the historical hybrids showed a reduction trend from -72 kg/ha/year for FAO groups 210-300, to -272 kg/ha/year for FAO groups over 300. The average yield of recently released hybrids showed an increasing trend from +91 kg/ha/year for FAO 300-hybrids, to +215 kg/ha/year for FAO groups 210-300. This suggests that genetic progress reflected in the release of new maize hybrids was able to counteract the negative effect of climate change seen on the yield of the historical hybrids. The yield difference between recently released hybrids and the historical ones showed the rate of genetic progress of +171 kg/ha/year for very early hybrids, +116 kg/ha/year for early hybrids, and +275 kg/ha/year for semi-early hybrids.**

**Keywords:** climate change, genetic progress, maize hybrids.

## INTRODUCTION

The growing of high-yield maize hybrids is one of the basic factors of modern agriculture. The judicious choice of the biological material - respectively of the hybrid - together with the hybrid plasticity to the changes of climatic and soil conditions, represent basic elements that must be in the attention of each farmer (Grecu and Haş, 2001).

The problem of fluctuating climatic conditions has become much more evident in the last two decades (after 2000), when the greater variability in grain yield has aroused the interest of researchers. Breeding of new maize hybrids adaptable to climate change is one potential solution, but this approach requires an understanding of complex adaptive traits for climate-change conditions (Wolf and Diepen, 1995; Tao and Zhank, 2011; Wang et al., 2014; Săulescu, 2015; Butts-Wilmsmeyer et al., 2019; Haş, 2019; Bonea and Urechean, 2020; Popescu et al., 2021).

According to Pu et al. (2020), climate change will substantially affect the productivity of major staple food crops such as maize (Jones and Thornton, 2003; Tao and Zhang, 2010; Ruane et al., 2013) because growth and development of crops are mainly dependent on sunlight, temperature, and water (Chen et al., 2013). Climate change may modify rainfall, soil water, runoff, and may reduce crop maturation period and in the same time increase yield variability and could reduce the areas suitable for the production of many crops (Olesen and Bindi, 2002).

Araya et al. (2017) showed that maize yield during the mid-21st century will decline relative to the present yield on average by 18-33%. The yield decline might be caused mainly by the shortening of the growing

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period (9-18% decline in days to maturity), attributed to elevated temperatures. Another idea supported by them was that under future climate early sowing may be suitable compared to late sowing for better water efficiency.

Barron et al. (2003), Liu et al. (2010), and Butts-Wilmsmeyer et al. (2019) concluded that warming and water deficiency during the flowering phenophase lead to a reduction in the length of the growing season, attributed to increased senescence of leaves due to temperatures above 34°C, generally leading to a negative impact on maize yield by decreasing up to 75%. Wang et al. (2014) concluded also that rainfall represented the dominant climatic factor driving maize yield variations. The tolerance of the maize hybrids depends on the severity of the water stress (Bonea and Urechean, 2020).

Hatfield (2016) and Oke (2016) showed that exposure to higher temperatures during the grain-filling period shortened the grain-filling period by increasing the rate of senescence, reducing grain yield. The same authors also reported that yield of maize was positively correlated with total rainfall and negatively correlated with average temperature. Bonea and Urechean (2020) concluded that for every increase of 1°C of average temperature during the grain-filling period, maize yield decreased by 3274 kg/ha.

Low and wet temperature determines the length of the growing seasons and generally of vegetative parts (Parry, 1990; Haş, 2019).

According to Săulescu (2015), the forecasted climate changes will create different conditions, probably much more difficult, and therefore, breeding will have to approach adaptation to a more and more difficult environment, by using all possible opportunities, including germplasm diversification, new efficient methods for testing reaction to heat and drought conditions, breeding for the resistance to diseases and pests that will become more frequent under climate change or in years with extreme weather conditions, but also breeding for traits which can help mitigate the climate change.

Căbulea (2004) and Sarca (2004) concluded that improving the following characteristics of maize could improve the genetic value of maize in relation to climate change: the difference between flowering-silk, the number of ears per 100 plants, and the number of grains per ear. The significant additive genetic correlation between flowering-silking differences and maize grain yield per plant can be considered one of the most effective criteria for improving parental inbred lines, in a recurrent selection program for drought resistance.

It is concluded that modern maize hybrids are more tolerant to climate change mainly by constitutively optimizing plant productivity. Future maize breeding programs should pay more attention to specifically address climate limiting factors (Niu et al., 2013; Lv et al., 2015; Popescu et al., 2021).

In Transylvania, since 2000 due to climate change during the maize growing season, genetic progress according to Haş et al. (2017) was partially reduced in grain yield, due to heat and drought stress, especially to older registered hybrids, which were created in a more temperate climate.

This paper attempts to estimate the effects of climate change on genetic progress, by analyzing the trends of yield, precocity and resistance of maize plants to broken and stalk lodging and the implications of all these changes, in improving maize hybrids at ARDS Turda.

## MATERIAL AND METHODS

Grain yields and some characters were analyzed at the historical and in newly released maize hybrids, tested during the period 2017-2020, in yield trials at Turda, in central area of Romania.

For the study of climate change in Turda, we aimed to analyze a period of 16 years (2004-2020), during the growing season of maize (May 1 - September 30). Meteorological data on rainfall, average active temperature (≥10°C) (Figure 1), and the number of hours of sunlight (Figure 2) were collected from the Meteorological Station - Turda (longitude: 23°47'; latitude 46°35; altitude 427 m), located in the immediate vicinity of the yield tests.

To estimate the performance of genetic progress in the breeding of maize hybrids, the behavior of old maize hybrids compared to recently released hybrids was studied. The average data, for the four years of yield trials, were used to establish the different meanings for each hybrid.

To analyze the influence of climate change on the behavior of 35 maize hybrids created at ARDS Turda, registered before and after 2000, the hybrids were tested for four years, during 2017-2020, at Turda.

A set of 35 maize hybrids (18 old hybrids and 17 recently released hybrids), were studied over in three yield trials, in relation to their vegetation period and the FAO groups:

- the FAO groups up to 200 (very early): HS 105, HD 115, HS 105A, Turda 200, Doina, Turda 200 Plus, Turda-SU 181, Turda-SU 182, Turda Mold-188, Turda 165, Turda 145 (Căbulea and Grecu, 1982);

- the FAO groups 210-300 (early): HD 211, Turda 215, Turda 228, Turda 100, Turda 213, Turda 199, Turda 160, Elan, Turda Super, Turda-SU 210, Turda 165, Turda 248 (Căbulea et al., 1999);

- the FAO groups over 300 (semi-early): Turda 215, Turda 260, Saturn, Turda Favorit, Turda 201, Turda Star, Turda 248, Marius TD, Turda 332, Turda 344, Turda 335, Turda 2020 (Haş et al., 2017).

To analyze the behavior of hybrids, objectives such as grain yield and stability, grain moisture at harvest, and plant sensitivity to broken and stalk lodging at harvest were taken into account. The yield trials were organized in a randomized block design with three replications. Each plot had 2 rows with a total area of 7.0 square meters. The sowing density of plants was 70,000 plants /hectare.

## RESULTS AND DISCUSSION

### Observed trends in weather characteristics during 2004-2020, during maize growing season (1 May - 30 September)

Several trends in climate change were observed in the period 2004-2020. A significant increase in average active temperatures (≥10°C) was observed during the maize growing season (Figure 1). In the last two decades, the sum active temperatures (the number of days with temperatures ≥10°C) has increased, also the total precipitation, while the hours of sunshine have decreased.

The regression line (Figure 1) was calculated based on the deviations of the sum of the annual active temperatures as well as the total amounts of rainfall, during the maize growing season, compared to the multiannual average (per 60 years). The analysis of the regression line equation shows the particularly oscillating nature of the annual and even multiannual climate, especially by the tendency to increase the sum of active temperatures (≥10°C) from 1116°C/or 50 years to 1134°C/for 60 years, respectively an increase of 18°C/10 years, with significant deviations from the regression line, every three years (2009, 2012, 2015, 2018).

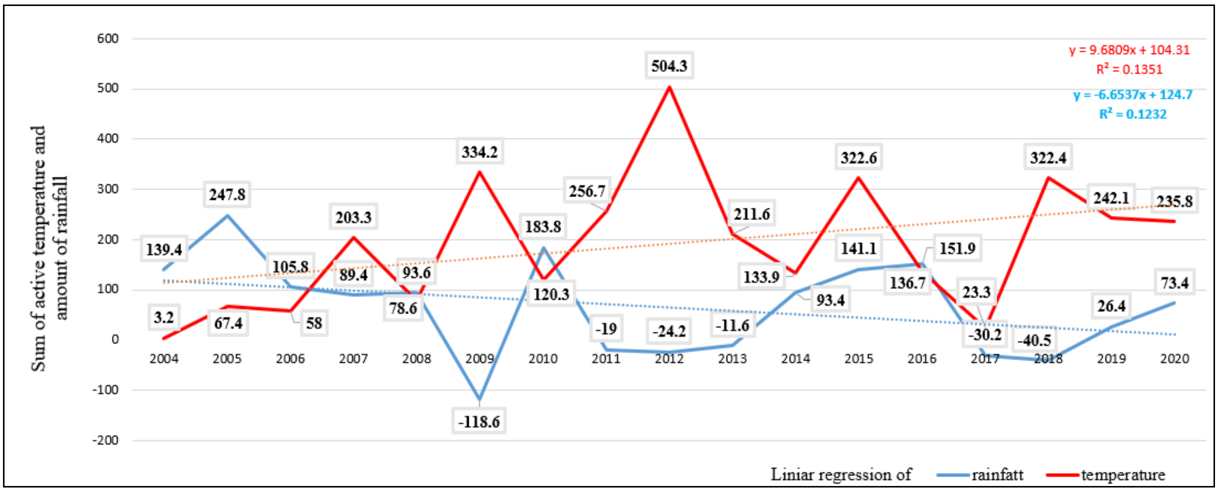


*Figure 1.* The deviations from the multiannual average of active temperatures (ta >10°C) and the rainfall amount summed over maize growing season (April - September), during 2004-2020

The sum of the total amount of rainfall, in the last two decades (2004-2020), recorded during the maize growing season, registered a slight exceeding of the multiannual average of 10 mm, from 366 mm/50 years to 376 mm/ 60 years. Of note, the poor distribution of rainfall, in the critical periods of June and July, in the trial years 2009, 2012, 2015, and 2018, respectively the years noted by large deviations of active temperatures, suggesting that the quantity of water in these years was insufficient to cover the maize water requirement, a fact also supported by Wang et al. (2014) and Butts-Wilmsmeyer et al. (2019).

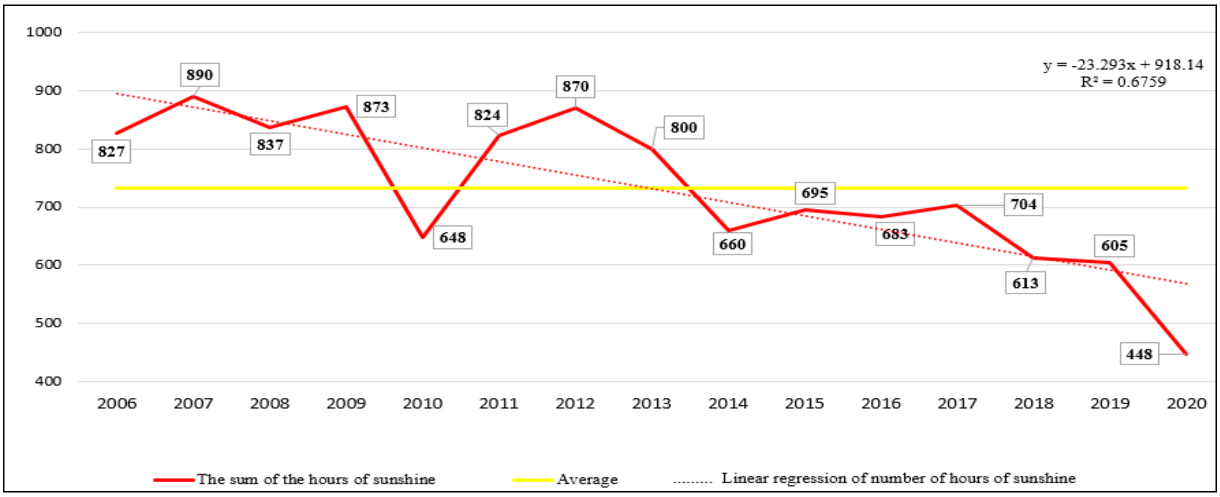


*Figure 2.* Evolution of deviations from the multiannual average of the number of hours of sunlight over maize growing season (May - July), during 2004-2020

During 2004-2020, the number of hours of sunshine, in the critical periods of the maize growing season, May, June, and July has decreased (Figure 2). The decrease in the number of hours of sunlight has negatively influenced the chlorophyll assimilation and vegetative development of plants. The decrease in the sunshine hours affected the time at which a crop canopy can intercept solar radiation and thus the efficiency with which solar radiation was used, decreased in making plant biomass. In the maize growing season, there is a two-stage vegetative cycle in which this crop is particularly sensitive to insufficient sunlight (Cristea, 2004; Renoux, 2014) such as: I. in the first part of the cycle - between the stage of 8-10 leaves formed and the stage of "exit" of the tassel; this pre-flowering period is particularly sensitive to insufficient sunlight, which can lead to disturbances the ear formation; II. the second part of the vegetative cycle - during the three weeks following fertilization, the plant remains sensitive to insufficient sunlight, which leads to grain abortion, results also supported by Cristea (2004), Renoux (2014), and Haş (2019).

In the four years of field trials, the climatic conditions were very different from year to year both in terms of the total rainfall during the maize growing season, and the annual distribution of temperatures compared to the multiannual average (Table 1). The deviation of the sum of annual temperature (ta ≥10°C) in the four years of yield trials was higher compared to the multi-annual sum of temperature active, with 238.3°C in 2017, with 322.4°C in 2018, with 242.1°C in 2019, and 160.4°C in 2020, reflecting the warming trend during the experimentation period.

*Table 1.* The amount of rainfall (mm) and the deviations (±°Cta) from the multiannual average of active temperatures (ta) (≥10°C) and number of hours of sunlight (no.), in maize growing season, at ARDS Turda, during the four trial years 2017-2020

| Item | Years | Sum | Multi annual average (60 years) | ±/Multi annual average | Sum/average 1.04 - 31.09 (%) | Character |
|---|---|---|---|---|---|---|
| Rainfall (mm) | 2017 | 298.5 | 375.5 | -77.0 | 79 | very dry |
| | 2018 | 335.0 | 375.5 | -40.5 | 89 | very dry |
| | 2019 | 402.0 | 375.6 | +26.4 | 107 | rainy |
| | 2020 | 431.0 | 375.6 | +55.4 | 115 | very rainy |
| | Average | 366.6 | 375.6 | -9.0 | 100 | dry |
| Active temperature (Σ°Cta) | 2017 | 1372.3 | 1134.0 | +238.3 | 121 | warm |
| | 2018 | 1456.4 | 1134.0 | +322.4 | 128 | warm |
| | 2019 | 1376.1 | 1134.0 | +242.1 | 121 | warm |
| | 2020 | 1294.4 | 1134.0 | +160.4 | 114 | warm |
| | Average | 1374.8 | 1134.0 | 240.8 | 100 | warm |
| No. of hours of sunlight (no.) 1.05 - 31.07 | 2017 | 241 | - | 23 | 111 | clear sky |
| | 2018 | 215 | - | -3 | 99 | low cloudness |
| | 2019 | 215 | - | -3 | 99 | low cloudness |
| | 2020 | 201 | - | -17 | 92 | cloudy sky |
| | Average | 218 | - | - | 100 | - |

The sum of the total amount of rainfall, in the four trial years (2017-2020), during the maize growing season, registered a slight exceeding of the multiannual average of 9.0 mm, 367 mm compared to 376 mm. In 2017, 2018, the rainfall represented only 79%, respectively, 89% of the multiannual average of the rainfall (375.6 mm), suggesting that the amount of water in these years was insufficient to ensure the water need of maize. In 2019 and 2020, the amount of water exceeded by 7% and 15% the multiannual average, suggesting favorable climatic conditions for high grain maize yield. The results obtained by Bonea and Urechean (2020) highlight the fact that for every increase of 1 mm of rainfall from sowing to anthesis, maize yield increased by 138 kg/ha.

In conclusion, the climatic conditions recorded during the year 2017-2020 showed fairly high variability, from the drought conditions during the first two years 2017 and 2018, to excess humidity in 2019-2020, and the shortest number of hours of sunlight in 2020, which had significant negative effects on the behavior of the hybrids studied (Table 1).

**Observed trends in maize traits during 2017-2020**

The climatic conditions registered in the four years of field experimentation had marked effects on the main characters and characteristics of the hybrids studied, the genotypes behaving differently depending on their genetic constitution (Table 2). The level of production was mainly influenced by the amount of precipitation and temperatures during the flowering to pollination and grain filling.

During the analyzed period, yields of the very early historical maize hybrids showed a reduction trend which averaged -102 kg ha/year, while the average yield of most recently released very early hybrids showed an increasing trend of +123 kg ha/year (Table 3). This suggests that genetic progress reflected in the release of the new very early maize hybrids counteracted the negative effect of climate change seen especially on the yield of the old maize hybrids.

The analysis of variance regarding the grain yield (Table 2) shows that the highest influence (%) is due to year, followed by hybrid, the interaction between year and hybrid, being insignificant. In the case of very early and early hybrids, the share of the year factor was twice as high as that of the hybrid factor.

*Table 2.* Analysis of variance for the grain yield (Turda, 2017-2020)

| FAO groups | up to 200 FAO groups | | | 200-300 FAO groups | | | over 300 FAO groups | | |
|---|---|---|---|---|---|---|---|---|---|
| Source | DF | Mean square | Share of factor (%) | DF | Mean square | Share of factor (%) | DF | Mean square | Share of factor (%) |
| Year (Y) | 3 | 47984220 | 54 | 3 | 56766140 | 48 | 3 | 39541760 | 31 |
| Hybrid (H) | 10 | 5683348 | 22 | 11 | 7757494 | 24 | 10 | 15411070 | 41 |
| Y x H | 30 | 914546 | 10 | 33 | 1517474 | 14 | 30 | 1208469 | 1 |
| Error A | 6 | 119232 | 0.003 | 6 | 710839 | 1 | 6 | 1089670 | 1 |
| Error H | 80 | 469674 | 14 | 88 | 524284 | 13 | 80 | 749866 | 16 |

The analysis of the variance regarding the share of the two factors, years and hybrids, shows that the influence of both factors was relatively equal in the realization of grain yield in semi-early hybrids.

In order to illustrate the genetic progress of the "Turda" maize hybrids, registered in the period 1971-2021, they were experimental tested, in Turda, in the period 2017-2020, and were studied for the potential of the grain yield, grain moisture and stalk lodging resistance at harvest, noticing an upward trend of new hybrids.

**Effect of rainfall, average temperature, and number of hours of sunshine on maize yield**

The levels of average yields/year of the 35 maize hybrids, differed in relation to the total climate changes specific to each year (Figure 3), in the maize growing season (1.04-30.09).

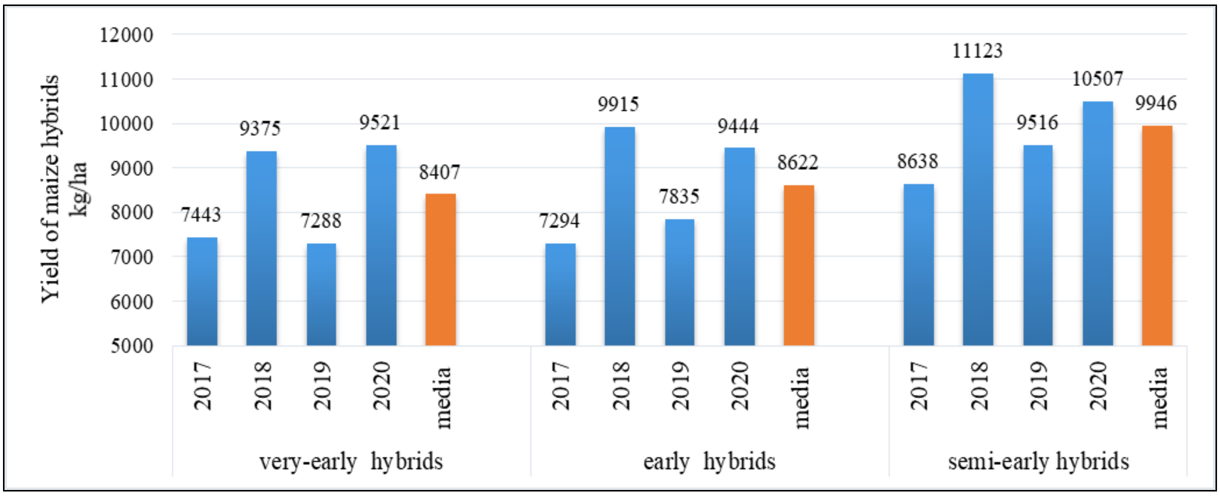


*Figure 3.* The variability of the average grain yield of the 35 hybrids, under the influence of the climatic conditions, studied according to the FAO groups, at Turda, in four years

The year 2017 was generally a drought one (-45.0 mm) and active temperatures exceeded the multi-annual average for the entire maize growing season, especially during the vegetative growth period, in June (-54.2 mm). The average grain yield in 2017 was negatively influenced especially for very early and early hybrids, the grain yield is 7443 kg/ha and 7294 kg/ha, respectively, while for semi-early hybrids, the grain yield was higher by over 1000 kg, being of 8638 kg/ha. The year 2018 with a surplus of precipitation and active temperatures in June and July, resulted in the highest grain yields of 9375 kg/ha in very early hybrids, 9915 in early hybrid, and 11123 kg/ha in semi-early hybrids, and in 2019 with a rainfall deficit in June and July, the average yield was 7288 kg/ha in very early hybrids, 7835 kg/ha in early hybrids and 9516 kg/ha. The year 2020 with a surplus of rainfall in June (81.8 mm) and July (9.7 mm), resulted in an average grain yield of 9521 kg/ha in very early hybrids, 9444 kg/ha in early hybrids, and 10507 kg/ha in semi-early hybrids. In this study it is observed that all climatic factors studied (average active temperature and amount of rainfall) had a great influence on maize grain yield, a conclusion also supported by Bonea and Urechean (2020).

### The study of very early and early maize hybrids

The development of very early maize hybrids represented in ARDS Turda relatively reduces proportion (about 15%) due to the requirements regarding grain hybrids, which would fully capitalize on the thermal resources of the area.

*Table 3.* The influence of climatic changes on behavior of very early maize hybrids, up to 200 FAO group (Turda, 2017-2020)

| Hybrid | Release year | Hybrid type | Grain yield | | Grain moisture | Sensitivity of plants to stalk lodging | Selection index |
|---|---|---|---|---|---|---|---|
| | | | kg/ha | ±mean trial | % | % | %/mean trial |
| 1. HS 105 | 1971 | SC | 7761 | $-646^{0}$ | 16.2** | 29.5*** | 78 |
| 2. HD 115 | 1973 | DC | 7452 | $-955^{000}$ | $15.0^{0}$ | 35.1*** | 70 |
| 3. HS 105 A | 1976 | SC* | 7419 | $-988^{000}$ | 15.2 | 26.6*** | 79 |
| 4. Turda 200 | 1976 | DC | 8668 | 261 | 16.2** | $10.6^{00}$ | 111 |
| 5. Doina | 1994 | TC | 8645 | 238 | 15.4 | 19.8 | 100 |
| 6. Turda 200 Plus | 1996 | TC | 8042 | -365 | 15.9 | $11.3^{00}$ | 103 |
| Mean hybrids (1971-1999) | | | **7998** | **-409** | **15.7** | **22.2** | - |
| 7. Turda-SU 181 | 2000 | HS | 8144 | -263 | 15.6 | $12.3^{0}$ | 103 |
| 8. Turda-SU 182 | 2000 | HS | 9266 | 859** | 15.5 | $9.1^{000}$ | 122 |
| 9. Turda Mold-188 | 2001 | HT | 8730 | 323 | $14.5^{000}$ | 15.1 | 108 |
| 10. Turda 165 | 2002 | HT | 8971 | 564* | 15.7 | 14.7 | 110 |
| 11. Turda 145 | 2004 | HT | 9379 | 972*** | 15.2 | 14.9 | 116 |
| Mean hybrids (2000-2004) | | | **8898** | **491** | **15.3** | **13.2** | **-** |
| Mean trial | | | **8407** | **-** | **15.5** | **18.1** | **100** |
| * - LSD (P<0.05)<br>** - LSD (P<0.01)<br>*** - LSD (P<0.001) | | | | 557<br>739<br>954 | 0.5<br>0.6<br>0.8 | 4.8<br>6.4<br>8.2 | |
| Rate of genetic progress/an | | | 171 | - | 0.02 | -2.2 | 4.3 |

The grain yield of very early maize hybrids was very negatively influenced by climate change, due to high temperatures during difficult periods of pollination and grain filling (July). The average grain yields of the very early hybrids achieved 8407 kg/ha. The grain yield of old hybrids was lower -409 kg/ha compared to the yield of hybrids registered after 2000 (+491 kg/ha). Also, the moisture of the grains, as well as the percentage of broken plants at harvest was higher than the average of the very early hybrids studied, 15.7%, respectively 22.2%.

During the analyzed period, grain yield increased above the average trial for two old hybrids Turda 200 (+261 kg/ha) and Doina (+238 kg/ha) (Table 3). In three of the hybrids registered after 2000, the grain yield significantly exceeded the average production of the 11 studied hybrids, Turda 165 (+564 kg/ha*), Turda-SU 182 (+859 kg/ha**), and Turda 145 (+972 kg/ha***).

Referring to the vegetation period of the hybrids (grain moisture content at harvest) the results presented in Table 3 show that there are not high differences between old and recent hybrids.

Regarding the resistance of the plants breaking and stalk lodging at harvest, the recently registered hybrids show genetic progress of 2.2%/year, achieved in improving the breaking plant resistance of very early maize hybrids.

The synthetic selection index calculated based on the three characters studied: grain yield, grain moisture content and percentage of the broken plants highlight the value of the following hybrids (111%) Turda 200 (oldest registered hybrid - 1976), Turda-SU 182 (122%), Turda 145 (116%) and Turda 165 (110%). Among the extra-early hybrids, the valuable behavior of the old Turda 165 hybrid stands out, through the grain yield, low moisture of the grains at harvest, and good resistance of the plants to breaking and stalk lodging. The Turda 165 hybrid ensures the transition between the two groups of FAO hybrids >100-200 and 200-300, for the vegetation period. The production of hybrid seed for both very early hybrids Turda 200 and Turda 165, is done at ARDS Turda.

The regressions suggest that, over the four years of the study, the average yields (the average yield of the 11 very early hybrids) increased with a genetic progress rate of about 171 kg $ha^{-1}$/year, despite the increase in average temperature in June-August and the annual rate of genetic progress of very early hybrids was for the resistance of plants to stalk-lodging increased by 2.2%/year.

The development of early maize hybrids (FAO 240-300) was until 2000 the major share of maize improvement activity in Turda. After 2000, with the climatic changes that took place in the area, by increasing the sum of active temperatures during the vegetation period of maize (Figure 1), the share of early hybrids decreased from 50% to 30%. This category of hybrids has spread in the maize growing areas of Transylvania, Moldavia, and in general the hills in the south and west of the country.

The grain yield of both very early and early maize hybrids was very negatively influenced by climate change, due to high temperatures during difficult periods of pollination and grain filling (July).

The general average grain yield of early hybrids was 8614 kg/ha, the yield being lower for the old hybrids (-287 kg/ha) and higher (+861 kg/ha) for in hybrids released between 2000-2012.The annual rate of genetic progress in grain yield was 16 kg/ha/year in early hybrids and the resistance of plant to broken and stalk lodging increased 1.6%.

Genetic progress in earliness has been made in some of the most recently released maize hybrids, Turda 165, Turda-SU 210.

Two early hybrids were distinguished by the value of the relatively synthetic index Turda 248 (136%) and Turda 165 (113%).

*Table 4.* The influence of climatic changes on behavior of early maize hybrids, FAO groups 210-300 (Turda, 2017-2020)

| Hybrid | Release year | Hybrid type | Grain yield | | Grain moisture | Broken and lodging plants | Selection index |
|---|---|---|---|---|---|---|---|
| | | | kg/ha | ±mean trial | % | % | %/mean trial |
| 1. HD 211 | 1975 | HD | 8463 | -151 | 16.4 | 30.3*** | 83 |
| 2. Turda 215 | 1976 | HT | 8915 | 301 | 18.1*** | 22.2 | 96 |
| 3. Turda 228 | 1979 | HT | 8039 | -575 | $16.1^{00}$ | 13.5 | 99 |
| 4. Turda 100 | 1979 | HD | 7646 | -968 | 17.3 | 32.4*** | 72 |
| 5. Turda 213 | 1984 | HS | 8826 | 212 | $16.2^{0}$ | 17.9 | 103 |
| 6. Turda 199 | 1984 | HT | 8185 | -429 | 19.3*** | 19.2 | 90 |
| 7. Turda 160 | 1990 | HS | 8447 | -167 | $15.9^{000}$ | 13.5 | 104 |
| 8. Elan | 1992 | HT | 7580 | -1034 | $15.7^{000}$ | 18.1 | 89 |
| 9. Turda Super | 1996 | HT | 8840 | 226 | 18.1*** | $9.6^{00}$ | 111 |
| Mean hybrids (1975-1996) | | | **8327** | **-287** | **17.0** | **19.6** | **-** |
| 10. Turda-SU 210 | 2000 | HT | 8807 | 193 | $16.3^{0}$ | 13.2 | 108 |
| 11. Turda 165 | 2002 | HT | 8970 | 356 | $15.6^{000}$ | $11.9^{0}$ | 113 |
| 12. Turda 248 | 2012 | HS | 10649 | 2035 | 17.3 | $8.9^{00}$ | 136 |
| Mean hybrids (2000-2012) | | | **9475** | **861**** | **16.4** | **$11.3^{0}$** | **-** |
| Mean trial | | | **8614** | **-** | **16.8** | **17.6** | **100** |
| * - LSD (P< 0.05)<br>** - LSD (P<0.01)<br>*** - LSD (P<0.001) | | | | 588<br>778<br>1006 | 0.5<br>0.7<br>0.9 | 5.4<br>7.2<br>9.3 | |
| Rate of genetic progress/an | | | 116 | | -0.1 | -1.6 | |

## The study of semi-early maize hybrids

The development of semi-early hybrids (FAO 310-380) represents in the last two decades, the major share of the maize breeding activity at ARDS Turda. After 2000, the sum of active temperatures during the maize growing season increased constantly exceeding the multiannual average from 1116°C/50 years to 1134°C/60 years, the semi-early hybrids fully capitalized on the thermal resources of the area. The hybrids from the FAO 300 group are of interest for the areas favorable to maize cultivation in the Transylvanian Plain and the surrounding plateaus, the meadows of the Mureş, Someş and Târnave rivers, central and northeastern Moldavia, as well as the subcarpathian valleys in the south and west.

Thermal requirements of hybrids from FAO 300 groups ∑°Cta (>1100) (Căbulea and Grecu, 1982; Sarca, 2004) as well as the sum of the multiannual average of active temperatures (ta ≥10°C) = 1134 ∑°Cta/60 years during the maize growing season (May - September), recommend the selection of semi-early maize genotypes at ARDS Turda.

Within the group of semi-early hybrids, the formula of simple hybrids was preferred in the development of hybrids due to their yield performance comparable to the hybrids of multinational companies, even if the difficulties in seed production were not in favor of this type of formula.

In relation to climate change, the behavior of hybrids created in recent years has proved to be much more stable. In the analyzed period of four years, the yields of the six historical hybrids have shown an average reduction trend of -228 kg/ha/year, while the average yield of most recently released hybrids have shown an upward trend at the hybrids: Turda 335, Turda 332 and Turda 2020 (Table 5). This suggests that genetic progress reflected in the release of new maize hybrids counteracted the negative effect of climate change seen on yield of the historical hybrids.

The highest values of the selection index were calculated for recently released hybrids Turda 335 (125%), Turda 332 (118%), Turda 2020 (118%), and Turda 344 (111%).

Genetic annual progress suggests that during the last years of study, yields increased by about a rate of 275 kg ha/year and plant resistance to stalk lodging improved with a rate of 0.9%/year.

*Table 5.* The influence of climatic changes on behavior of semi-early maize hybrids, FAO group 300-380 (Turda, 2017-2020)

| Hybrid | Release year | Hybrid type | Grain yield | | Grain moisture | Sensitivity of plants to stalk lodging | Selection index |
|---|---|---|---|---|---|---|---|
| | | | kg/ha | ±mean trial | % | % | %/mean trial |
| 1. Turda 215 | 1976 | HT | 9072 | $-981^{0}$ | 18.3 | 21.2*** | 79 |
| 2. Turda 260 | 1990 | HS | 8237 | $-1816^{000}$ | 18.5* | 7.9 | 84 |
| 3. Saturn | 1994 | HS | 9589 | -464 | 18.5* | 10.2 | 82 |
| 4. Turda Favorit | 2001 | HS | 9708 | -346 | 17.6 | 16.4** | 91 |
| 5. Turda 201 | 2001 | HT | 8664 | $-1389^{000}$ | $17.1^{0}$ | 11.6 | 86 |
| 6. Turda Star | 2005 | HT | 9569 | -484 | $16.9^{00}$ | 13.6 | 93 |
| Mean hybrids (1976-2005) | | | **9140** | **$-913^{0}$** | **17.8** | **13.5** | **-** |
| 7. Turda 248 | 2012 | HS | 10430 | 377 | 17.3 | 9.1 | 106 |
| 8. Marius TD | 2013 | HS | 9853 | -200 | 18.0 | 10.6 | 98 |
| 9. Turda 332 | 2014 | HS | 11532 | 1479*** | 18.1 | 7.9 | 118 |
| 10. Turda 344 | 2017 | HT | 10964 | 911* | 17.4 | 10.0 | 111 |
| 11. Turda 335 | 2021 | HS | 11788 | 1735*** | 17.5 | $5.1^{00}$ | 125 |
| 12. Turda 2020 | 2021 | HS | 11235 | 1182** | 17.8 | $5.5^{0}$ | 118 |
| Mean hybrids (2001-2021) | | | **10967** | **914*** | **17.7** | **8.0** | **113** |
| Mean trial | | | **10.053** | **-** | **17.8** | **10.8** | **100** |
| * - LSD (P< 0.05)<br>** - LSD (P<0.01)<br>*** - LSD (P<0.001) | | | | 703<br>933<br>1205 | 0.6<br>0.8<br>1.1 | 4.1<br>5.5<br>7.1 | |
| Rate of genetic progress/an | | | 275 | | -0. 1 | -0.9 | - |

## CONCLUSIONS

Based on the results obtained, it can be concluded that the rainfall, average active temperatures and number of hours of sunshine, during the four years of study, were very different, especially due to the quantity and uneven distribution of rainfall from one year to another.

During the past two decades, the sum of active temperatures (≥10°C) increased whereas the total precipitation and sunshine hours decreased. This climate change led to a reduction of potential yield across the different maize hybrids, especially very early and early (from FAO groups 100-280), in the study area.

In the years 2017-2020, grain yield of older hybrids and especially of hybrids from FAO groups 100-280 showed a decreasing trend (on average with -102 kg/ha/year; respectively -72 kg/ha/year).

Genetic progress in semi-early hybrids has been able to compensate the negative impact of climate change and produce a positive trend (on average by +275 kg/ha/year).

The results suggest that the selection of semi-early genotypes characterized by lower sensitivity to higher temperatures and drought during grain filling period, could contribute to the ability of new hybrids to counteract the effect climate change.

Therefore, these characteristics should be considered potential objectives in further improvement for reduction the impact of climate change.

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