RESEARCH

# Sowing date as a response to ecological conditions in maize seed production

**Marijenka Tabaković[1*], Milena Simić[1], Vesna Dragičević[1], Violeta Oro[2], Rade Stanisavljević[2], Milan Brankov[1], and Ljubiša Živanović[3]**

[1]Maize Research Institute, Zemun Polje, Slobodana Bajića 1, 11185 Belgrade-Zemun, Serbia.
[*]Corresponding author (mtabakovic@mrizp.rs).
[2]Institute for Plant Protection and Environment, Teodora Drajzera 9, 11040 Belgrade, Serbia.
[3]University of Belgrade, Faculty of Agriculture, Department for Crop Science, Nemanjina 6, Belgrade, Serbia.

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## ABSTRACT

The environment protection, energy, and resources preservation are especially pronounced under present climate changes. In agriculture, these changes are recognised as drought, high temperatures, occurrence of stormy winds and hail. The aim of this study was to determine variations in seed morphology that are a result of different sowing dates in relation with agro-ecological conditions of maize (*Zea mays* L.) cultivation. The material used for the study encompassed three inbred lines (G1, G2, G3) sown every 10 d on five sowing dates (T1, T2, T3, T4, T5) starting from 1 April to 10 May, during 2 yr (Y1: 2018, Y2: 2019). The following physical properties of seeds were estimated: width (W), length (L), thickness (Tk), ratio of small (SF) to large fraction (LF) and grain yield (GY). The width was the highest in all three inbreeds on T4 (1.00, 1.03, 0.99 cm, respectively); T5 was the least favourable date for L (1.09, 1.12, 1.09 cm, respectively) while Tk was the lowest in G1 (0.51 cm) and G2 (0.51 cm) sown on T1. The most significant differences in the formation of physical properties occurred in seeds sown on T5 ($p \leq 0.05$). The highest differences were observed in width between T5-T4 (-0.223 cm), in length between T5-T2 (-0.309 cm) and in thickness between T5-T3 (-0.129 cm). Later sowing dates favoured LF (85.2%) in comparison to SF (14.7%). Seed size variability participated with 50% in yield formation ($R^2 \geq 0.5$).

**Key words:** Maize, seed, shape properties, sowing date, *Zea mays*.

## INTRODUCTION

Although there is only one maize (*Zea mays* L.) species, it is so variable in its morphological, physiological, and other properties, which makes it the most variable plant species among cereals. This diversity is especially noticeable on seeds that are classified according to their shape, structure, and chemical composition. One of the initial classifications is mainly based on the shape and structure of grain (dent, flint, sweet, popping, soft, waxy, semi-dent and starch sweet maize).

Seed heteromorphism is defined as the ability of a plant to produce multiple types of seeds, which is a common strategy of survival under the unpredictable climate conditions (Bhatt and Santo, 2016). This seed trait affects the seed ability to disperse, germinate, to be dormant and persistent in the soil (El-Keblawy and Bhatt, 2015).

The seed number to seed size ratio is a starting point in the theory of ecology and evolution of survival and reproduction in the plant world. There are few explanations for the existence of advantages of the development of large seeds under different living conditions (Westoby et al., 1992; Tabakovic et al., 2020).

Consequently, according to some studies different seed morphogenesis and different germination patterns reflect seed longevity, especially in small seeds compared to large ones, as they are inherently longer-lived (De Pace et al., 2011; Dyer, 2017), not only in maize but also in other plant species.

The main determinants of the seed size are rate and duration of grain (Prado et al., 2013; Zhang et al., 2013). The seed size is a yield component and one of the factors of seed quality. According to the physiological and morphological properties, seed energy, germination, shape, size and the weight are criteria of seed quality (Zhao et al., 2020). The seed size gradation improves its quality and increases the efficiency of its use. Seed grading according to shape and size is one of the most efficient procedures to uniform physical and mechanical properties of seeds. During the seed processing, seed traits are uniformed to the condition suitable for sowing (Varga et al., 2012). Due to it, many companies began to classify seed by its shape in the early 1990s. Later, the technology of uniformity has been developed in the direction of monitoring the physiological and morphological properties of seeds. This includes pericarp colour, seed shape, weight, transparency, density and seed stream. Various software have been designed to recognise maize seeds by their size, shape, colour, while more advanced software have been also used to recognise some physiological properties such as germination (Sako, 2000).

Not only degradation of nature is among the most serious problems faced by the world, but also the world has to deal with mitigation of climate changes, feed the growing population and restore biodiversity (Mace et al., 2018). All such actions depend on an adequate supply of high-quality seeds at the right time and in the right place. In view of the economic importance of total seed production and primary seed ingredients (proteins, starch, oil), the aim of this study was to establish the impacts of meteorological conditions on morphological and physical maize traits, and to comprehend the mechanisms regulating various aspects of seed development.

## MATERIALS AND METHODS

### Plant material

Seeds of three maize (*Zea mays* L.) inbred lines derived at the Maize Research Institute, Zemun Polje (G1-217, G2-G325/75-2 and G3-G335/99) were used in the trial. One inbred (G1) belonged to the FAO maturity group 400, while the remaining two (G2, G3) belonged to the FAO maturity group 600.

### Soil properties

The soil was a slightly calcareous Chernozem, namely Molcal silt loam (coarse-loamy, mixed, superactive, mesic Vitrandic Calcixerolls) (USDA-NRCS, 1999). The 0 to 30 cm layer contained 3.3% organic matter, 0.21% total N, 1.9% organic C, 14 mg available P 100 $g^{-1}$ soil, 31 mg extractable K 100 $g^{-1}$ soil, 9.7% total $CaCO_3$, and pH 7.8.

### Seed production and processing

The 2-yr trial was carried out according to the split-plot system in the location of Zemun Polje (44°52'00" N, 20°19’00” E) in the vicinity of Belgrade, Serbia, in the period from 2018 (Y1) to 2019 (Y2). Sowing was performed on the following five dates: 1 April (T1), 10 April (T2), 20 April (T3), 30 April (T4) and 10 May (T5).

Seeds for sowing were divided by size into three fractions by passing through sieves of the appropriate mesh size with the aid of the Carter Day laboratory maize processing equipment (CEA, Minneapolis, Minnesota, USA). A small seed size (SD) amounted to 6.5-8.4 mm, while large (LD) and primary (PD) seed sizes amounted to 8.5-11.0 and 6.5-11.0 mm, respectively. The elementary plot size amounted to 4.0 m × 6.3 m. The plot consisted of nine rows with one inbred (3×3 rows of each seed size - SD, LD, PD). The inter-row distance was 0.7 m and the plant distance was 0.2 m (hence, the plant density was 71 000 plants $ha^{-1}$). Each trial variant was sown in four replicates for each inbred. The trial was performed under rainfed conditions (Table 1).

**Table 1. Mean monthly temperatures.**

| | Apr | May | Jun | Jul | Aug | Sep |
|---|---|---|---|---|---|---|
| | ºC | | | | | |
| Y1 | 18.0 | 21.7 | 22.7 | 23.6 | 25.7 | 19.8 |
| Y1-Y3 | 3.8 | 6.1 | -1.5 | -0.7 | -0.5 | -0.4 |
| Y2 | 14.6 | 15.7 | 24.2 | 24.1 | 25.9 | 18.6 |
| Y2-Y3 | 0.4 | 0.1 | 0.0 | -0.2 | -0.3 | -1.6 |
| Y3 | 14.2 | 15.6 | 24.2 | 24.3 | 26.2 | 20.2 |

Y1: 2018; Y2: 2019; Y3: reference period (1981-2010).

**Laboratory testing**

Physical properties of maize seeds, width (W), length, (L), thickness (Tk), and the ratio of seed fractions on the cob (small fraction, SF/large fraction, LF), were evaluated under laboratory conditions after harvest of inbreeds.

After harvesting and drying of ears, samples were drawn to determine percentage ratio of large (LF) to small seeds (SF). Five ears each were selected and shelled and then seeds were passed through sieves of mesh sizes 6.5-8.4 mm (SF) and 8.5-11.0 mm (LF). Sifted seeds were weighed to determine the proportional ratio of seeds by size.

The seed W, L and Tk were measured with a calliper (accuracy 1/10 mm, range 0-150 mm; Kern, Balingen, Germany) from five-seed samples drawn from the central part of the ear in three replicates.

The determination of the grain yield was done by measuring seed weight from middle rows of all maize ears, and the estimation was done at 14% moisture.

**Meteorological data**

The climate of Serbia can be described as temperate-continental with more or less local characteristics, which correspond to the climate of South-eastern Europe, the Balkans.

According to the Republic Hydrometeorological Service of Serbia (RHMS, 2021), temperatures in 2018 and 2019 were the highest since the beginning of recording temperatures in Serbia (1888). The average annual temperatures in relation to the reference period (1981-2010) deviated by 2.0 °C for 2018 and 2.2 °C for 2019. Mean monthly temperatures in the April-August period were characteristic of hot springs and summers (Table 1).

The precipitation distribution under the conditions of continental climate is uneven, with higher amounts in the warmer half of the year (April-September) and the annual precipitation sum ranges 540 to 820 mm. Maize is a plant with increased needs for water, particularly in the stage of intensive growth. The critical period in which the plant needs a sufficient moisture is 15-20 d after tasselling and 10-15 d after pollination. The precipitation sum during the 2-yr trial was almost equal for Y1 (336.5 mm) and Y2 (366 mm), which was lower by 130 and 100 mm, respectively, than the sum in the reference period (1981-2010). The highest differences occurred in April and May in Y1 at the time of sowing (Table 2).

**Statistical analysis**

The descriptive statistics was applied to process each of obtained parameters. Differences among different sowing dates were determined by the ANOVA and the LSD test at the 5% and 1% risk levels. In order to draw conclusions objectively about the impact of observed factors on studied traits of maize seeds, parametric tests (ANOVA and LSD-test), Person's correlation coefficient, linear regression analysis ($Y = \beta_0 + \beta_{1xi} + \varepsilon$) and the principal component analysis (PCA) were applied. The obtained experimental data were processed using the statistical package SPSS 21 (free version, IBM, Armonk, New York, USA).

## RESULTS AND DISCUSSION

Based on the gained mean values of the seed dimensions, width (W), length (L), thickness (Tk), a positive trend of increasing values up to T4 was observed, after which values decreased. The mean W value on T4 was the highest in all three inbreeds (1.00, 1.03 and 0.99 cm). The sowing date T5 was the most favourable for L, while Tk was the lowest for G1 and G2 on T1. The percentage of SF was higher on the first three sowing dates, i.e., it was the highest for G3 on T2, while T4 and T5 were characterised by a higher percentage of LF (Table 3).

**Table 2. Mean monthly precipitation sum.**

| | Apr | May | Jun | Jul | Aug | Sep | Sum |
|---|---|---|---|---|---|---|---|
| | mm | | | | | | |
| Y1 | 24.6 | 39.0 | 150.1 | 61.9 | 44.0 | 16.9 | 336.5 |
| Y1-Y3 | -52.2 | -103.2 | 11.4 | 18.9 | 4.3 | -9.2 | -130.0 |
| Y2 | 51.3 | 129.6 | 113.7 | 31.0 | 19.8 | 20.6 | 366.0 |
| Y2-Y3 | -25.5 | -12.6 | -25.0 | -12.0 | -19.9 | -5.5 | -100.5 |
| Y3 | 76.8 | 142.2 | 138.7 | 43.0 | 39.7 | 26.1 | 466.5 |

Y1: 2018; Y2: 2019; Y3: reference period (1981-2010).

**Table 3. Mean values of seed physical properties according to impacts of sowing dates (T) and genotype (G).**

| | Width | Length | Thickness | Small fraction | Large fraction |
|---|---|---|---|---|---|
| | cm | | | % | |
| G1 | | | | | |
| T1 | 0.90 | 1.14 | 0.51 | 24.48 | 75.52 |
| T2 | 0.96 | 1.17 | 0.54 | 16.51 | 83.49 |
| T3 | 0.95 | 1.16 | 0.52 | 16.64 | 83.36 |
| T4 | 1.00 | 1.13 | 0.55 | 15.77 | 84.23 |
| T5 | 0.95 | 1.09 | 0.52 | 17.40 | 82.60 |
| | 0.95 | 1.14 | 0.53 | 18.23 | 81.77 |
| G2 | | | | | |
| T1 | 0.97 | 1.14 | 0.51 | 15.58 | 84.42 |
| T2 | 0.97 | 1.16 | 0.52 | 15.37 | 84.63 |
| T3 | 0.97 | 1.15 | 0.55 | 23.78 | 76.22 |
| T4 | 1.03 | 1.14 | 0.54 | 10.76 | 89.24 |
| T5 | 0.98 | 1.12 | 0.53 | 7.81 | 92.19 |
| | 0.98 | 1.14 | 0.53 | 14.66 | 85.34 |
| G3 | | | | | |
| T1 | 0.88 | 1.11 | 0.55 | 25.91 | 74.09 |
| T2 | 0.88 | 1.16 | 0.55 | 32.24 | 67.76 |
| T3 | 0.99 | 1.16 | 0.54 | 18.26 | 81.74 |
| T4 | 0.94 | 1.12 | 0.55 | 23.76 | 76.24 |
| T5 | 0.91 | 1.09 | 0.51 | 19.29 | 80.71 |
| | 0.92 | 1.13 | 0.54 | 23.86 | 76.14 |

T1: 1 April; T2: 10 April; T3: 20 April; T4: 30 April; T5: 10 May; G1: 217; G2: G325/75-2; G3: G335/99G1.

Ecological conditions in the years of investigation affected the values of seed dimensions, W, L, Tk, and the percentage participation of fractions. Agro-ecological growing conditions in Y1 significantly affected W, L, and Tk, while in Y2, the conditions most significantly affected L and Tk on T5 (Figures 1a, 1b, 1c). Year 1 was characterised by large seeds (over 75% LF), while the SF to LF ratio in Y2 amounted to approximately 40% to 50% (Figures 2a, 2b). The remaining seeds were either smaller than 6.5 mm or larger than 11 mm. It is known that weather conditions affect yield, i.e., grain filling, which directly affects the percentage participation of small and large seeds (Mayer et al., 2016; Gavric and Omerbegovic, 2021). Seeds were formed under unfavourable conditions (high temperatures) during pollination. Both years, Y1 and Y2, were considered extremely hot, because temperatures of above 35.4 °C lasted for 49 and 48 d, respectively. Even a relatively large amount of precipitation could not mitigate the adverse effect of tropical days and nights on the formation and development of seeds of observed maize inbred lines.

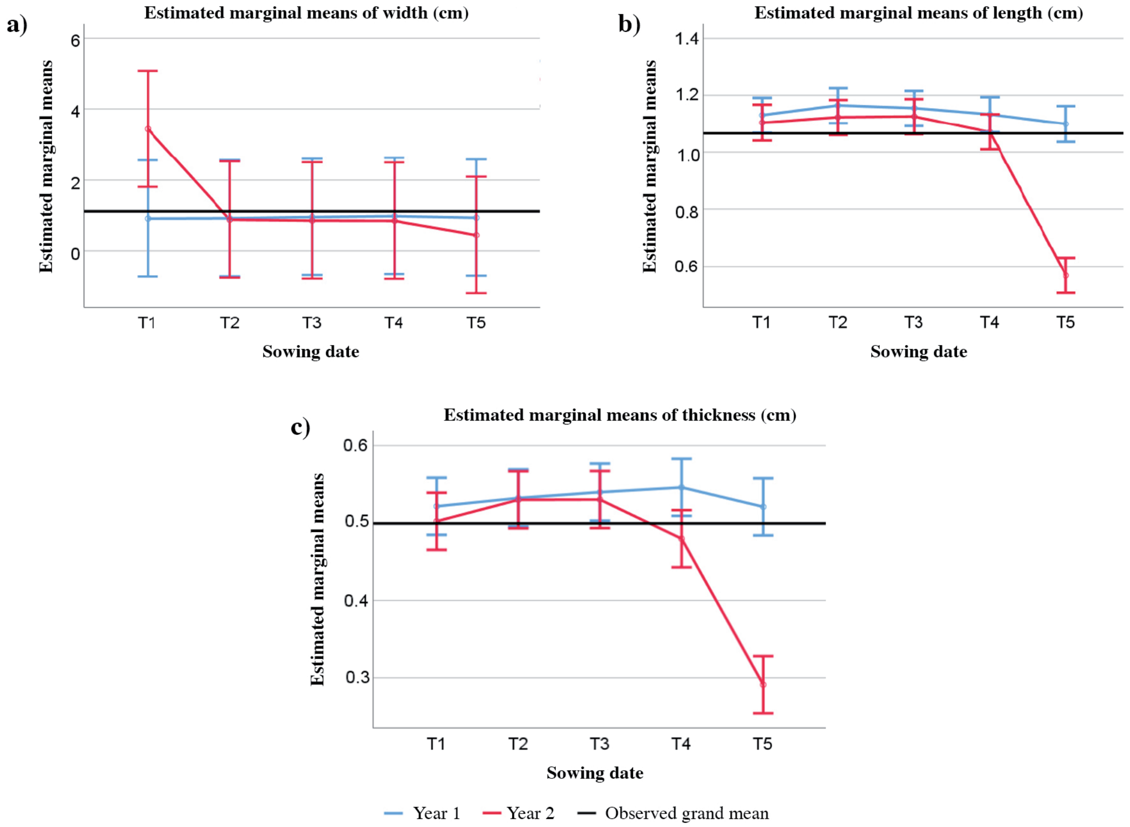
The most significant differences in the seed size were determined between T5 and remaining four sowing dates, T1-T4. Differences caused by the application of the first four sowing dates did not significantly affect variation in seed sizes (Table 4).

Factors observed in this trial (genotype, year, size, sowing date) were nonsignificant for the variations of W. The length (L) is a seed trait that varied over seed sizes on sowing dates, over years, sowing dates and their mutual interactions. The seed Tk depended the least on the seed size at sowing. The LF to SF ratio (LF/SF) depended on both genotypes and agro-ecological conditions, i.e., production year. Genetic and environmental factors regulate the seed size. Depending on genetic factors, biochemical and physiological abilities of plants, as well as on temperature, moisture and presence of available N in the soil, the duration and grain filling rate differ, which results in different seed sizes. The length of the endosperm formation has a key role in the seed size (Sekhon et al., 2014).

The classification of seeds at sowing into LD, SD and PD was not important for the formation of physical traits of seeds, except for L (Table 5).

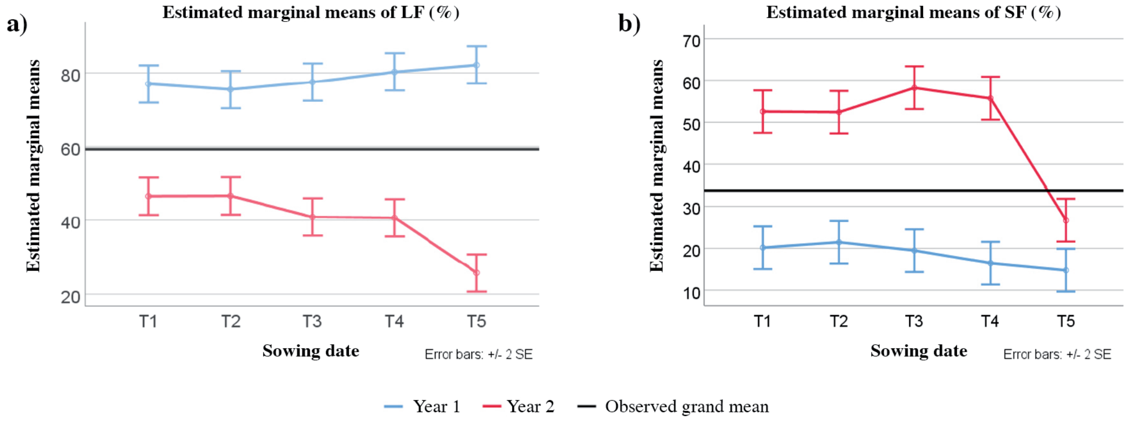
The extent to which the seed size will be expressed depends on a genotype, production year and a pheno-phase (Mayer et al., 2019). The size (dimension) and number of fractions have to be adjusted to the properties of the genotype, i.e., to the seed material composition for each genotype.

**Figure 1. Effects of different production years (Y1: 2018, Y2: 2019) and sowing dates (T1-T5) on physical properties (width, length, thickness) of maize hybrid seeds.**




Vertical bars correspond to the standard error (± 2 SE). T1: 1 April; T2: 10 April; T3: 20 April; T4: 30 April; T5: 10 May.

**Figure 2. Effects of production years (Y1: 2018, Y2: 2019) and sowing dates (T1-T5) on the large (LF) to small fraction (SF) ratio (LF:SF) of maize hybrid seeds.**




Vertical bars correspond to the standard error (± 2 SE). T1: 1 April; T2: 10 April; T3: 20 April; T4: 30 April; T5: 10 May.

**Table 4. Multiple comparison tests (LSD test) of average values of physical properties of seeds according to the sowing dates (T1-T5).**

| | Width | | | | | Length | | | | | Thickness | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | T1 | T2 | T3 | T4 | T5 | T1 | T2 | T3 | T4 | T5 | T1 | T2 | T3 | T4 | T5 |
| T1 | | 0.02 | 0.02 | 0.03 | -0.19* | | 0.03 | 0.02 | -0.02 | -0.28* | | 0.02 | 0.02 | 0.00 | -0.10* |
| T2 | -0.02 | | 0.00 | 0.01 | -0.20* | -0.03 | | 0.00 | -0.04 | -0.30* | -0.02 | | 0.00 | -0.02 | -0.12* |
| T3 | -0.02 | 0.00 | | 0.01 | -0.21* | -0.02 | 0.00 | | -0.04 | -0.30* | -0.02 | 0.00 | | -0.02 | -0.12* |
| T4 | -0.03 | -0.01 | -0.01 | | -0.22* | 0.02 | 0.04 | 0.04 | | -0.26* | 0.00 | 0.02 | 0.02 | | 0.10* |
| T5 | 0.19* | 0.20* | 0.21* | 0.22* | | 0.28* | 0.30* | 0.30* | 0.26* | | 0.10* | 0.12* | 0.12* | 0.10* | |

*Significant at the 0.05 probability level according to LSD test (P < 0.05). No markings: nonsignificant differences.
T1: 1 April; T2: 10 April; T3: 20 April; T4: 30 April; T5: 10 May.

**Table 5. Parameter tests (ANOVA).**

| | Width | Length | Thickness | Small fraction % | Large fraction % |
|---|---|---|---|---|---|
| Treatment (T) | ns | ** | ** | ** | ** |
| Genotype (L) | ns | ns | * | ** | ** |
| Year (G) | ns | ** | ** | ** | ** |
| Fraction (F) | ns | ** | ns | ns | ns |
| T × L | ns | ** | * | * | ** |
| T × G | ns | ** | ** | ** | ** |
| T × F | ns | ** | * | ** | * |
| L × G | ns | ns | ns | ** | ** |
| L × F | ns | ** | ** | ** | ** |
| G × F | ns | ** | ns | ns | ** |
| T × L × G | ns | ** | ** | ** | ** |
| T × L × F | ns | ** | ** | ** | ** |
| T × G × F | ns | ** | ** | ** | ns |
| L × G × F | ns | ** | ** | ** | * |
| T × L × G × F | ns | ** | ** | ** | ** |

*, **Significant at 0.05 and 0.01 probability levels according to F-test; ns: nonsignificant at the 0.05 probability level.

### Yield in relation to seed physical properties

By the observation of factor loads for the seed size traits (W, L, Tk, SF, LF) and GY, PCA analysis shows that two components represented 88.28% of the obtained variation. Length, Tk, SF, LF and GY were positively correlated with the first component (73.37%). On the other hand, the physical seed trait W was correlated with the second component (15.91%) (Figure 3b). By observing the distribution of regression factor score values of the research variant sowing date + seed sizes at sowing, it was determined that the most of the coefficients were located on the right side of the diagram as well as the component matrix of physical seed properties (Figure 3a). It can be concluded that the first component was a set of cropping practices that determined the formation of physical seed properties and yield. Late sowing, T5, was negatively correlated with all properties (W, L Tk, SF, LF) and GY. The second component, which was far less efficient than the first, was seed quality at sowing, responsible for W variability (0.964).

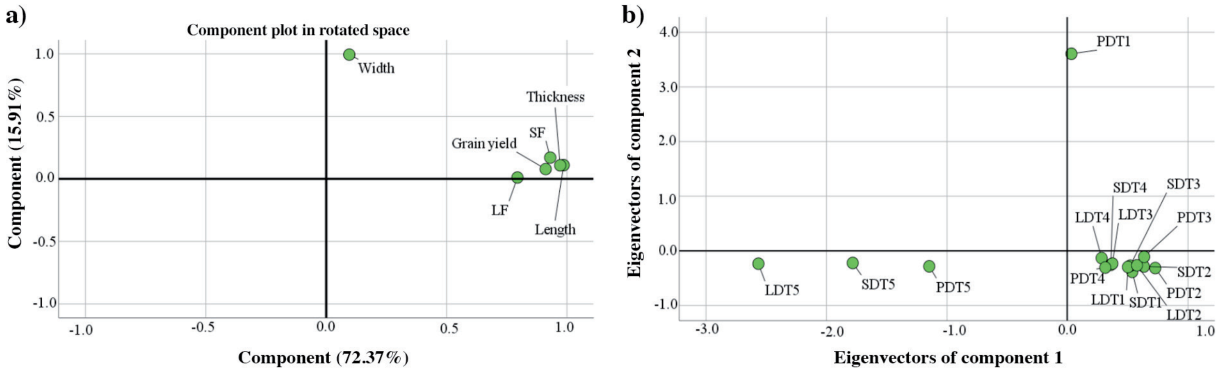
All properties of the seed size participate with over 50%, $r \geq 0.500$, in the yield variance (Table 6). Across environmental and genotypic sources of variation, the grain yield is more closely related to the seed number than to the seed weight (Dokic et al., 2020). The variation in seed weight is genetically determined, but it is often a result of adjusting to the number and shape of seeds.

The seed size variability mainly affected the grain yield of the genotype G1 ($R^2 \geq 0.600$), while variability in seed W, L and Tk had lesser effect on genotypes G2 and G3 ($0.24 \leq R^2 \geq 0.50$).

The highest effect of variability in seed morphological traits on GY was related to the sowing date. The seed size had nonsignificant effect on yield variability related to the first four sowing dates ($R^2 \leq 0.10$). On the other hand, all seed size properties (W, L, Tk) on T5, equally affected GY ($R^2 \geq 0.580$).

The effect of the year of production on the seed size to GY ratio was expressed in Y2, in which the yield was determined by the variability in the seed size ($R^2 \geq 0.49$). It varied the most with the change of seed L ($R^2 \geq 0.60$). In Y1, the seed size did not affect the yield.

**Figure 3. Principal component analysis of the variables in the study concerning effects of sowing date (T1-T5) and seed size on physical properties width (W), length (L), thickness (Tk) and grain yield (GY) (a) and eigenvectors of principal component, sowing date and seed sizes at sowing (SD, LD, PD) (b).**




SF: Small fraction; LF: large fraction; SD: small seeds 6.5-8.4 mm; LD: large seeds 8.5-11.0 mm; PD: primary seed sizes 6.5-11.0 mm; SDT1: seeds of small size sown on 1 April; LDT1: seeds of large size sown on 1 April; PDT1: seeds of primary size sown on 1 April; SDT2: seeds of small size sown on 10 April; LDT2: seeds of large size sown on 10 April; PDT2: seeds of primary size sown on 10 April; SDT3: seeds of small size sown on 20 April; LDT3: seeds of large size sown on 20 April; PDT3: seeds of primary size sown on 20 April; SDT4: seeds of small size sown on 30 April; LDT4: seeds of large size sown on 30 April; PDT4: seeds of primary size sown on 30 April; SDT5: seeds of small size sown on 10 May; LDT5: seeds of large size sown on 10 May; PDT5: seeds of primary size sown on 10 May.

**Table 6. Pearson's coefficient of correlation.**

| | Grain yield | Width | Length | Thickness |
|---|---|---|---|---|
| Grain yield | 1.000 | 0.605 | 0.681* | 0.597* |
| Width | 0.605* | 1.000* | 0.885* | 0.741* |
| Length | 0.681* | 0.885* | 1.000 | 0.841* |
| Thickness | 0.597* | 0.741* | 0.841* | 1.000 |

*Significant correlation among seed physical properties (width, length, thickness) according to the F-test ($P < 0.05$).

The yield varied mostly when SF seeds were sown. Within this fraction, all seed size properties equally contributed to the variation of GY, $R^2 \geq 0.40$.

There were nonsignificant differences in the obtained yields related to the first four sowing dates. The lowest yield and the highest variability $\sigma = 8.029$ were obtained with the latest sowing date, T5. The sowing date determined the weather conditions to which maize is exposed. The sowing date was determined by the weather conditions to which maize was exposed. Variations in weather conditions associated with the sowing date were the main factors influencing the maize growth. The significant reduction in yield occurred due to late sowings because of the reduced post-silking DM production (Zhou et al., 2016). An interesting approach in interpreting the key role of the seed size in determining the number of seeds per plant is that the seed size plays a significant role in modulating genetic and external control of the seed number.

The sowing dates that contribute to a better relationship between the seed size and the yield is the consistency of drying temperature, duration of the treatment and biological effect of the process (Egli and Rucker, 2012).

Late sowing reduces the effective grain filling rate compared to early sowing. The plant growth rate in the grain filling stage was slowed down in late sown plants due to a low level of daily radiation and radiation use efficiency. Daily temperatures significantly affected the grain filling rate increasing the weight by 0.3 mg per day per °C. Furthermore, there was a reduction in the source of assimilative, which caused the reduction of the seed weight (Kanatas et al., 2020).

Studies aimed at more complete understanding, estimation and evaluation of the properties of hybrid maize seeds provide the correct perception of new production conditions due to changes that occur in the form of temperature extremes and water deficits. Under the impacts of continental climate, weather can act as a strong abiotic factor affecting the maize seed yield (Li et al., 2019; Ghete et al., 2020). Climatic parameters such as water availability and temperature levels have been identified as key factors responsible for maize crop productivity (Tokatlidis, 2013; Butts-Wilmsmeyer et al., 2019). The precipitation sum in the April-August period affects maize yields more than N fertiliser does (Halmajan et al., 2017). Maize is particularly susceptible to drought stress during pollination and grain filling (Wang et al., 2019; Iqbal et al., 2020).

In the conducted studies, there were several groups of factors: controlled, partially controlled and absolutely uncontrolled ones. The genotypic combination and crop sowing were completely controlled factors. The seed size was a partially controlled factor, while agro-ecological conditions and the production location were absolutely uncontrolled factors. The degree of effects of the stated factors varied. Effects of sowing dates were just of partial importance. Such pattern of expression of sowing dates was contributed by ecological conditions in the period of studying. High temperatures (18.0-22.7 °C) at sowing (April-May, in Y1) and low levels of soil moisture (24.6-39.0 mm) resulted in a delay of germination, and thus the effect of sowing intervals was reduced. The fifth sowing date, T5, caused the greatest variations. The effect of ecological conditions at sowing on the seed size was even over 70% ($R^2 > 0.70$). The yield variance for T5 amounted to $\sigma = 8.029$. Later sowing dates coincided with high temperatures and drought. Moreover, T5 unfavourably affected stages of pollination and grain filling. In Y1 poor pollination was a result of high percentage of large fraction seeds (LF > 70%), and in Y2 poorer grain filling and lower GY.

A comparison of weather parameters across years of investigation showed that the daily mean temperature was the highest during most of the flowering stage. This stage is the most susceptible stage of the maize growth in terms of the impacts of high temperatures (Sharon et al., 2013; Hatfield and Prueger, 2015; Vinayan et al., 2020), causing significant losses in grain yields, mainly by affecting pollen viability (Windhausen et al., 2012; Alam et al., 2017). The variability of the seed size indicated that production conditions had the greatest impact within the hybrid combination and then within the growing practices, particularly sowing dates (Nave et al., 2016). The influence of the seed size at sowing was small and not so significant for the formation of good morphological properties of seeds, but it was significant for the creation of conditions for uniform germination that was a prerequisite for stable yields.

It is more than likely that the temperature and precipitation will increase in the near future, as projected in most weather modelling studies. However, the increase in precipitation will not compensate for the water loss on the surface of the planet due to intense thermal variations, which will increase the significance of irrigation. In addition, changes in heat resources due to regional warming will accelerate the crop growth. It has been predicted that the period of maize growth, especially in the grain filling stage, would be shortened by about 10 to 30 d in the current maize growing regions, which would lead to reduced yields (Wang et al., 2011).

The results of the simulation of climate changes in the temperate continental climate indicate that agriculture cannot avoid effects of climate changes, and unfortunately most of these effects will be adverse (Fodor and Pásztor, 2010).

## CONCLUSIONS

Climate changes that cause an increased frequency of extreme temperatures and uneven precipitation also result in variability in the physical properties of seeds. The year of production, together with other factors (genotype, sowing date, seed size at sowing) is a factor that affected all observed seed properties. The intensity of variations in properties depended on the genotype, while the sowing date indicated the importance of adjusting production to climatic conditions. The effects of the genotype, year, seed size, sowing date observed in the performed trial had the least significance on seed width. Seed length and thickness varied under the influence of the genotype, sowing date, year and the seed size at sowing. The mutual relationship of factors (Treatment × Genotype × Year × Fraction) is also very important for the degree of expression of physical properties of seeds.

By changing the seed size, each genotype (G) in its own way affected the yield: G2 and G3 had more stable physical properties, which resulted in more stable yield.

A properly selected sowing date that is important for mitigating unfavourable effects of climatic extremes has the strongest impact on the yield and oscillations in the yield.

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