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Original scientific paper

GENOTYPIC EFFECTS ON BORON CONCENTRATIONS AND RESPONSE ON BORON FERTILIZATION IN MAIZE INBRED LINES

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Andrić L., V. Kovačević, I.Kadar A. Jambrović, H. Plavšić and D. Šimić (2015): *Genotypic effects on boron concentrations and response on boron fertilization in maize inbred lines*- Genetika, Vol 48, No. 1,297 - 305.
Boron (B) deficiency in maize can result in barren cobs attributed to silks being non-receptive which is particularly important for the female parent in seed production. The objectives of this study were 1) to investigate genotypic differences among nine female inbred lines used in seed production for B concentration in ear-leaf and grain, as well as for grain yield and moisture in a three-year experiment (2006-2008) and 2) to determine response and relations among the traits when four of the female inbred lines are treated by foliar boron fertilization - three times in 10-days interval with 0.5% Solubor solution (17.5% B) during one growing season (2008). The investigations were performed on Experimental field of Agricultural Institute Osijek, (soil type: eutrical cambisol). Highly significant differences among the nine female inbred lines were detected for B concentration in ear-leaf (from 14.7 to 46.7 mg B kg^{-1}) and grain (from 1.20 to 2.06 mg B kg^{-1}) as well as for grain yield (from 3.33 to 4.83 t ha^{-1}) and grain moisture (from 14.7% to 26.6%). However, there were also significant effects of growing season and the genotype by environment interaction for all four traits. Positive and moderate correlations were found between the boron status in plant and grain yield. Although B concentrations were considerably increased by foliar boron fertilization (averages 41.7 and 125.3 mg B kg^{-1} in leaves, 1.79 and 2.80 mg B kg^{-1} in grain, for control and fertilization,

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respectively), in general grain yield differences among treatments were non-significant. (averages 5.21 and 5.15 t ha^{-1}, respectively).

Key words: boron, female parent inbred lines, foliar fertilization, grain, leaves, maize, yield

INTRODUCTION

Inbred lines of maize are important parent components for producing hybrid seed and subsequent growing single-cross hybrids for commercial production. Even though the vegetative growth and thus the canopy of inbred maize vary among genotypes, it is generally decreased compared with that of hybrid, mainly due to poor rooting ability of inbred genotypes making them more vulnerable to nutrient deficiencies and imbalances. Although maize is relatively insensitive to boron (B) deficiency, poor grain-setting can result in barren cobs, and this was attributed to silks being non-receptive (GUNES *et al.*, 2011; LORDKAEW *et al.*, 2011) which is particularly important for the female parent in seed production.

Generally, concerning the susceptibility of plants to B deficiency, many studies are published relating not only to "boron-intensive species of crops", but also to genotypic differences within a species (BERGMANN, 1992; MENGEL and KIRKBY, 2001). However, response of maize genotypes to B nutrition is not well documented in literature. The objectives of this study were 1) to investigate genotypic differences among nine female inbred lines used in seed production for boron concentration in ear-leaf and grain, as well as for grain yield and moisture in a three-year experiment and 2) to determine response and relations among the traits when four of the female inbred lines are treated by foliar boron fertilization.

MATERIALS AND METHODS

Field experiment

Nine inbred lines – female parents of maize hybrids developed by the Agricultural Institute Osijek were grown during three growing seasons (2006-2008) on experimental field of Agriculture Institute Osijek. Maize was planted at the end of April /beginning May by planters on interrow spacing 70 cm and distance in row 22 cm. Two seeds were sown on each sowing place. At 3-5 leaf stages maize crop was thinned and one plant in each sowing place was leaved (plant density = 64936 plant ha^{-1}). The experiment was conducted in four replicates (basic plot 28 m^2 or four 10-m long rows).

In third year of testing (2008), based on differences in boron uptake , four inbred lines were selected for testing of their response to foliar fertilization with boron (Table 3). Foliar spraying was made with 0.5% solution of Solubor (17.5% B) in three terms as follows: - June 18 (stage of 8-12 leaves), June 27 (stage of 10-14 leaves) and July 3 (before anthesis). Boron application was made by hand using back sprayer at evening hours.

Sampling,chemical and statistical analysis

Soil sampling of surface layer until 30 cm of depth (one average sample in level of experiment) was made by auger in October each year after harvesting. Plant available phosphorus and potassium were determined by ammonium-lactate extraction.

The ear-leaf at anthesis (middle of July: about twenty leaves in mean sample) and grain at maturity (ten cobs in mean sample) was taken for chemical analysis from each sub-plot. The total amount of boron in the leaf- and grain samples, after microwave digestion using concentrated HNO_3+H_2O_2, was measured by the ICPAES technique by Jobin-Yvon Ultrace 238 ICP-OES spectrometer in the laboratory of the Research Institute for Soil Science and Agricultural Chemistry (RISSAC) of Hungarian Academy of Science and Arts in Budapest, Hungary.

The data were statistically analyzed by ANOVA and treatment means were compared using t-test and LSD at 0.05 and 0.01probability levels.

Description of the maternal parents of maize hybrids

B1 line belongs to the Iodent heterotic group of maize (JAMBROVIĆ *et al.* 2014), FAO group 310, currently used as the female parent of the hybrid Os2983. It is tolerant to water deficit and high plant density. Our previous data indicated that the line yielded about 2 t ha^{-1} in seed production with no substantial deviations. B2 is the female parent of the flint hybrid Tvrtko 303 (KOVAČEVIĆ et al., 2013b) tracing back from a single cross, FAO group 510. It has unique pale green leaves and white silk indicating putative micronutrient deficit. The line B3 belongs to the BSSS heterotic group, B73 subgroup (JAMBROVIĆ *et al.* 2014), FAO group 450. The line is the female parent of the hybrid Os 499 (KOVAČEVIĆ *et al.*, 2013b) having average grain yield about 2-3 t ha^{-1}. B4 is the female parent of the hybrid OS 444 (KOVAČEVIĆ *et al.*, 2013b), FAO group 450, the line of the Lancaster heterotic group (JAMBROVIĆ *et al.*, 2014) yielding about 1.5-2.5 t/ha. B5 belongs to the BSSS heterotic group, the female parent of the hybrid Os 494. It is high yielding in seed production but with considerable deviations. The line B6 is related to the line B3 and it is the female parent of the hybrid OSSK 552 (KOVAČEVIĆ *et al.*, 2013b). The dark green inbred line B7 belongs to the BSSS heterotic group and it is the female parent of the hybrid OSSK 596 (KOVAČEVIĆ *et al.*, 2013b), FAO 620. The lines B8 and B9 belong also to the BSSS heterotic group and they are the female parents of the hybrid OSSK 602, (FAO 620), and OSSK 644 (FAO 650), respectively, with low to average grain yield in seed production.

Soil characteristics

Experimental field of Osijek Agricultural Institute is classified as soil of A-C profile (eutric cambisol) favorable physical and chemical properties. Reaction of surface layer is neutral /slightly acid, low in organic matter and normal supplied with plant available phosphorus and potassium (Table 1).

Table 1. Soil characteristics

Year	Surface soil layer until 30 cm of depth after maize harvesting				
	pH		mg $100g^{-1}$ (AL-method)		%
	H_2O	KCl	P_2O_5	K_2O	Org. matter
2006	7.35	6.68	15.4	26.7	1.65
2007	6.23	5.28	15.9	25.6	1.78
2008	6.74	5.92	23.9	33.5	2.04

Weather characteristics

Weather characteristics, particularly quantity and distribution of precipitation and air-temperatures are considerable factors of maize yield and yield variations among years. In general, lower precipitation and the higher air-temperatures in summer, especially in July and August, are in close connection with the lower yields of maize (MAKLENOVIĆ *et al*., 2009; MARKULJ *et al*., 2010; RASTIJA *et al.*, 2012; MAJDANČIĆ *et al*., 2015). With that regard, recent climatic change has mainly negative effects on global food production (PARRY *et al*., 2005; LOBELL and FIELD, 2007; SVEČNJAK *et al.*, 2007; SIPOS *et al.,* 2009; VIDENOVIĆ *et al.*, 2013; KOVAČEVIĆ *et al.. 2013a*; RENGEL, 2011, 2015).

In accordance with mentioned observations, the 2006 and particularly 2007 growing season were less favorable for maize growth compared to the 2008 growing season. Water deficit and high air-temperature in July are main adversely factor of maize growth in 2006, while about 40% lower precipitation and for 1.6 ^{o}C higher temperature characterized the 2007 growing season. Water deficit in 2007 was particularly observed in June-August period (about 50% lower precipitation compared to usual) and it was accompanied with 2.5 ^{o}C higher air-temperature. Total precipitation in the 2008 growing season was similar to 2006 growing season, but their monthly distribution was more balanced and more favorable for maize. Also, temperature regime in summer months of 2008 was more close to usual than in the previous two years (Table 2).

Table 2. The meteorological data (SHS, 2008)

Osijek: Precipitation and mean air-temperatures (61-90: averages 1961-1990)														
Year	Monthly precipitation (mm)							Monthly mean air-temperatures (^{o}C)						
	Apr.	May	June	July	Aug	Sept	Σ	Apr.	May	June	July	Aug	Sept	X
2006	87	79	91	15	134	11	*415*	12.7	16.2	20.1	23.5	19.3	17.8	*18.3*
2007	3	56	33	27	45	65	*230*	13.3	18.2	22.3	23.8	22.2	14.5	*19.1*
2008	50	67	76	79	46	86	*405*	12.5	18.1	21.5	21.8	21.8	15.7	*18.6*
61-90	54	58	88	65	59	45	*368*	11.3	16.5	19.5	21.1	20.3	16.6	*17.5*

RESULTS AND DISCUSSION

The B contents of monocotyledons are about 2 to 6 mg kg^{-1}. Ranges of 6 - 15 mg B kg^{-1} contents in dry matter of maize leaves are adequate for normal maize growth (BERGMANN, 1992). According to these criteria, leaf-B status from 8.8 to 58.1 mg B kg^{-1} in our study (Table 3) is adequate for maize.

Both growing season and genotype affected significantly on leaf-B status in maize. Under unfavorable weather conditions of the 2007 growing season (Table 2) average leaf-B concentration in maize was 19.7 mg B kg^{-1} or about twofold lower compared to values in remaining two growing seasons. Differences of leaf-B among genotypes (3-year averages) were from 14.7 (the line B2) to 46.9 (the line B4) mg B kg^{-1} and these differences were considerably higher than among years. In five genotypes, leaf-B concentrations were in range between 34 and 39 (average 36.9) mg B kg^{-1}, while in two genotypes between 22 and 29 (average 25.5) mg B kg^{-1} (Table 3). Significant differences for B status among maize inbred lines and their diallel crosses were also reported by KOVAČEVIĆ *et al.* (2001) for B-grain and among maize hybrids for B-leaf and B-grain (KOVAČEVIĆ *et al*., 2013b), while BRKIĆ *et al.* (2015) reported about significant differences among 127 maize genotypes for B concentration in root.

Table 3 . Impacts of growing season and genotype on maize status: leaf-boron, grain-boron, grain yield and grain moisture

Year (the factor A: A1=2006, A2=2007, A3=2008) and genotype (the factor B) impacts on boron status in maize and grain yield on Osijek eutric cabisol

Year	Maize genotype B1	B2	B3	B4	B5	B6	B7	B8	B9	Mean A
	Leaf-boron (mg B kg^{-1} in dry matter od the ear-leaf at silking stage)									
A1	24.1	13.8	38.2	51.7	32.7	34.8	38.9	44.5	37.2	*35.1*
A2	14.1	8.8	18.6	30.7	15.1	21.1	23.6	24.2	21.3	*19.7*
A3	29.3	21.6	57.4	58.1	37.3	57.9	41.7	47.6	46.0	*44.1*
x B	*22.5*	*14.7*	*38.1*	*46.9*	*28.4*	*37.9*	*34.7*	*38.8*	*34.8*	
	P 0.05	A: 3.1		P 0.05	B: 2.8		P 0.05	AB: 6.0		
	P 0.01	5.1		P 0.01	3.6		P 0.01	9.0		
	Grain-boron (mg B kg^{-1} in dry matter at maturity stage)									
A1	1.14	0.73	2.03	2.60	1.76	2.24	1.70	1.48	1.43	*1.68*
A2	2.20	1.60	2.07	1.69	1.37	1.67	1.34	1.33	1.37	*1.63*
A3	1.84	1.28	1.63	1.88	1.60	2.16	1.91	1.71	1.53	*1.73*
x B	*1.73*	*1.20*	*1.91*	*2.06*	*1.58*	*2.03*	*1.65*	*1.51*	*1.44*	
	P 0.05	A: n.s.		P 0.05	B: 0.14		P 0.05	AB: 0.34		
	P 0.01			P 0.01	0.19		P 0.01	0.53		
	Grain yield (t ha^{-1} on 14% grain moisture basis)									
A1	2.81	2.94	4.41	3.84	3.81	3.35	4.42	4.00	3.47	*3.67*
A2	3.98	4.72	5.12	3.66	3.80	4.84	3.21	1.80	2.20	*3.70*
A3	4.64	5.50	4.96	5.76	5.98	6.23	5.22	5.27	4.31	*5.32*
x B	*3.81*	*4.39*	*4.83*	*4.42*	*4.53*	*4.81*	*4.28*	*3.69*	*3.33*	
	P 0.05	A: 0.62		P 0.05	B: 0.56		P 0.05	AB: 1.19		
	P 0.01	0.84		P 0.01	0.73		P 0.01	1.56		
	Grain moisture (%) at harvesting									
A1	14.7	18.9	19.2	20.5	18.4	22.9	26.4	29.9	30.5	*22.4*
A2	13.0	18.7	17.5	19.1	17.2	17.8	24.9	24.5	23.8	*19.6*
A3	16.4	22.3	224	23.3	21.0	20.5	23.9	23.7	25.5	*22.1*
x B	*14.7*	*20.0*	*19.7*	*21.0*	*18.9*	*20.4*	*25.1*	*26.0*	*26.6*	

Grain-B was considerably lower compared to leaf-B status in maize (3-year averages 1.68 and 33.0 mg B kg^{-1}, respectively). Differences of average grain-B among years were non-significant, but differences among genotypes were from 1.20 (B2) to 2.06 (B4) mg B kg^{-1}. In two genotypes (the lines B4 and and B6) grain-B was above 2.0, while in four genotypes it was below 1.6 mg B kg^{-1} (the lines B5, B8, B9 and B2).

Differences among B concentrations in level of year x genotype interaction were from 8.8 to 58.1 (leaf-B) and from 0.73 to 2.60 (grain-B) mg B kg^{-1}. The lowest values were found in in B2 (both in leaf and grain) in 2007 (leaf) and 2006 (grain). The highest values were found in parent 135-88 in 2008 (leaf) and 2006 (grain).

No strong associations were found between B status in maize with yield because two the most divergent genotypes had similar yields (3-year averages 4.39 and 4.42 t ha^{-1}, for the B2 and B.4 lines, respectively), probably because B status in maize was in adequate levels. Across all three growing seasons, pooled correlations coefficients were moderate between the leaf-B and grain yield (r=0.41) and between the grain B concentrations and grain yield (r=0.44). No association was detected between the grain B concentrations and grain moisture (4=0.04).

Table 4. Impact of genotype and foliar spraying with boron solution on maize status

Impact of genotype and foliar fertilization (A1 = the control, A2 = three-times foliar fertilization*) with Solubor* on boron status , yield and grain moisture in maize (the 2008 growing season)

Treat-ment	Maize genotype (the factor B) * B1	B2	B4	B6	Mean A	Maize genotype (the factor B)* B1	B2	B4	B6	Mean A
	Leaf -B (mg B kg^{-1} in dry matter)					Grain-B (mg B kg^{-1} in dry matter)				
A1 (0)	29.3	21.6	58.1	57.9	*41.7*	1.84	1.28	1.88	2.16	*1.79*
A2 (FF)	100.1	88.0	147.0	166.0	*125.3*	2.96	2.40	3.16	2.90	*2.80*
Mean B	*64.7*	*54.8*	*102.6*	*112.0*		*2.40*	*1.84*	*2.52*	*2.53*	
	A		B		AB	A		B		AB
	P 0.05 11.6		P 0.05 16.4		P 0.05 ns	P 0.05 0.08		P 0.05 0.15		P 0.05 ns
	P 0.01 16.0		P 0.01 22.7			P 0.01 0.11		P 0.01 0.19		
	Grain yield (t ha^{-1})					Grain moisture (%) at harvest				
A1 (0)	4.64	5.50	4.96	5.76	*5.21*	16.4	22.3	23.3	20.5	*20.6*
A2 (FF)	4.54	5.18	4.67	6.19	*5.15*	17.0	22.1	23.7	20.1	*20.7*
Mean B	4.59	5.34	4.82	5.98		16.7	22.2	23.5	20.3	*20.7*
	A		B		AB	A		B		AB
	P 0.05 ns		P 0.05 0.38		P 0.05 ns	P 0.05 ns		P 0.05 1.8		P 0.05 ns
			P 0.01 0.54					P 0.01 2.5		

* foliar spraying (3x) with 0.5 % of Solubor (17,5 % B) solution (June 18 and 27, July 3)

In experiment with B foliar fertilization performed with four genotypes, the lines B1 and B2 had considerably lower leaf-B concentrations (average 59.8 mg B kg^{-1}) compared B4 and B6 parents (average 134.4 mg B kg^{-1}). Application of B fertilizer had considerable effect on leaf-B concentrations (averages 41.7 and 125.3 mg B kg^{-1}, for control and B fertilization, respectively), but grain yields were independent on B fertilization (averages 5.21 and 5.15 t ha^{-1}, respectively).

Application of B had also significant impact on grain-B status in maize inbreeds (averages 1.79 and 2.80 mg B kg^{-1}, respectively.

Regarding grain-B, only B2 had considerably lower B concentrations (average 1.84 mg B kg^{-1}), because in remaining three genotypes average B concentrations were 2.48 mg B kg^{-1}. (Table 4). However, the results indicate that foliar boron fertilization did not consistently affects grain yield due to non-significant difference between the two treatments. However, the inbred line B6 did respond on B fertilization having considerably higher yield when treated.

CONCLUSIONS

In the three-year experiment, highly significant differences among the nine female inbred lines used in seed production were detected for boron concentration in ear-leaf and grain as well as for grain yield and grain moisture. However, there were also significant effects of growing season and the genotype by environment interaction for all four traits. Positive and moderate correlations were found between the boron status in plant and grain yield. Foliar boron fertilization affected boron status in ear-leaf and grain but there was generally no effect on grain yield with the exception of only one female inbred line.

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GENETIČKI EFEKTI NA KONCENTRACIJE BORA I REAKCIJA INBRED LINIJA KUKURUZA NA ĐUBRENJE BOROM

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Izvod

Nedostatak bora (B) u kukuruzu može biti uzrokom pojavi jalovog klipa, jer svila ne može prihvatiti polen, a što je veoma značajno za majčinsku komponentu u proizvodnji semena.
Predmeti ovoga rada bili su 1) u trogodišnjim istraživanjima (2006.-2008.) ustanoviti genetske razlike u koncentracijama bora u listu i zrnu, prinosima zrna i vlažnosti zrna, između devet majčinskih inbred linija koje se koriste u proizvodnji semena i 2) ustanoviti reakciju četiri odabrane linije na folijarno đubrenje borom - tri puta u 10-dnevnom u intervalu s 0.5% rastvorom Solubora (17,5% B) tokom jedne godine (2008.). Istraživanja su provedena na oglednom polju Poljoprivrednog instituta Osijek, na tipu zemljišta eutrični kambisol. Ustanovljene su visoko signifikantne razlike između devet genotipova kukuruza u koncentracijama bora u listu ispod klipa tokom svilanja (od 14.7 do 46.7 mg B kg^{-1}) i u zrnu (od 1.20 do 2.06 mg B kg^{-1}), te u prinosima zrna (od 3.33 do 4.83 t ha^{-1}) i vlažnosti zrna (od 14.7% do 26.6%). Takođe, postojali su i značajni uticaji faktora godina, te interakcije genotipa i okoline na sva četiri analizirana svojstva. Pozitivne i umerene korelacije su ustanovljene između koncentracija bora u biljci i prinosa zrna. Iako su koncentracije bora značajno povećane folijarnom prihranom (prosečno 41.7 i 125.3 mg B kg^{-1} u listu, 1.79 i 2.80 mg B kg^{-1} u zrnu, za kontrolu odnosno tretman folijarnog đubrenja), razlike prinosa nisu bile statistički značajne (5,21, odnosno 5,15 t ha^{-1}).

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