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Original scientific paper

VARIABILITY OF FACTORS THAT AFFECT AVAILABILITY OF IRON, MANGANESE AND ZINC IN MAIZE LINES

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Deficiencies of some mineral elements are causing serious health problems, which could be prevented by increase of mineral nutrients in food with supplementation, food fortification or plant breeding. From this point, experiment with 78 maize inbred lines was set up to determine maize lines with improved contents of Fe, Zn and Mn, as well as their relations with phytic acid, inorganic phosphorus and β-carotene, as factors which affect their absorption. Obtained results suggest that investigated maize lines show high variability in concentration of Fe, Mn and Zn, as well as phytic acid (which sustain availability of mineral elements) and β-carotene (which enables better absorption of mineral element and minimize negative effect of phytic acid). From this point of view, group of genotypes with phytic P ≤ 3 g kg^{-1} was interesting. Among them, L2 and L23 are maize lines with relatively high inorganic P, Fe and Zn contents, and together with relatively low ratio between phytic and inorganic P, they could be used as a good source of P, Fe and Zn. On the other hand, L1 and L4 are also maize lines with high inorganic P, β-carotene and Mn, and favourable ratio between phytic acid and Fe and Zn, what could give them advance as source of Mn in breeding programs. The same maize lines could also be candidates with improved ability for Fe and Zn absorption, what is based on high β-carotene content. Maize line L14, with relatively high concentration of all three

Key words: maize lines, microelements, phytic acid, β-carotene

INTRODUCTION

For normal functioning, human body needs more than 22 mineral elements, which can be provided by an appropriate diet. Some diets, based on cereals and legumes, as well as foods produced on soils deficient in some minerals, could cause serious health problems. These

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deficiencies can be surpassed by increase of mineral nutrients in food including supplementation, food fortification or plant breeding (LÖNNERDAL, 2003; WHITE and BROADLEY, 2005).

Iron and zinc are the mineral elements with the greatest significance in vegetarian diets. With elimination of meat and increased intake of phytate-containing legumes and whole grains, the Fe and Zn absorption decrease (HUNT, 2003). Fe and Zn deficiencies are common worldwide. The most prevalent deficiency is Fe deficiency anemia, affecting an estimated 30% of the world's population. Zn is essential element involved in the immune system, activation of many enzymes and the growth. Zn deficiency has been recognized in Western countries due to inadequate dietary supply, abnormal blood losses or high physiological requirements for growth, puberty, pregnancy and lactation (HUNT, 2003; WHITE and BROADLEY, 2005). Manganese is also essential for humans: it is part of the antioxidant system in the mitochondria, it is involved in metabolism, bone development and wound healing. It is closely connected to Fe deficiency, since the higher Mn absorption was noticed in humans with long-term Fe deficiency (FINLEY, 1999; KIM and LEE, 2008). Variability of mineral elements in maize grain is significant (MLADENOVIĆ DRINIĆ *et al.*, 2013) and it could also depend on applied cropping systems (DRAGIČEVIĆ *et al.,* 2013).

One of the moist important factors which obstruct absorption of mineral nutrients is phytic acid - Phy (myo-inositol 1,2,3,4,5,6-hexakisphosphate), major phosphorus storage compound in grains (can account for up to 80% of grain total P). Because of its high density of negatively charged phosphate groups, it forms very stable complexes with mineral ions, making them unavailable for intestinal absorption. As the phytic acid content in diet increase, the intestinal absorption of Zn, Fe and other mineral nutrients decreases (WALTER LOPEZ *et al.,* 2002).

Any reduction in phytic acid content in food is likely to result in improved Fe, Zn and Mn status (UNDERWOOD and SUTTLE, 1999; LÖNNERDAL, 2003). Some plants, like maize, could have normal levels of total P but significantly reduced levels of phytic acid, which in turn increases the level of inorganic phosphorus (LÖNNERDAL, 2003). In maize, great variations in content of phytic acid and inorganic P is present among genotypes (DRAGICEVIC *et al.,* 2010, MLADENOVIC DRINIC *et al.,* 2010) what gives different nutritional properties of its grains (STEVANOVIĆ *et al.,* 2012). According to the Phy/Zn and Phy/Fe molar ratios and the available-P/total-P ratio, it is possible to determine maize lines or foods with potentially high ability of Fe and Zn utilization, which could contribute to the reduction of Fe and Zn deficiencies in populations that use maize as their diets (MA *et al.,* 2007; QUEIROZ *et al*., 2011).

Opposite than phytic acid, β-carotene positively affects absorption of mineral nutrients also. LÖNNERDAL (2003) stated that β-carotene can enhance iron absorption in humans. LUO and XIE (2012) find that addition of food rich in β-carotene or pure β-carotene can significantly enhance the Fe and Zn bioavailability from the food grains. The complexity of this process was supported by low β-carotene absorption in low zinc intake or marginal zinc deficiency (NOH and KOO, 2003).

According to present data, breeding for biofortification of Fe and Zn in cereals is possible (WHITE and BROADLEY, 2005). This initiated the experiment with 78 maize inbred lines, in order to screen grain chemical composition and to determine relations between phytic acid, inorganic phosphorus and β-carotene, as factors affecting the absorption of Fe, Zn and Mn.

MATERIALS AND METHODS

Seventy eight maize inbred lines were grown in a randomized complete block design (RCBD) with two replications on Maize Research Institute trial fields in Zemun Polje, on slightly calcareous chernozem type of soil (with optimal content of examined elements), during 2010. Maize lines were manually self-pollinated (they were in high degree of homozygosity). Genetic background of the examined lines: dent BSSS – L2-L5, L11, L13, L14, L18, L28-L32, L34, L36-L42, L51, L53, L61-L66, L69-L74, L77; dent BSSS Iowa: L20, L26, L27, L48-L50, L67, L68; dent BSSS Lancaster x tropical white: L24; dent BSSS Ohio: L75; dent Iowa: L8, L16; dent Lancaster Iowa: L25; dent Lancaster: L9, L15, L17, L33, L43-L47, L56-L60; dent Lancaster x tropical white: L54; dent WF9: L12; domestic dent BSSS: L6, L7; flint: L1; semident BSSS Iowa: L35; semident Lancaster: L21; white dent Lancaster x Iowa: L55; tropical white dent: L7, L8; dent unrelated: L10; domestic dent unrelated: L19; white dent unrelated: L22, L23.

After harvesting, contents of phytic phosphorus (P_{phy}), inorganic phosphorus (P_i), total phosphorus (P_{tot}) β-carotene, as well as mineral elements: Fe, Mn and Zn were analyzed in grains.

To determine P_{phy} and P_i, a 0.25 g sample was treated with bi-distilled water for 1 h at room temperature in a rotary shaker. The extract was centrifuged on 14,000 rpm for 15 min and the supernatant was decanted and diluted. P_{phy} and P_i were determined colorimetrically by the method of DRAGIČEVIĆ *et al*. (2011). P_{tot} was determined after wet digestion with HNO_3 + $HClO_4$, colorimetrically, according to POLLMAN (1991). Β-carotene was determined according to AACC (1995) procedure after extraction with saturated butanol. Mineral elements were determined from the same solution prepared for P_{tot} analysis, by Inductively Coupled Plasma - Optical Emission Spectrometry.

The experimental data were statistically processed by analysis of the variance (ANOVA) and analysed by the LSD-test (5 %) and correlation.

RESULTS AND DISCUSSION

The analysed maize lines had moderate P_{phy} content, with range 2.28-3.86 g kg^{-1} (Table 1). Variations in P_{phy} concentration were insignificant, while the significant variations were observed in P_{tot} and P_i concentration, ranging from 5.32 g kg^{-1} (L34) to 8.78 g kg^{-1} (L78) and from 0.32 g kg^{-1} (L71) to 0.80 g kg^{-1} (L76), respectively. Obtained results point that P_{phy} makes majority of P_{tot} in maize grains, what illustrates significant correlation between P_{tot} and P_{phy} (Table 3), similarly with results obtained by DRAGICEVIC *et al.* (2010) and MLADENOVIC DRINIC *et al*. (2010). Meanwhile, this is present in some extent; mainly, grains with $P_{phy} \leq 3$ g kg^{-1}, had also $P_{tot} \leq 7.5$ g kg^{-1}. In maize lines with $P_{phy} \leq 3$ g kg^{-1} significantly high P_i content was noticed in L2, L4, L9, L23, L24, L28, L30 and L32. Additionally, in grains of L2, L30 and L32 ratio between P_{tot}/P_{phy} was about 2.2-2.6, and with relatively low P_{tot}/P_i ratio (< 10) indicate that P pool in maize grains consists of P_i (as the available P form) in higher extent, thus playing the positive role of spontaneous decrease of phytic acid in grains (LÖNNERDAL, 2003, DRAGICEVIC *et al.,* 2010). This is also purported with significant correlation between P_{tot} and P_i (Table 3). Mentioned maize lines could be used in further breeding process as sources of increased content of available P (LÖNNERDAL, 2003; MLADENOVIĆ DRINIĆ et al., 2010). This was also supported by the lowest P_{phy}/P_i ratio (< 4) present in grains of L1, L2, L4 and L30 (Table 4).

Table 1: Content of the phytic (Pphy), inorganic (Pi) and total (Ptot) in grain of 78 maize lines

Line	P_{phy} *n.s.	P_i		P_{tot}	
		g kg^{-1}			
L1	2.28	0.61	n	6.04	c
L2	2.40	0.79	t	6.15	c
L3	2.47	0.46	f	6.25	cd
L4	2.48	0.63	o	7.66	i
L5	2.67	0.59	m	6.06	i
L6	2.75	0.45	f	6.04	i
L7	2.76	0.44	e	5.73	b
L8	2.78	0.55	k	5.96	c
L9	2.79	0.69	q	7.13	fg
L10	2.82	0.40	c	7.20	g
L11	2.82	0.49	h	6.93	f
L12	2.85	0.50	h	7.28	gh
L13	2.87	0.46	f	7.13	fg
L14	2.87	0.45	f	6.97	f
L15	2.87	0.46	f	6.69	ef
L16	2.92	0.45	f	6.57	e
L17	2.93	0.42	d	7.39	a
L18	2.93	0.41	d	5.70	b
L19	2.93	0.48	g	6.44	d
L20	2.94	0.46	f	6.55	d
L21	2.94	0.44	e	7.13	fg
L22	2.94	0.42	d	6.57	e
L23	2.95	0.69	q	7.91	j
L24	3.00	0.61	n	6.65	e
L25	3.02	0.44	e	7.49	hi
L26	3.02	0.47	g	7.33	h
L27	3.02	0.45	f	7.13	f g
L28	3.03	0.61	n	6.93	f
L29	3.04	0.47	g	6.27	cd
L30	3.05	0.79	t	6.80	ef
L31	3.05	0.46	f	6.84	f
L32	3.06	0.75	s	7.13	f g
L33	3.06	0.49	h	6.69	ef
L34	3.07	0.46	f	5.32	a
L35	3.08	0.55	k	7.14	f g
L36	3.11	0.68	p	6.99	f g
L37	3.12	0.34	b	6.02	c
L38	3.15	0.39	c	6.93	f
L39	3.22	0.47	g	7.32	gh
L40	3.22	0.42	d	6.92	f
L41	3.25	0.56	k	6.72	b

L42	3.26	0.42 d	7.37 h
L43	3.26	0.50 h	7.54 i
L44	3.26	0.44 e	7.20 gh
L45	3.27	0.39 c	7.18 g
L46	3.28	0.49 h	7.64 i
L47	3.30	0.43 e	7.03 f
L48	3.31	0.67 p	7.68 i
L49	3.31	0.72 r	8.25 jk
L50	3.31	0.54 j	7.53 i
L51	3.34	0.59 m	7.68 i
L52	3.35	0.49 h	6.80 ef
L53	3.38	0.52 i	7.79 i
L54	3.39	0.64 o	8.17 j k
L55	3.40	0.68 p	8.44 l
L56	3.41	0.61 n	7.89 i
L57	3.41	0.39 c	7.20 g
L58	3.42	0.44 e	8.02 i
L59	3.42	0.48 g	7.81 i
L60	3.43	0.44 e	7.11 f g
L61	3.43	0.39 c	7.87 i j
L62	3.44	0.33 a	7.14 f g
L63	3.46	0.46 f	7.14 f g
L64	3.46	0.55 k	7.24 gh
L65	3.48	0.51 i	7.58 i
L66	3.49	0.45 f	7.62 i
L67	3.53	0.61 n	7.89 j
L68	3.54	0.55 k	8.10 j
L69	3.54	0.62 n	8.02 j
L70	3.55	0.45 f	7.70 j
L71	3.55	0.32 a	7.45 hi
L72	3.56	0.69 q	8.29 k
L73	3.56	0.48 g	7.87 ij
L74	3.60	0.67 p	8.61 l m
L75	3.62	0.53 j	8.29 k
L76	3.64	0.80 t	8.48 l
L77	3.75	0.59 m	7.60 hi
L78	3.86	0.52 i	8.71 m
Aver.	3.17	0.52	7.21
LSD 0.05	1.86	0.02	0.24

The values followed by same letters are not significantly different at the 0.05 level; [*n.s]The values are under the level of significance of 0.05.

Table 2: Content of the β-carotene, Fe, Mn and Zn in grain of 78 maize lines

Line	β-carotene		Fe		Mn		Zn	
	mg kg^{-1}							
L1	15.54	j	23.66	qr	9.31	l	25.13	fg
L2	8.54	de	24.59	rs	6.03	gh	32.25	i
L3	14.19	ij	11.59	fg	5.84	g	20.91	e
L4	4.55	b	12.72	gh	10.09	m	22.00	ef
L5	10.64	f	16.47	k	5.38	f	18.16	de
L6	10.18	ef	11.28	f	5.47	fg	17.69	de
L7	12.30	g	16.34	jk	6.53	h	17.66	de
L8	12.22	g	15.63	jk	6.38	h	16.13	cd
L9	9.79	ef	8.22	d	5.09	ef	15.84	cd
L10	9.80	ef	21.59	op	4.38	d	20.13	e
L11	5.20	bc	23.63	qr	7.03	i	20.50	e
L12	9.38	ef	25.19	s	5.00	ef	17.84	de
L13	7.83	de	20.09	n	6.41	h	10.84	b
L14	14.26	ij	23.03	q	4.03	cd	29.19	h
L15	10.31	ef	30.50	w	7.34	ij	26.38	g
L16	7.70	d	18.97	m	4.06	cd	21.97	ef
L17	8.37	de	15.81	jk	5.66	fg	17.56	d
L18	12.99	gh	4.81	bc	4.84	e	34.13	ij
L19	12.28	g	18.75	m	4.25	cd	23.78	f
L20	10.40	ef	22.03	p	3.72	bc	22.47	ef
L21	8.30	de	13.22	h	4.16	cd	14.94	cd
L22	7.82	de	21.00	o	4.38	d	20.28	e
L23	10.31	ef	25.47	st	2.81	a	18.97	de
L24	9.94	ef	12.91	gh	3.91	c	15.41	cd
L25	7.03	cd	18.13	lm	4.38	d	30.94	hi
L26	12.82	gh	14.06	hi	4.88	ef	11.59	b
L27	9.09	de	21.44	op	5.69	fg	20.63	e
L28	10.76	f	13.47	h	4.28	cd	22.63	ef
L29	12.63	gh	18.59	m	9.41	l	13.03	bc
L30	3.88	b	10.19	e	9.22	l	19.59	de
L31	9.11	e	20.44	no	7.13	i	24.34	fg
L32	11.89	fg	24.16	r	6.59	hi	35.75	j
L33	3.52	ab	22.75	pq	5.44	fg	25.16	fg
L34	9.83	ef	27.91	u	4.31	cd	23.25	f
L35	8.61	de	17.09	kl	4.75	de	20.47	e
L36	9.38	ef	16.19	jk	5.38	f	22.00	ef
L37	10.72	f	15.50	j	6.38	h	18.66	de
L38	12.55	gh	16.63	k	7.88	j	15.78	cd
L39	8.60	de	9.00	de	2.88	a	18.91	de
L40	9.64	ef	10.59	ef	3.56	bc	12.31	bc
L41	7.56	cd	11.84	fg	4.72	de	15.69	cd

L42	9.61	ef	18.50	lm	5.13	ef	22.38	ef
L43	16.64	j	14.66	ij	9.16	l	21.00	e
L44	8.84	de	17.66	l	6.38	h	20.19	e
L45	6.24	c	16.44	k	5.38	f	17.25	d
L46	7.83	de	12.19	g	5.47	fg	18.41	de
L47	7.14	cd	10.56	ef	4.84	e	15.78	cd
L48	8.51	de	21.19	op	4.44	de	30.31	hi
L49	10.90	fg	13.44	h	8.97	l	18.00	de
L50	12.19	g	14.56	i	5.91	g	8.34	a
L51	10.57	f	20.66	no	8.50	k	16.22	cd
L52	6.64	cd	5.91	c	2.94	ab	27.03	gh
L53	11.00	fg	22.03	p	4.94	ef	34.59	ij
L54	9.17	e	28.97	v	5.31	f	15.59	cd
L55	1.98	a	19.00	m	5.25	ef	22.28	ef
L56	11.68	fg	27.56	u	8.00	jk	15.19	cd
L57	9.65	ef	16.03	jk	3.44	b	19.25	de
L58	6.87	cd	10.34	e	5.19	ef	14.69	c
L59	12.82	gh	12.25	g	7.88	j	16.06	cd
L60	7.82	de	18.44	lm	4.28	cd	16.22	cd
L61	17.45	k	22.66	pq	8.72	kl	21.84	ef
L62	10.54	f	26.09	t	5.47	fg	27.19	gh
L63	7.77	d	10.13	e	4.69	de	11.97	b
L64	12.39	g	21.41	op	6.66	hi	26.53	g
L65	11.24	fg	9.75	e	3.84	bc	14.00	bc
L66	12.12	g	10.34	e	4.66	de	17.88	de
L67	15.84	j	23.28	q	5.56	fg	27.09	gh
L68	8.22	de	12.22	g	5.72	fg	13.31	bc
L69	13.80	i	19.38	mn	8.34	k	16.59	cd
L70	12.07	g	5.59	c	3.56	bc	21.19	ef
L71	9.18	e	12.00	fg	5.13	ef	16.28	cd
L72	6.48	c	20.50	no	7.75	j	23.03	f
L73	9.09	de	13.56	h	4.69	de	20.16	e
L74	4.51	b	21.00	o	3.75	bc	20.16	e
L75	2.44	a	15.63	jk	6.16	gh	20.28	e
L76	12.46	gh	4.06	b	5.53	fg	15.69	cd
L77	9.39	ef	2.31	a	4.59	de	17.31	d
L78	11.44	fg	23.66	qr	6.41	h	22.13	ef
Aver.	9.78		16.92		5.66		20.16	
LSD 0.05	1.40		0.85		0.45		2.51	

The values followed by same letters are not significantly different at the 0.05 level; *n.s The values are under the level of significance of 0.05.

High variations among genotypes were noticed at the level of β-carotene (Table 2), with concentrations ranging from 1.98 mg kg^{-1} (L55) to 17.45 mg kg^{-1} (L61). In breeding program for selection of high carotenes maze lines, SAFAWO *et al.* (2010) have also determined high variation in β-carotene in maize grains. The highest β-carotene concentration (> 14 mg kg^{-1}) was noted in grains of L1, L3, L14, L43, L61 and L67, where L1, L3 and L14 are also in group of genotypes with $P_{phy} \leq 3$ g kg^{-1}. This could be important, since the increased β-carotene concentration in maize grains enables better absorption of mineral nutrients by forming a complex with Fe that keeps it soluble in the intestinal lumen and prevents the deleterious effect of phytic acid on Fe assimilation (WALTER LOPEZ et al., 2002). Moreover, high β-carotene content in other three genotypes (L43, L61 and L67) could also have positive effect on absorption of mineral nutrients, possibly by decreasing negative effect of phytic acid (LÖNNERDAL, 2003; LUO and XIE, 2012). The noticed remark could be supported by the lowest P_{phy}/β-carotene ratio in those 3 lines (< 600, Table 4).

Table 3. Correlation between examined traits: phytic (P_{phy}), inorganic (P_i) and total (P_{tot}) phosphorus, and β-carotene, Fe, Mn and Zn in grain of 78 maize lines

	P_{phy}	P_i	P_{tot}	β-carotene	Fe	Mn
P_i	0.05					
P_{tot}	0.43*	0.31*				
β-carotene	0.12	-0.11	-0.01			
Fe	0.01	0.23	0.15	0.06		
Mn	0.36*	0.17	0.30*	0.21	0.20	
Zn	-0.25*	0.17	0.06	0.05	0.34*	-0.04

*The significant values at the level of significance of 0.05.

Fe concentration in grains of examined maize lines (Table 2) ranged from 2.31 mg kg^{-1} (L77) to 30.50 mg kg^{-1} (L15), with the highest values (> 24 mg kg^{-1}) obtained in grains of L2, L12, L15, L23, L32, L34, L54, L56 and L62. Additionally, all these lines, together with L1 and L11, have favourable ratio between phytic acid and Fe (< 40; Table 4) indicating higher potential for Fe availability. The obtained Fe concentrations were higher than those reported by QUEIROZ *et al.* (2011) indicating that lines examined in our study were relative high in phytic acid. Among mentioned lines, L2 and L23 also have high P_i concentration (Table 1), what makes them potentially desirable as sources of P and Fe in breeding programs. Since β-carotene enables better Fe absorption from food (LÖNNERDAL, 2003; LUO and XIE, 2012; WALTER LOPEZ *et al.,* 2002), higher contents of both components, particularly present in grains of L1, L61 and L67 (Table 2), provides certainly increased quality of such food.

Variations of Mn concentration in maize grains ranged from 2.81 mg kg^{-1} (L23) to 10.09 mg kg^{-1} (L4), with the highest values (≥ 8 mg kg^{-1}) found in grains of L1, L4, L29, L30, L43, L49, L51, L56, L61 and L69 (Table 2). Ratio between phytic acid and Mn is favourable (< 100) only in grains of L1, L4, L29 and L30 (Table 4), making them desirable lines in breeding for higher Mn assimilation. UNDERWOOD and SUTTLE (1999) also obtained that phytate breakage in rumen increases Mn assimilation in ruminants.

Zn concentration in grains of maize lines ranged from 8.34 mg kg^{-1} (L50) to 35.75 mg kg^{-1} (L32), with the highest values (≥ 30 mg kg^{-1}) found in grains of L2, L18, L25, L32, L48 and

L53 (Table 2). Besides that, low phytic acid - Zn ratio in grains found in L2, L18 and L32 (≤ 30, Table 4), characterized them as potential sources of available Zn (similarly to results of QUEIROZ *et al*. (2011). High concentrations of both, β-carotene and Zn, is desirable characteristics: Zn absorption highly depends on β-carotene content in food (HESS *et al*., 2005; LUO and XIE, 2012)': β-carotene absorption and efficiency depends on Zn concentration in human plasma and in consumed food (NOH and KOO, 2003). Such commonly high contents of Zn and β-carotene were noticed in grains of L1, L3, L14 and L18 (Table 2), which are also in the group of genotypes with P_{phy} ≤ 3 g kg^{-1}, making them desirable objects in breeding programs for increased Zn availability. Significant and negative correlation between P_{phy} and Zn content, as well as positive correlation between Zn and Fe (Table 3) in maize grain could also enlighten that lines with low P_{phy} could be a good source of Zn and Fe. High concentration of both, Fe and Zn, found in L2, L14 and L15, gives them relatively high nutritional quality, as sources of Fe and Zn.

Table 3. Correlation between examined traits: phytic (P_{phy}), inorganic (P_i) and total (P_{tot}) phosphorus, and β-carotene, Fe, Mn and Zn in grain of 78 maize lines

	P_{phy}	P_i	P_{tot}	β-carotene	Fe	Mn
P_i	0.05					
P_{tot}	0.43*	0.31*				
β-carotene	0.12	-0.11	-0.01			
Fe	0.01	0.23	0.15	0.06		
Mn	0.36*	0.17	0.30*	0.21	0.20	
Zn	-0.25*	0.17	0.06	0.05	0.34*	-0.04

*The significant values at the level of significance of 0.05.

Table 4. Molar ratios between phytic/inorganic phosphorus, phytic acid/β-carotene, phytic acid/Fe, phytic acid/Mn, phytic acid/Zn

Line	P_{phy}/P_i	Phy./β-carot.	Phy./Fe	Phy./Mn	Phy./Zn
L1	3.71 b	423.71 a	28.96 a	72.37 a	31.92 ab
L2	3.04 a	812.46 bc	29.34 ab	117.69 cd	26.19 a
L3	5.40 ef	503.22 a	64.07 de	125.04 cd	41.59 bc
L4	3.90 bc	1570.28 d	58.50 d	72.51 a	39.59 bc
L5	4.51 cd	725.25 ab	48.75 c	146.95 de	51.77 cd
L6	6.14 g	781.83 b	73.37 ef	148.88 de	54.78 cd
L7	6.34 gh	648.91 ab	50.79 cd	125.01 cd	55.03 cd
L8	5.05 de	657.54 ab	53.50 cd	128.99 cd	60.69 de
L9	4.05 bc	823.48 bc	102.00 h	161.89 ef	61.94 de
L10	7.04 i	831.46 bc	39.26 bc	190.60 fg	49.31 c
L11	5.75 f	1566.80 d	35.88 ab	118.60 cd	48.41 c
L12	5.70 f	877.23 bc	33.98 ab	168.40 ef	56.15 cd
L13	6.30 gh	1057.88 bc	42.89 bc	132.34 cd	93.04 g
L14	6.34 gh	581.57 ab	37.47 ab	210.59 gh	34.61 ab
L15	6.30 gh	804.53 bc	28.30 a	115.60 bc	38.30 b
L16	6.52 gh	1095.61 bc	46.24 bc	212.40 gh	46.74 bc
L17	6.97 hi	1009.81 bc	55.62 cd	152.96 de	58.62 d

L18	7.23	i	651.87	ab	183.00	j	178.86	f	30.21	ab
L19	6.10	fg	689.37	ab	46.97	bc	203.85	gh	43.35	bc
L20	6.33	gh	816.07	bc	40.08	bc	233.59	hi	46.01	bc
L21	6.69	h	1023.05	bc	66.80	e	209.00	gh	69.20	e
L22	7.09	i	1087.45	bc	42.11	bc	198.82	g	51.04	cd
L23	4.28	c	825.41	bc	34.76	ab	309.68	k	54.64	cd
L24	4.89	d	871.45	bc	69.79	ef	226.83	hi	68.44	e
L25	6.81	hi	1238.88	cd	50.02	cd	203.85	gh	34.31	ab
L26	6.43	gh	680.60	ab	64.55	de	183.18	fg	91.66	g
L27	6.75	hi	959.58	bc	42.35	bc	157.01	e	51.53	cd
L28	5.00	de	812.93	bc	67.58	e	209.13	gh	47.09	bc
L29	6.52	gh	696.51	ab	49.20	cd	95.68	b	82.19	fg
L30	3.88	b	2270.64	e	89.92	g	97.75	b	54.73	cd
L31	6.61	h	967.95	bc	44.88	bc	126.64	cd	44.11	bc
L32	4.05	bc	742.52	ab	38.02	b	137.01	d	30.07	ab
L33	6.21	g	2516.40	e	40.47	bc	166.58	ef	42.85	bc
L34	6.70	hi	901.52	bc	33.04	ab	210.30	gh	46.42	bc
L35	5.60	ef	1034.22	bc	54.21	cd	191.91	fg	53.00	cd
L36	4.59	cd	959.35	bc	57.83	cd	171.32	ef	49.81	c
L37	9.27	m	840.66	bc	60.47	de	144.63	de	58.81	d
L38	8.11	k	724.15	ab	56.87	cd	118.11	cd	70.14	ef
L39	6.83	hi	1083.46	bc	107.68	h	331.58	l	60.00	de
L40	7.67	j	966.83	bc	91.48	gh	267.59	j	92.14	g
L41	5.77	fg	1242.57	cd	82.52	fg	203.74	gh	72.93	ef
L42	7.77	jk	979.29	bc	52.89	cd	187.82	fg	51.19	cd
L43	6.48	gh	565.96	ab	66.84	e	105.25	bc	54.61	cd
L44	7.34	ij	1066.79	bc	55.55	cd	151.35	de	56.88	cd
L45	8.36	k	1515.14	d	59.82	de	179.94	f	66.72	de
L46	6.77	hi	1211.21	cd	80.96	f	177.50	f	62.76	de
L47	7.76	jk	1336.44	cd	93.98	gh	201.59	g	73.63	ef
L48	4.94	de	1122.90	c	46.91	bc	220.31	h	38.38	b
L49	4.58	cd	876.64	bc	73.96	ef	109.00	bc	64.63	de
L50	6.08	fg	784.61	b	68.33	e	165.72	ef	139.60	h
L51	5.69	ef	912.65	bc	48.57	c	116.11	c	72.41	ef
L52	6.86	hi	1454.98	cd	170.26	i	336.76	l	43.55	bc
L53	6.53	gh	887.82	bc	46.13	bc	202.46	g	34.39	ab
L54	5.30	e	1067.85	bc	35.16	ab	188.61	fg	76.47	ef
L55	4.97	de	4946.19	g	53.73	cd	191.29	fg	53.64	cd
L56	5.63	ef	842.22	bc	37.13	ab	125.83	cd	78.87	f
L57	8.70	l	1020.50	bc	63.90	de	293.17	k	62.30	de
L58	7.80	jk	1436.91	cd	99.27	h	194.72	fg	81.84	f
L59	7.06	i	770.71	b	83.92	fg	128.41	cd	74.92	ef
L60	7.85	jk	1267.17	cd	55.88	cd	236.75	hi	74.37	ef
L61	8.71	l	568.20	ab	45.53	bc	116.38	c	55.28	cd
L62	10.34	n	942.13	bc	39.58	bc	185.76	fg	44.47	bc

L63	7.43	ij	1284.72	cd	102.58	h	217.96	gh	101.58	g
L64	6.33	gh	806.07	bc	48.52	c	153.49	de	45.83	bc
L65	6.83	hi	893.01	bc	107.13	h	267.31	j	87.34	fg
L66	7.70	j	832.49	bc	101.43	h	221.66	h	68.71	e
L67	5.84	fg	644.47	ab	45.62	bc	187.84	fg	45.89	bc
L68	6.50	gh	1244.57	cd	87.12	fg	183.12	fg	93.61	g
L69	5.75	fg	741.59	ab	54.94	cd	125.51	cd	75.10	ef
L70	7.91	jk	849.68	bc	190.73	j	294.60	k	58.95	d
L71	11.03	o	1116.68	bc	88.91	g	204.78	gh	76.71	ef
L72	5.19	de	1586.53	d	52.16	cd	135.72	d	54.35	cd
L73	7.34	ij	1131.49	c	78.93	f	224.64	hi	62.17	de
L74	5.37	e	2306.95	e	51.53	cd	283.89	jk	62.85	de
L75	6.79	hi	4290.75	f	69.56	ef	173.68	ef	62.74	de
L76	4.54	cd	844.84	bc	269.58	k	194.77	fg	81.72	f
L77	6.40	gh	1153.16	c	487.35	l	241.33	i	76.20	ef
L78	7.40	ij	975.79	bc	49.09	cd	178.30	f	61.44	de
Aver.	6.36		1098.13		71.88		180.52		59.87	
LSD 0.05	0.40		346.00		9.56		19.33		9.63	

The values followed by same letters are not significantly different at the 0.05 level;

Based on obtained results it could be concluded that investigated maize lines show high variability in concentration of important mineral elements (Fe, Mn and Zn), phytic acid (which sustain availability of mineral elements) and β-carotene (which enables better absorption of mineral element and minimize negative effect of phytic acid). From this point of view, genotypes with $P_{phy} \leq 3$ g kg^{-1} were separated. Among them, L2 and L23 are lines with relatively high P_i, Fe and Zn contents, and favourable P_{phy}/P_i ratio, so they could be used as good source of P, Fe and Zn. On the other hand, L1 and L4 are lines with high P_i content, β-carotene and Mn, and also favourable P_{phy}/Fe and P_{phy}/Zn ratio. That could characterize them as source of Mn and improved ability for Fe and Zn absorption, based on high β-carotene content. Relatively high concentration of all three factors (Fe, Zn and β-carotene) in L14, is advantageous in breeding programs as basis for mineral improved maize crop.

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VARIJABILNOST FAKTORA KOJI UTIČU NA PRISTUPAČNOST GVOŽĐA, MANGANA I CINKA U LINIJAMA KUKURUZA

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Izvod

Nedostatak pojedinih mineralnih elemenata može dovesti do ozbiljnih zdravstvenih problema koji se mogu sprečiti povećanjem sadržaja minerala u ishrani preko suplemenata, fortifikacijom hrane ili oplemenjivanjem biljaka. Sa te tačke gledišta, postavljen je eksperiment sa 78 samooplodnih linija kukuruza, kako bi se odredile linije sa poboljšanim sadržajem Fe, Zn i Mn, kao i njihove relacije sa fitinskom kiselinom, neorganskim fosforom i β-karotenom, kao faktorima koji utiču na njihovu apsrpciju. Dobijeni rezultati ukazuju na visoku varijabilnost isipitivanih linija u pogledu koncentracije Fe, Mn i Zn, kao i fitrinske kiseline (koja smanjuje pristupačnost mineralnih elemenata) i β-karotena (koji omogućava bolju apsorpciju mineralnih elemenata i minimizira negativan uticaj fitiske kiseline). Sa te tačke gledišta, grupa genotipova sa fitinskim P $\leq$ 3 g kg^{-1} je bila izdvojena. Od njih, L2 i L23 su linije kukuruza sa relatvno visokim sadržajem neorganskog P, Fe i Zn, što sa relatvno niskim odnosom između fitinskog i neorganskog P upućuje da bi mogle biti izvor P, Fe i Zn u ishrani. Sa druge strane, L1 i L4 su takođe linije kukuruza sa visokim sadržajem neorganskog P, β-karotena i Mn, kao i povoljnim odnosom između fitinske kiseline i Fe i Zn, što im može dati prednost, kao izvoru Mn u selekcionim programima. Iste linije kukuruza takođe bi mogle imati visoku apsorpciju Fe i Zn, zahvaljujući visokom sadržaju β-karotena. Linija kukuruza L14, sa relatvno visokom koncnetracijom sva tri faktora (Fe, Zn i β-karotena) je pogodna za selekcione programe kao osnova za poboljšanje useva kukuruza preko povećanja pristupačnih minerala.

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