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JOINT AND DIRECT EFFECTS OF GENOTYPES AND ENVIRONMENT CONDITIONS ON YIELD AND YIELD COMPONENTS VARIABILITY OF MAIZE INBRED LINES
ZAJEDNIČKI I DIREKTNI EFEKTI GENOTIPA I USLOVA ŽIVOTNE SREDINE NA VARIJABILNOST PRINOSA I KOMPONENTI PRINOSA LINIJA KUKURUZA

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ABSTRACT

This study aimed to evaluate the influence of environmental conditions and genotype on the yield of three maize lines and the morphological properties of ears and seeds. Three hybrid maize lines were used as material in the study conducted in two consecutive years (2018 and 2019) at one location (Zemun Polje, Belgrade, Serbia). The following parameters were monitored: seed weight (SW), seed volume (V), bulk density (BD), ear length (EL), ear thickness (ET), fraction content and seed yield (MSY). Calibration divided the seed into a small seed fraction of 6.5-8.4 mm (SF) and a large seed fraction of 8.5-11 mm (LF). Seeds smaller than 6.5 mm and larger than 11 mm are presented as seed waste fraction (FW). The average seed yield for all three lines in the first and the second year was 6.13 and 4.66 t ha^{-1}, respectively. A significant impact of the environment was noticed on seed weights in both years (2018 and 2019), i.e. 327.56 and 251.77 g, respectively. The total variation in yield determined by the morphological characteristics of the seed was R^2 =0.514.

***Keywords**: genotype, yield, fractions, ear.*

REZIME

Cilj rada bio je da se oceni uticaj uslova sredine i genotipa na prinos tri linije kukuruza i morfološke osobine klipa. U radu je korišćeno seme tri linije kukuruza, u dvogodišnjem ogledu izvedenom u 2018 i 2019 godini, na jednoj lokaciji. Parametri koji su posmatrani bili su prinos zrna (MSY), apsolutna masa semena (SW), zapremina semena (V), gustina semena (BD), dužina klipa (EL), debljina klipa (ET) i težina klipa (EW). Kalibracijom semena dobijene su tri frakcije semena: sitna, veličine semena 6,5-8,4mm (SF), krupna, veličine semena 8,5-11mm (KF) i frakcija otpada, veličine semena ispod 6,5mm i iznad 11mm (FW).Prosečan prinos za sve linije u prvoj godine bio je 6,13 a u drugoj 4,66 t ha^{-1}. Značajan efekat ekoloških uslova bio je i na apsolutnu masu semena (327,56 g u prvoj; odnosno 251,77 g u drugoj godini). Ovako velika razlika u apsolutnoj masi semena odrazila se i na ukupan odnos sitne (SF) i krupne frakcije (LF) semena na klipu. Ukupno variranje prinosa klipa determinisano morfološkim osobinama semena bilo je R^2 = 0.514. Sve morfološke osobine klipa i semena međusobno su značajno korelirale na oba nivoa značajnosti ($p \leq 0,01$, $p \leq 0,05$).

***Ključne reči:** genotip, prinos, frakcije semena, klip.*

INTRODUCTION

The variability of yield in relation to the environment is within the limits of average monthly changes in temperature and precipitation (*Cegler et al., 2016*). Due to rapid changes in meteorological conditions, agriculture has focused on new cropping systems. Intra-seasonal weather changes can affect plant production throughout the year (*Olsen et al., 2000*). Complex systems are used to solve this problem, taking into account the long-term results of yield, fertilization, crop rotation and other agricultural practices (*Asseng et al., 2013*). The advantage of these systems is the ability to predict and model production (*Balkovic et al., 2014*). However, it also has its drawbacks, as weather conditions have a local character (*Folberth et al., 2012*). The yield components and their relationship are key yield factors. The main components of maize seed yield are ear length, ear thickness, and the number of kernel rows. According to Zhang et al. (2019), in the conditions of drought, due to the lack of water in the seed filling phase, the main yield components are the number of kernels per plant, seed weight and seed filling rate. The number of kernels per plant, and assimilation units of nutrients, are the main elements for estimating the final yield, as well as the influence of stress caused by temperature changes (*Lizaso et al., 2018*). Maize seed yield is a result of complex relationships of yield components with successive effects at different growth stages (*Novacek et al., 2014*). The potential number of seeds is determined in the late phase of pollination. The presence of stress during this phase affects the duration of the pollination and silking phase which affects the number of kernels per row, the number of kernels per ear, the seed weight, or the yield components. The seed number develops from phase V7 to R2, while the seed weight is formed at the filling stage (*Cicchino et al., 2010; Abendroth et al., 2011*). Managing production to reduce heat stress leads to an increase in kernel number per row and seeds weight (*Milander et al, 2016 a*). The influence of the environment on crop production is a limiting factor regarding the genetic and physiological development of yield and yield components to achieve high yields (Slafer et al., 2014; Madosa et al., 2019).

The objectives of this study were to compare the morphological characteristics of the ear and the relative importance of yield components of three maize lines during two variable seasons.

MATERIAL AND METHODS

The experiment was designed according to the randomised complete block design (RCBD), at the location Zemun Polje (Belgrade, Serbia), for two consecutive years (2018 and 2019). The object of research were three maize inbred lines (L1, L2, and L3), created at the Maize Research Institute Zemun Polje. The elementary plot size of 5×5.6m included nine rows, with three rows from each maize inbred line, in three replications. All inbred lines were sown with the inter-row distance of 70 cm and the within-row plant distance of 20 cm. Standard cropping practices for maize were applied, identically for all plots and all three inbred lines. Ears were harvested manually at the full seed maturity. All ears from the middle (out of three) row were used to measure the yield. Yield components and morphological seed properties were determined by forming five-ear samples. After the harvest, the seeds were threshed, dried and processed on laboratory equipment for calibration Carte Day (CEA, Minneapolis, Minnesota, USA)., using sieves with hols of 6.5-8.4 mm and 8.5-11 mm. The calibration divided the seeds into small seed fraction size of 6.5-8.4mm (SF) and large seed fraction size of 8.5-11mm (LF). Seeds smaller than 6.5mm and larger than 11 mm are presented as a seeds waste fraction (FW). Seed samples were drawn from processed seed material for laboratory testing of seed weight (SW), volume (V) and bulk density (BD). Seed weight (SW) was established by counting 4×100 seeds (ISTA) and then measuring the digital balance. Volume and bulk density were determined according to Babić and Babić (2007) methods. The sample of five ears per each variant was drawn to determine the ear length (EL), ear thickness (ET), ear weight (EW), the kernel rows number (KRN), kernel number per row (KNR).

Meteorological data were used from the Republic Hydrometeorological Service of Serbia (RHMZ, 2020) (Table 1).

Table 1. Meteorological data during the maize growing season for 2018 and 2019.

	Monthly mean air temperature (°C)							
Year	April	May	June	July	Aug.	Sept.	Oct.	Average
2018	18.0	21.7	22.7	23.6	25.7	19.8	15.9	21.1
2019	14.6	15.7	24.2	24.1	25.9	18.6	16.9	20.0
961-1990	11.4	16.6	19.6	21.1	20.6	16.9	11.5	16.8
991-2020	13.6	18.2	21.9	23.8	23.7	18.5	13.3	19.0
	Monthly sum of precipitation (mm)							
Year	April	May	June	July	Aug.	Sept.	Oct.	Sum
2018	24.6	39.0	150.1	61.9	44.0	16.9	20.8	357.3
2019	51.3	129.6	113.7	31.0	19.8	20.6	7.2	350.5
961-1990	57.6	69.3	89.3	70.0	54.3	51.3	41.0	433.0
991-2020	51.5	72.3	95.4	66.5	53.9	59.8	53.5	452.9

Descriptive statistics was applied to process each of the obtained parameters. The load factor of the variable was quantified by factor analysis (ANOVA) at the 5% level. The shape and character of the relationship between yield and seed morphological characteristics were determined by regression analysis. The obtained experimental data were processed using the statistical package SPSS 21 (version free of charge, IBM, Armonk, New York, USA).

RESULTS AND DISCUSSION

The influence of the year was significantly manifested in the variability of MSY and morphological characteristics of seeds: SW, V, BD, SF, LF, FW, and of yields component EL. The influence of genotype was significant for SW, FW, ET and for KNR and MSY; while the interaction of both factors was significant only for the percentage of LF and FW (Table 2). Compliance of maize cultivation with environmental conditions is a prerequisite for achieving high yields (Yang et al., 2019). Most variability can be explained by the participation of 10-30% of genotypes and years, on seed size, i.e., the percentage of fractions SF (R^2 0.544), LF (R^2 0.673), and FW (R^2 0.458) (Table 2).

Table 2. Influence of year and genotype on seed morphological traits, yield components and yield (ANOVA).

	Genotype (P - value)	Year (P - value)	Genotype×Year (P - value)	Coefficient of Determination
SW	0.000	0.000	0.540	R Squared = 0.252 (Adjusted R Squared = 0.242)
V	0.449	0.000	0.133	R Squared = 0.218 (Adjusted R Squared = 0.207)
BD	0.449	0.000	0.133	R Squared = 0.118 (Adjusted R Squared = 0.106)
SF	0.000	0.000	0.205	R Squared = 0.550 (Adjusted R Squared = 0.544)
LF	0.000	0.000	0.015	R Squared = 0.677 (Adjusted R Squared = 0.673)
FW	0.000	0.000	0.024	R Squared = 0.465 (Adjusted R Squared = 0.458)
EL	0.101	0.000	0.193	R Squared = 0.036 (Adjusted R Squared = 0.022)
ET	0.008	0.282	0.352	R Squared = 0.023 (Adjusted R Squared = 0.010)
KRN	0.101	0.381	0.212	R Squared = 0.046 (Adjusted R Squared = 0.033)
KNR	0.001	0.889	0.279	R Squared = 0.013 (Adjusted R Squared =-0.001)
EW	0.174	0.724	0.622	R Squared = 0.134 (Adjusted R Squared = 0.122)
MSY	0.000	0.000	0.209	R Squared = 0.252 (Adjusted R Squared = 0 242)

seed weight (SW), volume (V) and bulk density (BD), large seeds fraction (LF), small seeds fraction (SF), seeds waste fraction (FW), ear length (EL), ear thickness (ET), ear weight (EW), kernel row number (KRN), kernel number per row (KNR), maize seed yield (MSY).

Observations in the first year (2018) indicate favourable conditions for greater SW, V, BD, LF, FW, EW and the yield components: EL, ET. Contrary to these properties was SF. The percentage of small fraction increased with decreasing SW, V, BD, EL and ET properties. The same trend of the influence of the year was on the KNR. 2018 was more successful in terms of yield achievement. The greatest differences were recorded in L2, 5.6 t ha-1 in G1 and 3.9 t ha-1 in G2. The second year of research (2019) was significant for L3, for an increased percentage of SF (62.3%) and ET (24.6 cm) (Table 3).

Differences in the morphological properties of seeds as a consequence of the influence of different environmental conditions in 2018 and 2019 are significant (p≤0,05) for SW, V, BD, SF, LF FV and MSI for all three lines. EW differs significantly in L1 and L3 between Y1 and Y2. The traits of EL, ET KRN and KNR ears did not show significant differences.

Table 3. Mean trait values by year of production and genotype

	L1			L2			L3			$\overline{X}$		
	Y1	Y2	$\overline{X}$	Y1	Y2	$\overline{X}$	Y1	Y2	$\overline{X}$	Y1	Y2	$\overline{X}$
SW	319.1	239.1	279.1	336.6	251.6	294.1	327.0	264.5	295.7	327.6	251.8	289.7
V	271.1	218.7	244.9	270.5	202.8	236.7	263.2	222.8	243.0	268.3	214.8	241.5
BD	1.2	1.0	1.1	1.2	1.1	1.2	1.2	1.1	1.2	1.2	1.1	1.1
SF	17.7	45.3	31.5	12.9	39.9	26.4	24.8	62.3	43.5	18.5	49.2	33.8
LF	78.9	40.5	59.7	84.3	51.0	67.6	72.2	28.7	50.5	78.5	40.1	59.3
FW	3.4	0.8	2.1	2.8	0.8	1.8	3.0	0.7	1.8	3.0	0.8	1.9
EL	79.1	67.2	73.1	87.5	88.4	88.0	80.8	79.4	80.1	82.5	78.3	80.4
ET	22.0	18.5	20.3	22.0	20.1	21.1	22.6	24.6	23.6	22.2	21.0	21.6
KNR	12.6	11.6	12.1	12.4	12.8	12.6	13.7	14.1	13.9	12.9	12.9	12.9
NKR	28.8	27.2	28.0	30.7	32.5	31.6	28.5	30.0	29.3	29.3	29.9	29.6
EW	113.5	95.5	104.5	131.0	120.6	125.8	124.0	118.9	121.4	122.8	111.6	117.2
MSY	6.1	4.8	5.4	5.6	3.9	4.8	6.7	5.3	6.0	6.1	4.7	5.4

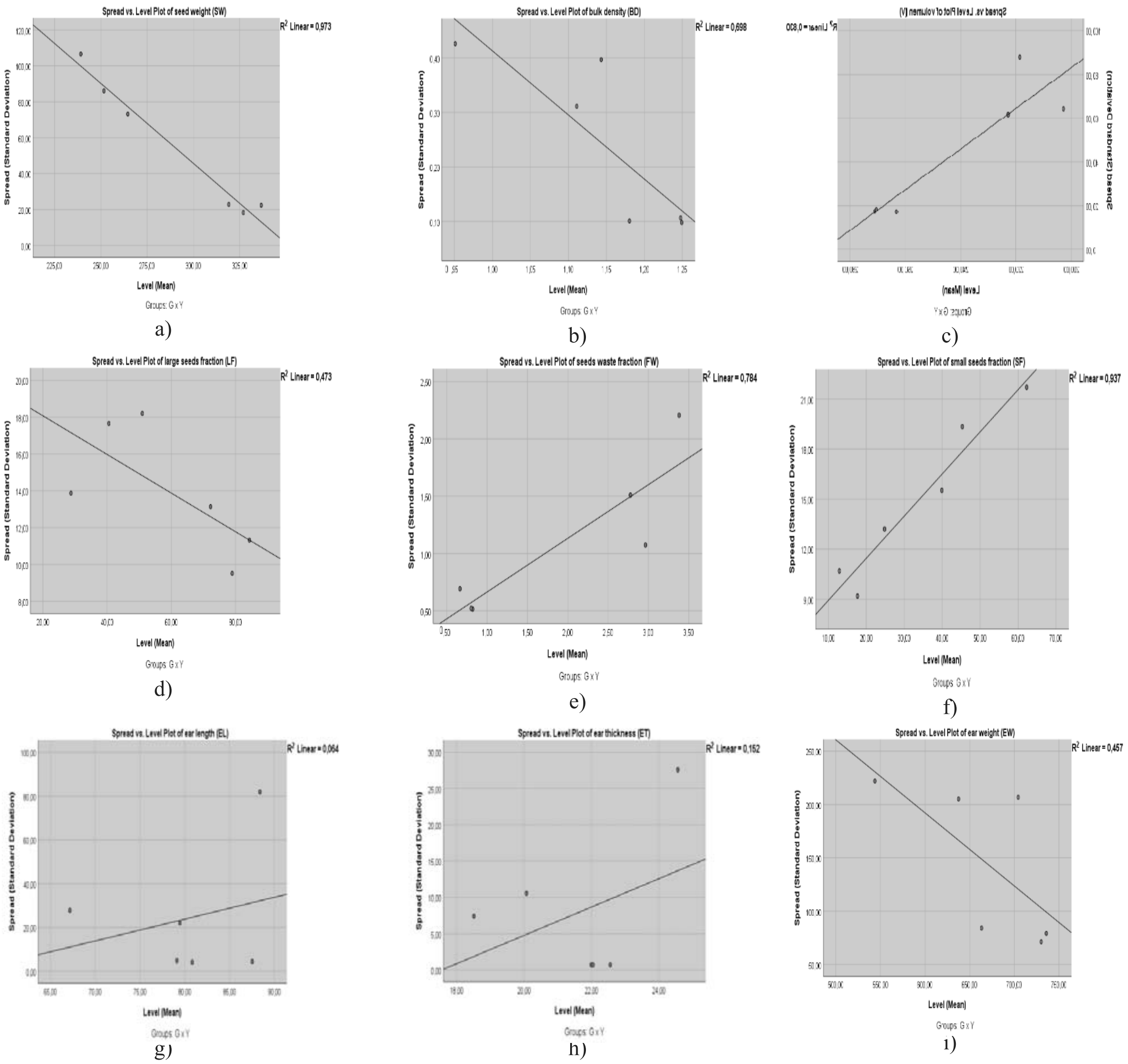
seed weight (SW), volume (V) and bulk density (BD), large seeds fraction(LF) small seeds fraction (SF), seeds waste fraction (FW), ear length (EL), ear thickness (ET), ear weight EW), kernel row number (KRN), kernel number per row (KNR), maize seed yield (MSY), Y1- 2018, Y2-2019

Table 4. Differences in morphological properties of inbred maize lines based on observed mean values (LSD).

Dependent Variable	Mean Difference		
	(L1Y1-L1Y2)	(L2Y1-L2Y2)	(L3Y1-L3Y2)
SW	79,9750*	84,9883*	62,4267*
V	52,4333*	67,6667*	40,3333*
BD	,2293*	,1060*	,1367*
SF	-27,6220*	-26,9882*	-37,4358*
LF	38,3975*	33,3477*	43,4722*
FW	2,5575*	1,9733*	2,2982*
EW	119,4833*	92,5567*	31,51
EL	11,96	-0,86	1,38
ET	3,48	1,97	-2,01
KRN	0,97	-0,42	-0,39
KNR	1,63	-1,76	-1,54
MSY	1,2915*	1,7150*	1,3832*

seed weight (SW), volume (V) and bulk density (BD), large seeds fraction(LF) small seeds fraction (SF), seeds waste fraction (FW), ear length (EL), ear thickness (ET), ear weight EW), kernel row number (KRN), kernel number per row (KNR), maize seed yield (MSY), Y1- 2018, Y2-2019, L-inbred line.

Variations in the morphological properties of seeds and ears in most traits have a linear character ($p \leq 0.05$). The dispersion of mean values in relation to the trend is linear regarding the properties of bulk density, volume and percentage share of fractions (SF, LF and FW). It is most pronounced in SW and SF ($R^2$0.973, R^2 0.937) (Figure 1- a, b, c, d, e, f). The expression of these traits in the late phase of vegetation is influenced by stressful environmental conditions, which usually lead to loss of seed mass (Abendroth et al., 2011). On the other hand, increased insolation, rate of seed filling period and fast growth of plants enable the creation of seeds with greater mass, larger with greater volume and bulk density (Lindsey and Thomison, 2016). Yield components EL, ET, EW and maize seed yield are traits that vary due to the influence of genotype and year and do not have a linear distribution, which is confirmed by their coefficients of determination (R^2 0.064, R^2 0.152, R^2 0.326, R^2 0.211) (Figure 1-g, h, I). The lowest coefficient of determination for the dispersion of mean values is in KRN and KRN (Figure 1-j, k, l). Similar results were obtained by Milander et al., 2016 (b), who claimed that the yield has an inconsistent distribution in relation to changes in population, environment, soil type and genotype.



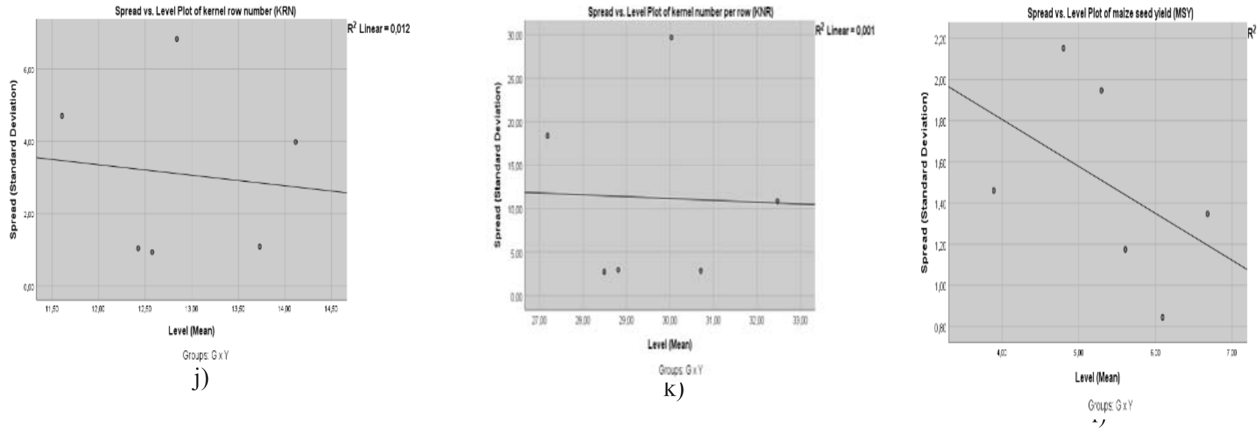


Fig. 1. Dispersion of mean values according to the schedule of changes in trait levels, for a) seed weight (SW), b) bulk density (BD), c) volume (V) d) large fraction (LF), e) seeds waste fraction (FW), f) small fraction (SF), g) ear length (EL), h) ear thickness (ET), i) ear weight (EW), j) kernel row number (KRN), k) kernel number per row (KNR), l) maize seed yield (MSY), G×Y-interaction genotypes×years.

CONCLUSION

Modern genotypes have been selected for high yields. Their production performance will largely depend on the environmental conditions. The experiment was set up in two years. The first year of the experiment was more favorable for the manifestation of seed properties SW, V, BD, LF, FW. Variability of EL, EK ET as well as KRN and KNR are different in relation to the year and genotype. Morphological properties of volume, bulk density, seed weight, and percentage of different seed fractions in the ear mostly depended on the influence of environmental conditions. The morphological properties of the ear, the kernel rows number, the length of the ear, the thickness, and the ear weight are stable genetic traits that vary less under the impact of environmental factors, there are no significant differences between the years. In times of frequent temperature and precipitation variations, observing the impact of their changes on yields and yield components, it is important to build models that incorporate climate change and that will be reliable for planning adequate growing measures.

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