UDC 575.633
https://doi.org/10.2298/GENSR1701183K
Original scientific paper

GENOTYPE EFFECTS ON PHOSPHORUS, POTASSIUM, CALCIUM AND MAGNESIUM STATUS IN MAIZE

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Kovačević V., I. Brkić, M. Antunović, D. Iljkić, I. Varga (2017): *Genotype effects on phosphorus, potassium, calcium and magnesium status in maize*. - Genetika, Vol 49 No. 1, 183-191.

Nine maize lines, commonly used as female parents of maize hybrid (B1=♀2-48; B2=♀1767/99; B3=♀ 87-24; B4=♀135-88, B5=♀84-28; B6=♀84-44; B7=♀438-95; B8=♀30-8; B9=♀B-73) were grown under field conditions on Podgorac acid soil in Osijek-Baranya County for two growing seasons (2006 and 2007). The ear-leaves at flowering and grain at maturity were taken from each basic plot (14 m^2) for chemical analysis with inductively coupled plasma atomic emission spectroscopy (ICP-OES). Average concentrations (2-year means: g kg^{-1} in dry matter) were as follows: 3.21 and 3.00 (P), 20.8 and 3.45 (K), 6.60 and 0.05 (Ca), 2.44 and 1.04 (Mg) for leaves and grain, respectively. Differences among genotypes were from 2.69 to 3.95 and from 2.70 to 3.57 (P), from 18.0 to 23.3 and from 3.03 to 3.71 (K), from 5.45 to 8.02 and from 0.04 to 0.07 (Ca), from 1.35 to 3.09 and from 0.84 to 1.36 (Mg), for leaves and grain, respectively. Specifies of leaf composition of individual genotypes were as follows: B1 (the highest Ca and Mg), B2 (the highest P), B4 (the lowest Ca, Mg and P), B6 (the highest K) and B7 (the lowest K). Grain composition was mainly in accordance with specifies of leaf composition. Very high correlation in maize mineral composition under identical environmental conditions for nine genotypes between two years (0.97***, 0.97*** and 0.91*** for K, Ca and Mg, respectively) are indication of high hereditary effects, while P was more under environmental impact (r = 0.43). Significant correlations were found between grain-P and grain-K (0.55*), grain-Ca (0.49*) and grain-Mg (0.86***), grain-Ca and grain-Mg (0.54*). However, regarding mineral composition of leaves, only leaf-Ca and leaf-P had significant correlation (-0.46*).

Key words: maize lines, calcium, magnesium, phosphorus, potassium, leaves and grain

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INTRODUCTION

Low levels of plant available P, alone or in combination with K, are limiting factor of soil fertility, mainly present on the hydromorphic and clay soils, in Croatia. Adequate fertilization is possible solution for increase yields of field crops under these conditions (KOMLJENOVIĆ *et al*., 2015). However, alleviation of nutritional stress is possible by the other management practices, for example selection of more tolerant genotypes by correspondingly plant breeding strategies (NAWAZ, 2006; RENGEL and DAMON, 2008; TAYYAR and GUL, 2008; JELIĆ *et al*., 2009; KOVAČEVIĆ *et al*., 2011; REZAEI and RAZZAGHI, 2015; ANDRIĆ *et al*., 2016). The lower tolerance to environmental stress is possible to expect in seed production of open-pollinated plants like maize is. The parental pairs of maize in seed-production are mainly inbred lines which are degenerated in some properties (height, root developments, etc.) including less tolerance to abiotic stress as affected by the long-term autogamy (TROYER, 2009; RIOS, 2015). In general, genetic potential of maize and other field crops is inadequate efficient because of different ecological constraints (KRESOVIĆ *et al*., 2011; DIMITRIJEVIĆ *et al*., 2012; VIDENOVIĆ *et al*., 2013).

Aim of this study was testing phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg) status of nine female parental lines of maize used in commercial seed-production of maize hybrids in Croatia.

MATERIALS AND METHODS

The field experiment

A field trial was set up on moderate acid soil in Eastern Croatia (45°47' N and 18°23' E) in 2006 and 2007 growing seasons. Total nine maize lines, usually used as female parents of maize hybrids (B1=♀2-48; B2=♀1767/99; B3=♀ 87-24; B4=♀135-88, B5=♀84-28; B6=♀84-44; B7=♀438-95; B8=♀30-8; B9=♀B-73) were grown under field conditions.

Total of 36 rows of tested lines was sown at beginning of May in both years by pneumatic sowing machine (distance in row 19.5 cm and inter-row spacing 70 cm = theoretical plant density 73,259 plants ha^{-1}). Distribution of female lines was by order from B1 to B9 from the central line of trial toward left (2 rows each parent) and right (2 rows each parent) margins. Weather conditions present during two maize growing seasons were shown in detail by the earlier study (ANDRIĆ *et al*., 2012).

Sampling, chemical and statistical analysis

Soil sampling (depth 0-30 cm) was made in October of 2006 after maize harvesting. Plant available P, K, Ca and Mg in soil were extracted by NH_4-Acetate + EDTA (pH 4.6) solution. Soil pH was determined electrometrically and organic matter according to sulfochromic oxidation.

The ear-leaf at flowering (middle of July 2006 and 2007: twenty leaves in the mean sample) and grain at maturity (five cobs in the mean sample) were taken from each sub-plot for chemical analysis. The total amounts of P, K, Ca, Mg in maize leaves and grain were determined using ICP-OES spectrometer (Jobin-Yvon Ultrace 238) after their microwave digestion by conc. HNO_3+H_2O_2.

Data were statistically analyzed by ANOVA as two-factorial trial (the factor A = year; the factor B = genotype). Treatment means were compared using t-test and LSD at 0.05 and 0.01 probability levels while correlation analysis (Pearson correlation coefficients) was done by Minitab Statistical Software (MINITAB Inc., 2007).

The soil and weather characteristics

Moderate acid reaction and adequate supplies of plant available phosphorus, potassium, calcium and magnesium were main chemical characteristics of the soil during experiment (Table 1).

Table 1. Soil characteristics of the experimental site

Soil properties (0-30 cm of surface layer) after maize harvesting (October 2006)						
pH		% Organic	mg kg^{-1} (NH$_4$Acetate+EDTA /pH=4.6/ extraction)			
H_2O	KCl	matter	P_2O_5	K_2O	Ca	Mg
6.32	5.75	3.19	170	288	4203	1037

The 2006 and 2007 growing seasons of maize characterized lower precipitation amounts and higher air-temperatures compared to long-term mean (LTM: 1961-1990). However, regarding maize demands during growing season, precipitation distribution and temperature regime were more favorable in the 2006 growing season. Drought stress is main characteristic of the 2007 growing season because precipitation in June-August period was 50% lower compared to LTM. At the same time, air-temperatures were for 2.5^{o}C higher (ANDRIĆ *et al*., 2012).

RESULTS AND DISCUSSION

In general, average concentrations (2-year means: g kg^{-1} in dry matter) of tested elements for leaves and grain were as follows: 3.21 and 3.00 (P), 20.8 and 3.45 (K), 6.60 and 0.05 (Ca), 2.44 and 1.04 (Mg), respectively. Mineral composition of maize was mainly considerably affected with growing season (Table 2). With that regard, average concentrations of leaf-P and leaf-Mg were considerably higher under drought conditions of 2007 compared to more favorable 2006 (3.58 g P kg^{-1} and 2.84 g P kg^{-1}; 2.74 g Mg kg^{-1}and 2.13 g Mg kg^{-1} respectively), leaf-Ca was lower (5.96 g Ca kg^{-1} and 7.23 g Ca kg^{-1}), while leaf-K was similar in both years (20.4 g K kg^{-1} and 21.0 g K kg^{-1}, for 2007 and 2006, respectively). Similar trends were found in grain-P and grain-Mg status (3.14 g P kg^{-1} and 2.87 g P kg^{-1}; 1.09 g Mg kg^{-1} and 0.99 g Mg kg^{-1}, respectively), while grain-K was the higher in 2007 (3.53 g K kg^{-1} and 3.38 g K kg^{-1}).

In our study differences among the genotypes were from 2.69 to 3.95 and from 2.70 to 3.57 (g P kg^{-1}), from 18.0 to 23.3 and from 3.03 to 3.71 (g K kg^{-1}), from 5.45 to 8.02 and from 0.04 to 0.07 (g Ca kg^{-1}), from 1.35 to 3.09 and from 0.84 to 1.36 (g Mg kg^{-1}), for leaves and grain, respectively. B1 genotype had the highest Ca and Mg content, B2 had the highest P content, B4 had the lowest Ca, Mg and P content, B6 had the highest K content and B7 had the lowest K content. Grain composition was mainly in accordance with trend of leaf composition.

In our study average grain yield (2-year means) were 2.89 t ha^{-1} (Table 3) with considerable impact of the growing season (averages 4.33 t ha^{-1} and 1.44 t ha^{-1}, for 2006 and 2007). Extremely unfavorable weather conditions of 2007 as affected by drought and high temperatures, particularly in June and July (Osijek: 60% lower precipitation and for 2.8^{o}C higher temperatures compared to the long-term average 1961-1990) are responsible for very low yields of maize in 2007. Similar result was shown KOVAČEVIĆ *et al.* (2013). Consequently, genotypes of the longer vegetation period, particularly B7, B8 and B9, had drastically reduced yields. Variation of yield among the genotypes (2-year averages) was in range from 2.23 t ha^{-1} to 3.84 t ha^{-1}. Five genotypes (B1, B2, B4, B8 and B9) were in the group of the low-yielding genotypes (average 2.48 t ha^{-1}: non-significant difference in the level P≤0.05), while remaining four genotypes (B3, B5, B6 and B7) had considerably the higher yields (average 3.40 t ha^{-1}). These yield differences could be partially explained by differences in plant density realization (averages 61.0% and 67.1%, for the low and high-yielding group, respectively). On the other side, lower differences for grain moistures at harvest for the lower and the higher-yielding group were found (averages 28.1% and 26.7%).

Table 2. Year and genotype effects on phosphorus, potassium, calcium and magnesium status in maize leaves and grain

Impact of genotype (female parents of maize hybrid: the factor B) and environment (weather conditions: the factor A: A1 = 2006, A2 = 2007) on P, K, Ca and Mg status in maize (Podgorac, Osijek-Baranya County)

Maize		**Phosphorus (P)**			**Potassium (K)**			**Calcium (Ca)**			**Magnesium (Mg)**		
genotype		A1	A2	x B	A1	A2	x B	A1	A2	x B	A1	A2	x B
		The ear-leaf at silking stage (g kg^{-1} on dry matter basis) *											
B1	♀2-48	2.50	4.09	**3.30**	20.1	15.8	**18.0**	8.97	7.08	**8.02**	2.64	3.53	**3.09**
B2	♀1767/99	3.33	4.56	**3.95**	20.4	25.0	**22.7**	6.13	5.37	**5.75**	2.44	3.49	**2.97**
B3	♀87-24	2.67	3.29	**2.98**	24.0	21.9	**23.0**	8.37	6.24	**7.31**	2.31	3.22	**2.77**
B4	♀135-88	2.29	3.09	**2.69**	22.5	22.4	**22.5**	5.43	5.46	**5.45**	0.96	1.73	**1.35**
B5	♀84-28	2.90	4.16	**3.53**	21.5	16.9	**19.2**	7.17	5.36	**6.27**	1.72	2.26	**1.99**
B6	♀84-44	2.58	3.28	**2.93**	24.9	21.8	**23.3**	8.37	7.32	**7.85**	2.15	3.47	**2.81**
B7	♀438-95	2.77	2.77	**2.77**	16.3	19.6	**18.0**	6.93	6.43	**6.68**	2.09	2.04	**2.07**
B8	♀30-8	3.36	3.96	**3.66**	18.5	20.6	**19.5**	7.57	4.95	**6.26**	2.82	2.58	**2.70**
B9	♀B-73	3.16	3.00	**3.08**	21.0	20.4	**20.7**	6.10	5.46	**5.81**	2.02	2.39	**2.20**
Mean A		***2.84***	***3.58***	*3.21*	***21.0***	***20.5***	*20.8*	***7.23***	***5.96***	6.60	***2.13***	***2.74***	2.44
		A	B	AB	A	B	AB	A	B	AB	A	B	AB
$P_{0.05}$		0.08	0.11	0.19	ns	1.0	1.7	0.30	0.43	0.68	0.18	0.24	0.35
$P_{0.01}$		0.10	0.15	0.24		1.4	2.3	0.38	0.55	0.87	0.24	0.31	0.45
		Grain at maturity stage (g kg^{-1} on dry matter basis)											
B1	♀2-48	3.03	3.50	**3.27**	2.96	3.49	**3.22**	0.062	0.056	**0.059**	1.34	1.38	**1.36**
B2	♀1767/99	3.64	3.50	**3.57**	3.76	3.45	**3.61**	0.051	0.085	**0.068**	1.35	1.37	**1.36**
B3	♀87-24	2.57	2.98	**2.78**	3.38	3.81	**3.60**	0.048	0.078	**0.063**	0.81	0.99	**0.90**
B4	♀135-88	3.15	3.65	**3.40**	3.48	3.94	**3.71**	0.064	0.076	**0.070**	1.12	1.24	**1.18**
B5	♀84-28	2.53	3.07	**2.80**	3.16	3.45	**3.30**	0.046	0.050	**0.048**	0.81	1.05	**0.93**
B6	♀84-44	2.48	3.04	**2.76**	3.41	3.73	**3.57**	0.050	0.048	**0.049**	0.74	0.98	**0.86**
B7	♀438-95	2.63	2.76	**2.70**	3.01	3.06	**3.03**	0.058	0.058	**0.058**	0.93	0.99	**0.96**
B8	♀30-8	2.88	2.93	**2.91**	3.68	3.55	**3.62**	0.037	0.037	**0.037**	0.97	0.99	**0.98**
B9	♀B-73	2.90	2.81	**2.86**	3.55	3.28	**3.42**	0.047	0.041	**0.044**	0.87	0.81	**0.84**
Mean A		***2.87***	***3.14***	3.00	***3.38***	***3.53***	3.45	***0.051***	***0.059***	0.055	***0.99***	***1.09***	1.04
		A	B	AB	A	B	AB	A	B	AB	A	B	AB
$P_{0.05}$		0.06	0.10	0.18	0.06	0.10	0.17	0.005	0.009	0.016	0.05	0.08	0.12
$P_{0.01}$		0.09	0.14	ns	0.08	0.13	ns	0.008	0.012	ns	0.08	0.11	0.16

* adequate contents in leaves (according to BERGMANN, cit. KOVACEVIC and RASTIJA, 2014): from 2.5 to 5.0 g P kg^{-1}, from 20 to 35 g K kg^{-1}, from 2.5 to 10.0 g Ca kg^{-1} and from 2.0 to 5.0 g Mg kg^{-1}

Table 3. Year and genotype effects on grain yield, plant density realization and grain moisture

Impact of genotype (female parents of maize hybrid: the factor B) and environment (weather conditions: the factor A: A1 = 2006, A2=2007) on grain yield (14% grain moisture basis) of maize , grain moisture at harvest and plant density realization (Podgorac, Osijek-Baranya County)

Maize genotype		Grain yield ($t\ ha^{-1}$)			Plant density (% of planned)*			Grain moisture at harvest (%)		
		A1	A2	x B	A1	A2	x B	A1	A2	x B
B1	2-48	2.54	1.92	**2.23**	67.2	50.5	**58.9**	24.3	24.5	**24.4**
B2	1767/99	3.35	1.92	**2.64**	63.4	56.5	**60.0**	29.5	23.4	**26.5**
B3	87-24	5.69	1.98	**3.84**	77.0	65.9	**71.5**	27.7	20.7	**24.2**
B4	135-88	3.71	1.45	**2.58**	57.9	54.9	**56.4**	28.7	20.4	**24.6**
B5	84-28	5.22	1.55	**3.39**	68.9	60.2	**64.6**	28.5	25.3	**26.9**
B6	84-44	4.25	1.54	**2.90**	68.9	66.2	**67.6**	27.0	27.5	**27.3**
B7	438-95	5.92	1.00	**3.46**	70.1	59.3	**64.7**	27.4	29.4	**28.4**
B8	30-8	3.85	0.77	**2.31**	63.8	60.0	**61.9**	33.6	31.6	**32.6**
B9	B-73	4.45	0.81	**2.63**	78.4	57.0	**67.7**	34.0	31.1	**32.6**
Mean A		***4.33***	***1.44***	*2.89*	***68.4***	***58.9***	*63.7*	***29.0***	***26.0***	*27.5*
		A	B	AB						
	$P_{0.05}$	0.55	0.34	0.81	* 100% = 73260 plants ha^{-}					
	$P_{0.01}$	0.77	0.48	1.13						

Leaf-P status was in adequate range with exception the genotype B4 in 2006. However, leaf-K status was bellow adequate range in four genotypes (B1, B5, B7 and B8: 18.0, 19.2, 18.0 and 19.5 g K kg^{-1}, respectively). These genotype could be designated as K-inefficient. Leaf-Ca was in adequate range, while leaf-Mg was mainly close to adequate minimal value or below adequate limit (Table 2). With that regard, the most unfavorable leaf-Mg status was found in Mg-inefficient B4 and B5 genotypes (2-year averages 1.35 g Mg kg^{-1} and 1.99 g Mg kg^{-1}), particularly B4 in 2006 (0.96 g Mg kg^{-1}). The most favorable leaf-Mg status was found in B1 and B2 (2-year averages 3.09 g Mg kg^{-1} and 2.97 g Mg kg^{-1}, respectively). Based on these findings, our recommendation is avoidance of growing seed-maize crops including K-inefficient and Mg-inefficient parents under soil conditions characterizing moderate / low levels of either K or Mg nutrients. Potassium fixation and oversupply of magnesium are the main reasons for the appearance of potassium deficiency symptoms in maize plants, especially inbred lines, when grown on some drained gleysols of Eastern Croatia (KOVAČEVIĆ *et al*., 2002). Six inbred lines of maize were grown under these stress conditions. According to authors, grain yields ranged from 0.73 to 1.85 t ha^{-1}, stalk lodging incidences from 3% to 51%, while ear-leaf composition ranged as follows (mg 100 g^{-1} on dry matter basis): from 414 to 621 (K), from 951 to 1458 (Mg) and from 751 to 1335 (Ca). Growing these genotypes on plot fertilized with ameliorative dose of KCl in amount 3250 K_2O ha^{-1} resulted by considerable improvement of mentioned properties as follows: from 1.97 to 3.42 t ha^{-1} (yield), from 3 to 24 % (lodging), from 1074 to 1907 (K), from 442 to 1049 (Mg) and from 659 to 1203 (Ca). The higher lodging tolerance under K-deficiency conditions was mainly in close connection with the higher leaf-K status. Also, according by the other studies considerable impact of hereditary factors on K efficiency in maize was found. MINJIAN *et al.* (2007) tested under hydroponic conditions two inbred lines of maize and four levels of K concentrations were applied. Under K-deficient conditions K-inefficient genotype absorbed 0.62% K in shoot and 0.68% K in root, while K status in K-efficient genotype were 0.93% K in shoot and 1.21% K in root. AHMAD *et al*. (2012) tested three maize hybrids under field conditions and increased rates of K fertilization. Hybrid Pioneer 30D55 had significantly higher K-efficiency compared to Pioneer 3012.

RASTIJA (2006) investigated impacts of soil, weather conditions and genotype on status of P and K in leaves and grain of maize. Total 17 maize genotypes were tested under two soils of low fertility (neutral soil characterized by low K supplies and acid soil of low P supplies) during two growing seasons. The parent Os438-95 was more tolerant under K-deficient conditions, while the hybrid OsSK552 was more tolerant to acid soil and low P conditions. Variability among the genotypes (averages for two soils and two growing seasons: mg kg^{-1} in dry matter) were in range from 3.0 to 4.7 (P) and from 2.6 to 3.1 (P), from 15.4 to 19.0 (K) and from 3.2 to 04.1 (K), for leaves and grain, respectively. In our study, quantities ranges of variations among genotypes were similar, with exception the lower contents of K in leaves compared to RASTIJA (2006).

Very strong correlation (r) in maize grain mineral composition between two growing seasons (0.97***, 0.97*** and 0.91*** for K, Ca and Mg) are indication of very high hereditary effects (Table 4), while nutritional status of P was more under agroecological impact (non-significant correlation 0.43). In our study, grain yield was in negative correlation with leaf-P and grain-P (-0.47*) and in positive correlation with leaf-Ca (0.50*). Also, significant correlations were found between grain-P and grain-K (0.55*), grain-Ca (0.49*) and grain-Mg (0.86***), grain-Ca and grain-Mg (0.54*). However, regarding mineral composition of leaves, only leaf-Ca and leaf-P had significant correlation (-0.46*).

Table 4. Correlation coefficients (r), correlation between P, K Ca and Mg status in maize leaves and grain and grain yield

		Correlation coefficients (r)*							
		P		**K**		**Ca**		**Mg**	
		Leaf	**Grain**	**Leaf**	**Grain**	**Leaf**	**Grain**	**Leaf**	**Grain**
P	L								
	G	0.50 ns							
K	L	-0.21 ns	-0.07 ns						
	G	0.35 ns	**0.55 ***	0.23 ns					
Ca	L	**-0.46 ***	-0.45 ns	0.05 ns	-0.36 ns				
	G	0.11 ns	**0.49 ***	0.30 ns	0.13 ns	-0.19 ns			
Mg	L	0.64 ns	0.27 ns	-0.11 ns	0.23 ns	0.15 ns	0.12 ns		
	G	0.41 ns	**0.86 *****	-0.18 ns	0.19 ns	-0.18 ns	**0.54 ***	0.33 ns	
Yield		**-0.47***	**-0.47 ***	0.09 ns	-0.26 ns	**0.50 ***	-0.17 ns	-0.37 ns	-0.37 ns
2006 : 2007		0.43 ns		0.97 ***		0.97 ***		0.91 ***	

Total 18 pairs (two years for nutrients; leaf and grain for correlations between two years)

Levels of significance: ns – not significant; * P<0.05; ** P<0.01; *** P<0.001; L = leaves, G = grain

CONCLUSION

In our study, considerable variations of P, K, Ca and Mg among tested maize genotypes were found. With that regards, agreement of results or very high correlations between two years of testing were found for K, Ca and Mg, while the low and non-significant correlation for P is indication of the higher environmental impact. Leaf-K status was bellow adequate range in four K-inefficient genotype while leaf-Mg was mainly close to adequate minimal value or below adequate limit. Our recommendation is avoidance of growing seed-maize crops including K- and Mg-inefficient parents under soil conditions characterizing moderate/low levels of either K or Mg nutrients. As significant but moderate negative correlations were found between grain yield and P status both in leaves and grain, as well positive correlation between leaf-Ca, there is indication that under tested soil conditions are something more favorable genotypes characterized by the lower P and the higher Ca contents. However, for reliable conclusions are needed additional investigations because in our study yields were considerably more under impacts of the other factors, for example length of the growing season, particularly under drought stress conditions of the 2007 which was especially unfavorable for genotypes of the higher FAO groups (B7, B8 and B9).

Received May 17th, 2016
Accepted December 25th, 2016

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UTICAJ GENOTIPA NA SADRŽAJ FOSFORA, KALIJUMA, KALCIJUMA I MAGNEZIJUMA KOD KUKURUZA

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Izvod

Devet linija kukuruza, koje se koriste kao majke u hibridima (B1=♀2-48; B2=♀1767/99; B3=♀ 87-24; B4=♀135-88, B5=♀84-28; B6=♀84-44; B7=♀438-95; B8=♀30-8; B9=♀B-73) gajene su u polju na kiselom zemljištu kod Podgorača (Osječko-baranjski okrug) tokom dve godine (2006 and 2007). Sa svake elementarne parcele, uzet je klipni list u vreme cvetanja i zrno u punoj zrelosti za hemijske analize plazma emisionom atomskom spektroskopijom (ICP-OES). Prosečne koncentracije (g kg^{-1} suve materije) za dve godine iznosile su: 3.21 i 3.00 (P), 20.8 i 3.45 (K), 6.60 i 0.05 (Ca), 2.44 i 1.04 (Mg) za list, odnosno zrno. U zavisnosti od specifičnosti lista, sadržaj po genotipovima bio je: B1 (najviši sadržaj Ca i Mg), B2 (najviši P), B4 (najniži sadržaj Ca, Mg i P), B6 (najviši sadržaj K) i B7 (najniži K). Sastav zrna je uglavnom bio u saglasnosti sa sastavom lista. Veoma visoka korelacija u mineralnom sastavu pod identičnim uslovima spoljašnje sredine za devet genotipova između dve godine (0.97***, 0.97*** i 0.91*** za K, Ca i Mg), ukazuje na visok uticaj naslednog faktora, dok je sadržaj P bio pod većim uticajem sredine (r = 0.43). Značajne korelacije su utvrđene između sadržaja P-zrno i K-zrno (0.55*), Ca-zrno (0.49*) i Mg-zrno (0.86***), kao i između Ca-zrno i Mg-zrno (0.54*). Međutim, u listu je utvrđena značajna korelacija samo između sadržaja Ca i P (-0.46*).

Primljeno 17.V.2016.
Odobreno 25.XII. 2016.