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VARIATIONS IN MINERAL CONTENT OF OPIUM POPPY SEEDS (*PAPAVER SOMNIFERUM* L.)

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ABSTRACT

Due to its special chemistry, opium poppy is a valuable raw material for the pharmaceutical and food industries. This research aimed to determine the mineral content of seeds in eight opium poppy accessions. We studied one registered culinary, ('Zeno Plus'); three industrial varieties ('Botond', 'Hunor', 'Korona'), and four strains of landrace origin ('Lilla', 'MB', 'T18', 'T28') using ICP-OES, to open the way for their utilisation in functional food development. Highly significant differences in mineral content were found among the accessions. 'Zeno Plus' had the highest macromineral content (15976.667±440.038 mg/kg d.w. for Ca; 3733.000±78.689 mg/kg d.w. for Mg; 8219.333±47.648 mg/kg d.w. for K), 'Botond' accumulated the most of the iron (110.043±3.966 mg/kg d.w.), whilst 'MB' proved to be the most effective in the accumulation of Zn (84.233±1.478 mg/kg d.w.), Cu (18.660±0.897 mg/kg d.w.), Na (68.237±1.410 mg/kg d.w.) and Mn (108.267±2.706 mg/kg d.w.). All three accessions are promising materials for food fortification or biofortification breeding programs.

Keywords: food fortification; chemical variability; presscake

INTRODUCTION

New industries such as food supplements and food fortification have emerged. These are the combined response of the agriculture, food and health industries to current global food challenges such as quality hunger and food which is impoverished in vitamins and minerals (*Thomas* 2007, *Mayer* 1997, *Ekholm et al*. 2007). Several minerals have been recognized for their nutraceutical potential and thus have become candidates for functional food ingredients. The most obvious minerals and trace elements with nutraceutical potential are calcium, magnesium, manganese, copper, zinc, selenium and iron (*Wildman* and *Kelley* 2007, *Ferrari* and *Torres* 2002). Micronutrient deficiency is common around the globe. These silent epidemics affect people of all genders and ages. Food fortification is a population based approach to help in meeting community health needs safely, an approach which has led to success in the past century (*Tulchinsky* (2010). Micronutrient supplementation must be carefully controlled, given the toxic effects ascribed to trace elements (*Fraga* (2005).

Mineral malnutrition is a burning global challenge, and different strategies have been created to prevent it, such as agricultural production methods, food processing procedures, as well as economic and consumer education programs (*Miller* and *Welch* 2013). Biofortification is an innovative and sustainable strategy for addressing micronutrient malnutrition (*White* and *Broadley* 2005, *Welch* and *Graham* 2005). Nowadays, biofortification programs such as HarvestPlus and Biofort Brazil are being developed (*Miller* and *Welch* 2013). Among others, food and flour fortification with iron is a current and long term strategy to prevent or to overcome *iron deficiency anemia* in numerous countries (*Huma et al*. 2007). At present, technical challenges limit the bioavailability of minerals in fortified foods, but plant breeding is a very promising new approach to improve dietary nutritional quality (*Zimmerman* and *Hurrel* 2007).

Opium poppy (*Papaver somniferum* L.) is an industrial crop whose cultivation and usage dates back to prehistoric times (*Tétényi* 1997, *Nencini* 1997). The manufacture of morphine in Europe started in the 19th century with small pharmaceutical companies. After the method of producing morphine from dried capsules instead of opium was invented by the Hungarian pharmacist Kabay in 1928, the perspective of a dual benefit appeared, integrating the pharmaceutical and food industries' purposes and demands (Anonymus 1925, Anonymus 1931). Thanks to Kabay's method, high quality seeds (the most significant use in food industry) and valuable pharmaceutical raw material became available simultaneously (*Bernáth* 1998). Poppy seeds are a rich source of stearic, palmitic, oleic, linoleic and linolenic acids, β-tocopherol, and polyphenols with antioxidant activity (*Özcan* and *Atalay* 2006). Poppy seed has a high nutritional value compared to other valuable plant materials (*Table 1*) and incorporating it into the diet could satisfy some human nutritional needs and promote health. In the last few decades, the main breeding goals of poppy have been to reach high yields with favourable alkaloid content and composition, while breeding for optimal fatty acid composition has been greatly limited (*Singh* 1990, *Singh* 1995). Consequently, there is a large pool of different poppy accessions and varieties with only minimum information available on the components of the seeds.

Poppy-seed meal is created from presscake, which is a by-product of the edible oil industry; it contains a high amount of crude protein and 11-14% of residue oil, depending on the variety and the extraction parameters (*Eklund* and *Agren* 1975). The following minimal information has been published thus far on the utilization of poppy-presscake and seed-meal: additive to forage supplement (*Akinci* and *Bayram* 2003), survey on the effect of ruminal methane production (Wang et al. 2017) and food product development possibilities (*Aksoylu, Cagindi* and *Köse* 2015, *Gök et al.* 2011). The modern concept of waste management tends to identify agro-food waste from a different perspective: waste materials are seen as resources which can be bioconverted into high value-added, useful products (*Ezejiofor, Enebaku* and *Ogueke* 2014). Edible oil-derived, processed presscake can be an economically beneficial raw material for the food industry, especially because there is a necessity to utilize as many valuable by-products as possible in order to stay competitive (*Helkar, Sahoo* and *Patil* 2016).

Table 1: Comparison of mineral content in poppy seed with other plant materials which have high nutrition value (mg/kg d.w.)

Species	Minerals									References
	Ca	Mg	K	Na	Na to K ratio	Fe	Cu	Zn	Mn	
Poppy seed	14 380	3 470	7 190	260	1:27.65	97.60	16.27	79.00	67.07	USDA 2020
Hemp seed	700	7 000	12 000	50.00	1:240	79.50	16.00	99.00	76.00	
Flax seed	2550	3 920	8 130	300	1:27.10	57.30	12.20	43.40	24.82	
Beets, raw	160	230	3 250	780	1:4.17	8.00	0.75	3.50	3.29	
Spinach, raw	990	790	5 580	790	1:7.06	27.10	1.30	5.30	8.97	
Kale	15 400	2 900	17 200	88 700	1:0.19	185.80	1.90	36.20	184.00	Miller-Cebert, Sisatani, Cebert 2009
Cabbage	4 700	1 900	18 400	38 000	1:0.48	76.50	-	14.50	24.70	
Hazelnut	1 860	1 730	8 630	2 600	1:3.32	42.00	23.00	29.00	56.00	Köksal et al. 2009
Almond	2 774	3 261	8 276	114	1:72.6	77.60	27.50	67.70	33.30	Simsek, Kizmaz 2017
Apple	312	331	31 976	9.62	1:3323.9	3.68	3.57	1.93	1.81	Todea et al. 2014.

In the last half century, global production of poppy seeds has doubled, during which time the main producer countries have been Australia, Turkey, India, and the Czech Republic – among others (*Procházka* and *Smutka* 2012). In Hungary, for a century poppy has been a traditional crop in several thousands of hectares. The intensive and broad scale breeding activity in the producing countries has resulted in a relatively large number of varieties and valuable selected genotypes. Therefore, the objective of this paper is to reveal the quantitative and qualitative variability of some essential minerals in the seeds. Hungarian poppy genotypes can reveal their potential in natural food fortification in the future. Furthermore, we wanted to find valuable breeding stocks and genotypes to improve nutritional value in staple foods.

MATERIALS AND METHODS

Plant material, growth conditions and sampling

Eight different opium poppy accessions were tested. The propagation material originated from the gene bank of the Department of Medicinal and Aromatic Plants of Szent István University. The plant material contained one registered culinary ('Zeno Plus') and three industrial varieties ('Botond', 'Hunor', 'Korona'), along with a further four selected strains of landrace origin ('Lilla', 'MB', 'T18', 'T28'). The industrial varieties are special high alkaloid containing cultivars, among which 'Botond' is characterised by morphine as the main component, and 'Hunor' has both morphine and tebaine in its capsules, while 'Korona' has been bred for high noscapine content. The culinary variety has a very low (below 0.2%) alkaloid content in the capsules. Among the other strains, only 'MB' has a higher alkaloid content (close to 2.0%) while the others are intended for culinary use. 'T18' has white seeds; all the others have blue or greyish ones.

The plants were grown at the Experimental and Research Farm of the University in Budapest. Seeds were sown into small plots ($10m^2$) by hand at the end of September 2017 (in the case of the overwintering genotypes ('Hunor', 'Lilla', 'T18' and 'T28'); and in March 2018 for the others, summer poppy genotypes. Row and plant distances were 0.5 m and 0.05 m, respectively.

The Research Farm's soil type is sandy with a low humus content (0.6-0.8%) with a pH of 7.6-7.9. Nitrogen (80 kg/ha) was added in March and boron (2%) as leaf fertilizer at budding stage. Weed control was done by hoeing and occasional irrigation was applied in the dry periods. Plants were harvested by hand in early July (overwintering genotypes) and middle July 2018 (summer poppies), at the stage of full ripening.

Determination of mineral contents using ICP-OES

Instrumentation

All the samples were analysed in three replicates by ICP-OES (PerkinElmer, model: Optima 8000 ICP OES), using winLab32 software for the analysis. The spectrometer was equipped with a Charge-Coupled Device (CCD) array detector that measures from 160 nm to 900 nm. The introduction system was composed of a glass cyclonic spray chamber and a glass concentric (Meinhard) nebulizer. The injector tube diameter of the torch was 2.0 mm. A part of ICP-OES was also the Monochromator that detects the chemical elements separately. Instrument operating conditions are listed in *Table 2*. The selected analytical wavelengths are compiled in *Table 3.*

Table 2: ICP-OES operating conditions

Parameter	**Value**
Nebulizer type	Meinhard
Spray chamber	Cyclonic
Sample flow	1.50 mL/min
Plasma gas flow	15 L/min
Auxiliary gas flow	0.3 L/min
Nebulizer gas flow	0.6 L/min
RF power	1300 W
Viewing distance	15 mm

Table 3: Wavelengths and plasma view which were selected

Element	**Wavelength (nm)**	**Plasma view**
Ca	315.887	Attn. radial
Mg	279.077	Radial
K	766.490	Attn. radial
Na	589.592	Attn. radial
Fe	259.939	Radial
Cu	324.752	Radial
Zn	213.857	Radial
Mn	257.610	Attn. radial

Sample preparation - Microwave assisted digestion

The presence of the following minerals: Ca (calcium), Mg (magnesium), K (potassium) and Na (sodium), Fe (iron), Cu (copper), Zn (zinc) and Mn (manganese) was investigated by inductively coupled plasma optical emission spectrometry (ICP-OES). All samples were prepared for the analysis via the microwave digestion method and measured in triplicate.

Aliquots of each sample (0.5 g) were accurately weighed into a digestion vessel, then 5 mL of concentrated nitric acid (65% HNO_3) was added. This mixture was left for one night, and the next day 3 mL of hydrogen peroxide (30% H_2O_2) were added in the digestion vessels. The vessels were placed in the microwave oven digestion system (Mars 5, CEM Corporation) which followed a specific digestion program. It took 20 minutes to reach a pressure of 250 psi inside the oven, then the samples were treated for 15 minutes in 2200 °C at a pressure of 250 psi, and finally cooled down for 20 minutes.

After mineralization, the resulting solutions were cooled to room temperature, and then transferred to autosampler tubes and diluted to a final volume of 25 mL with Milli-Q water. The determination of mineral contents in this clear solution was carried out by ICP-OES. The equipment calibration was performed with standard elemental solutions, diluted to the desired concentration. The dilutions were prepared using HNO_3 (2M). The first calibration solution (blank) contained only nitric acid; the second calibration solution was a dilution of the standard elemental solutions with nitric acid, containing the following minerals: Ca, Mg, K and Na. The third calibration solution was a dilution of standard elemental solutions with nitric acid, containing the following elements: Fe, Cu, Zn and Mn. The concentrations of the solutions ranged from 1 to 100 mg/kg (1.5, 10, 100 mg/kg, respectively) to match the amount of the elements possibly present in the samples.

Statistical analysis

The examined accessions were compared for the mineral content of their seeds using one-way multivariate ANOVA (MANOVA). In order to normalize the data and regulate the variances, iron was square-root-transformed, calcium was inverse-transformed, and manganese and sodium were inverse-square-root-transformed. Normality of the residuals then was accepted by Shapiro-Wilk's test ($p>0.05$). Homogeneity of variances was checked by Levene's test ($p>0.05$). Multivariate factor effect was tested by Wilk's lambda. When there was a significant multivariate overall result, follow-up univariate

ANOVA was run with Bonferroni’s correction in order to avoid Type I error accumulation. Homogeneous subgroups were separated by Tukey’s hoc test. Statistical analysis was performed by using IBM SPSS v25.

RESULTS

In terms of the mineral contents, considerable differences were found among the accessions. The overall MANOVA result was highly significant (Wilks’ lambda<0.001; $p<0.001$). The follow-up between-subjects effect was significant for each mineral ($F(7;16)> 209.9$; Bonferroni’s corrected $p<0.001$). Tukey’s post-hoc test result is given in *Table 4.*

Among the macrominerals studied, Ca was the one showing the highest concentration in opium poppy seeds, with a global mean content of 9937.13 mg/kg (Table 5). Global mean contents for the other macrominerals were 5602.88 mg/kg for K, 2578.13 mg/kg for Mg and 23.82 mg/kg for Na. Accessions with the highest Ca accumulation were ‘Zeno Plus’ (15976.667±440.038 mg/kg d.w.), ‘Hunor’ (14075.333±293.423 mg/kg d.w.) and ‘MB’ (10985.333±97.167 mg/kg d.w.) (Table 4). The highest K concentration was recorded in ‘Zeno Plus’ (8219.333±47.648 mg/kg d.w.), ‘Hunor’ (6392.000±38.158 mg/kg d.w.) and ‘Botond’ (6238.667±59.501 mg/kg d.w.) (Table 4). ‘Zeno Plus’ (3733.000±78.689 mg/kg d.w.), ‘Hunor’ (3558.000±61.612 mg/kg d.w.) and ‘Lilla’ (2651.667±54.501 mg/kg d.w.) presented the highest Mg concentration, while ‘MB’, ‘Botond’ and ‘Hunor’ accumulated the highest quantity of Na (*Table 4*). On average, registered varieties had a higher content of the investigated essential minerals than landraces and breeding strains (except Na and Mn).

Global mean contents for the microminerals investigated here were: 66.36 mg/kg for Fe, 56.36 mg/kg for Mn, 54.96 mg/kg for Zn, and 12.77 mg/kg for Cu (Table 5). The maximum Fe content was measured in ‘Botond’ (110.043±3.966 mg/kg d.w.), ‘Korona’ (90.973±1.390 mg/kg d.w.) and ‘MB’(88.533±0.948 mg/kg d.w.), while Zn accumulation was the highest in ‘MB’ (84.233±1.478 mg/kg d.w.), ‘Botond’ (71.443±1.091 mg/kg d.w.) and ‘Zeno Plus’ (70.173±1.193 mg/kg d.w.) (Table 4). Accessions showing high Mn accumulation were ‘MB’, ‘Botond’ and ‘Hunor’, while the accessions of ‘MB’, ‘Korona’ and ‘Botond’ accumulated a high amount of Cu in their seeds (*Table* 4). Ca accumulation is the only case where each of the studied opium poppy accessions differed significantly. In the cases of the K, Fe, Na and Mn, seven genotypes showed significant differences (*Table 4*). In general, there was a large variation among the studied accessions in the content of essential minerals, with high differences in the content of Ca ('Korona': 6330.667±68.879 mg/kg d.w. - 'Zeno Plus': 15976.667±440.038 mg/kg d.w.), in the content of Fe ('T18': 27.277±0.698 mg/kg d.w. - 'Botond': 110.043±3.966 mg/kg d.w.), and in the content of Mn ('Lilla': 31.763±0.803 mg/kg d.w. - 'MB': 108.267±2.706 mg/kg d.w.) (*Table 4*). Moisture content of opium poppy seeds were 4,38%, whilst moisture content of the presscake was 6,48%.

Table 4: Means (mg/kg d.w.) and standard deviations of minerals of the eight investigated poppy accessions. Different letters are for significantly different genotypes (Tukey's, p<0.05)

Mine-rals	**Statistical parame-ters**	**Accession**							
		'Botond'	**'Hunor'**	**'Korona'**	**'Lilla'**	**'MB'**	**'T18'**	**'T28'**	**'Zeno Plus'**
Ca	Mean	10430.667	14075.333	6330.667	6839.667	10985.333	6603.000	8255.667	15976.667
	StDev	75.002	293.423	68.879	40.501	97.167	29.000	42.782	440.038
	Tukey's	e	g	a	c	f	b	d	h
Mg	Mean	2365.667	3558.000	2315.667	2651.667	2295.333	2009.000	1696.667	3733.000
	StDev	82.597	61.612	55.869	54.501	32.716	43.313	40.377	78.689
	Tukey's	c	e	c	d	c	b	a	f
K	Mean	6238.667	6392.000	5744.333	4735.000	4383.333	4506.000	4604.333	8219.333
	StDev	59.501	38.158	63.532	61.000	22.898	36.428	20.526	47.648
	Tukey's	e	f	d	c	a	ab	bc	g
Na	Mean	48.263	22.850	9.923	7.545	68.237	10.008	8.830	14.883
	StDev	1.184	1.486	0.370	0.105	1.410	0.219	0.090	0.405
	Tukey's	f	e	c	a	g	c	b	d
Fe	Mean	110.043	54.453	90.973	32.493	88.533	27.277	60.530	66.553
	StDev	3.966	0.670	1.390	0.755	0.948	0.698	0.741	1.159
	Tukey's	g	c	f	b	f	a	d	e
Cu	Mean	15.150	12.773	16.680	11.047	18.660	7.259	7.737	12.817
	StDev	0.362	0.614	0.572	0.294	0.897	0.074	0.257	0.262
	Tukey's	d	c	e	b	f	a	a	c
Zn	Mean	71.443	46.310	56.517	39.917	84.233	28.613	42.460	70.173
	StDev	1.091	0.779	1.115	0.335	1.478	0.978	0.979	1.193
	Tukey's	e	c	d	b	f	a	b	e
Mn	Mean	72.933	62.377	53.807	31.763	108.267	35.713	37.963	48.053
	StDev	2.026	0.990	1.347	0.803	2.706	0.753	0.415	0.267
	Tukey's	f	e	c	a	g	c	b	d

Table 5: Mineral content (mg/kg) of poppy seed according to different references, compared with the results of the current research

Minerals	*Origin of the seeds*				
	Southern Turkey (Özkutlu et al. 2007)	*India (Ramasastri 1983)*	*Konya, Turkey (Özcan 2004)*	*USA* (United States Department of Agriculture 2020)	*Budapest* Zubay et al. (Current research, global mean)
Ca	*no data*	*17200*	*10583*	14380	9937.13±*3615,20*
Mg	*no data*	*no data*	*4256*	3470	2578.13±716.56
K	*no data*	*no data*	*5906*	7190	5602.88±*1327.38*
Na	*no data*	*no data*	*no data*	260	23.82±22.44
Fe	*29 ± 1.4*	*127*	*91.1*	97,6	66.36±28.92
Cu	*11 ± 0.4*	*no data*	*14.4*	16.27	12.77±4.04
Zn	*25 ± 0.4*	*no data*	*42.5*	79	54.96±18.95
Mn	*24 ± 1.7*	*no data*	*56.1*	67.07	56.36±25.21

DISCUSSION

In the cases of Ca, K, Fe, Na and Mn, at least seven accessions differed significantly. Three accessions accumulated the minerals in the highest levels: 'Zeno Plus', strain 'MB' and 'Botond' (Fig 1. and 2.). 'Zeno Plus' is a spring ecotype variety meant for the food industry, while 'Botond' and strain 'MB' are high alkaloid containing winter poppies developed for pharmacological use. 'T18', the white coloured strain, differed in mineral content from the accessions with blue seeds, similar to other important properties described before by (*Eklund* and *Agren* 1975, *Lo* and *Chua* 1992, *Hayes et al.* 1987). All of the genotypes are of European origin, six of them originating from Hungary. Therefore, it seems that no strong connection exists between the origin of the accessions and their mineral contents. Similarly, neither overwintering characteristics nor alkaloid content of the capsules appear in connection with the nutrient values as measured. Further investigation is needed to understand the eventual anatomical and metabolomical backgrounds of the determined differences among poppy accessions in their essential mineral content.

Until recently, extremely little information was available in the literature about the mineral content of poppy seeds with different origins (*Table 5*). This has caused a high standard deviation among the results reported by these references. Compared to the previous references, the poppy genotypes in our study have average mineral contents. At the same time, variety 'Zeno Plus' accumulated a prominent amount of K, while 'MB' was characterised by high concentrations of Zn and Mg compared to poppy-seed accessions from India, Turkey and the USA (*Table 5*).

Minerals accumulated in the highest concentrations were Ca, Mg, Fe and Zn. Similar to calcium, vitamins D and K together have a synergic effect on the skeletal and cardiovascular system (*Kidd* 2010); in the case of food product development, it is worth determining the vitamin D and K content of the fatty oil of poppy seed. Increased dietary magnesium intake fosters protection against many diseases typical in western civilization (*Bo* and *Pisu* 2008); and poppy may play a role in delivering a high proportion of magnesium. Iron deficiency is the most threatening type of mineral malnutrition in the world, causing serious consequences for human health (*Haas* and *Brownlie* 2001, *Oski* 1979). Also, poppy seed is an excellent, high iron content plant material for a food fortification approach. The modern diet is lacking in potassium and loaded with energy-rich foods (*Sebastian et al.* 2006), thus a reconditioned, adequate potassium-to-sodium intake ratio is essential for human health (*Jansson* 1990, *He* and *MacGregor* 2008, *Yang et al.* 2011).

The bioconversion from waste to wealth of the poppy-seed presscake could be a sustainable way of alleviating malnutrition by delivering bioavailable, plant-based essential minerals to the population. Differences among the poppy-seed accessions could greatly benefit from sophisticated cross-sector collaborations between the pharmaceutical and food industries. Developers could process the poppy-seed presscake as a by-product of the edible oil industry into health promoting functional and novel foods. This could be based on the information from the best mineral-accumulating genotypes utilised by the food or pharmaceutical industries. Adding value to the by-products by applying knowledge of genetic potential and sharing research-based information would benefit those market players who are willing to cooperate with each other. The capsules of opium poppy plant accumulate narcotic alkaloids, though the seeds do not contain alkaloids unless they are contaminated by pest damage and during harvesting. Functional food is the manifestation of a modern theory which addresses contemporary food and nutrition problems. The development of fortified food using oilseeds could be an effective solution to these problems (*Asma*, *El Fadil* and *El Tinay* 2006, *Shilpa* and *Lakshmi* 2012). Development of poppy genotypes with enhanced mineral content may be included in breeding programs. Among the examined accessions, 'Zeno Plus', 'Botond' and the strain 'MB' were found to be promising for this purpose. Poppy-seed products are commonly consumed at festive meals in East-Central Europe.

Breeding, cultivation, processing and consumption of poppy is organically connected to Hungarian tradition and national identity, along with other populations in the region. Thus, a well-directed development of functional food products based on the new results and theory which were suggested in this article may make the poppy product line even more prosperous.

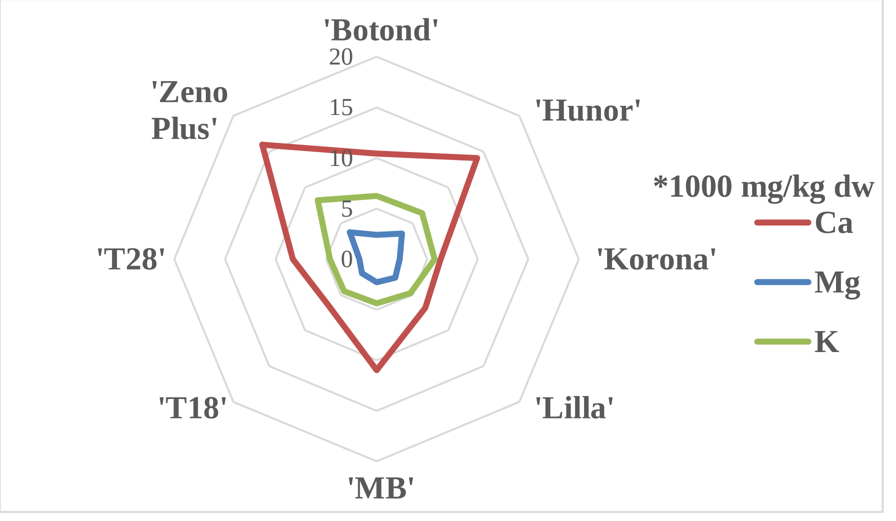

Figure 1: Mean values of macromineral contents (Mg, Ca and K, *1000 mg/kg d.w.) of the eight investigated poppy accessions

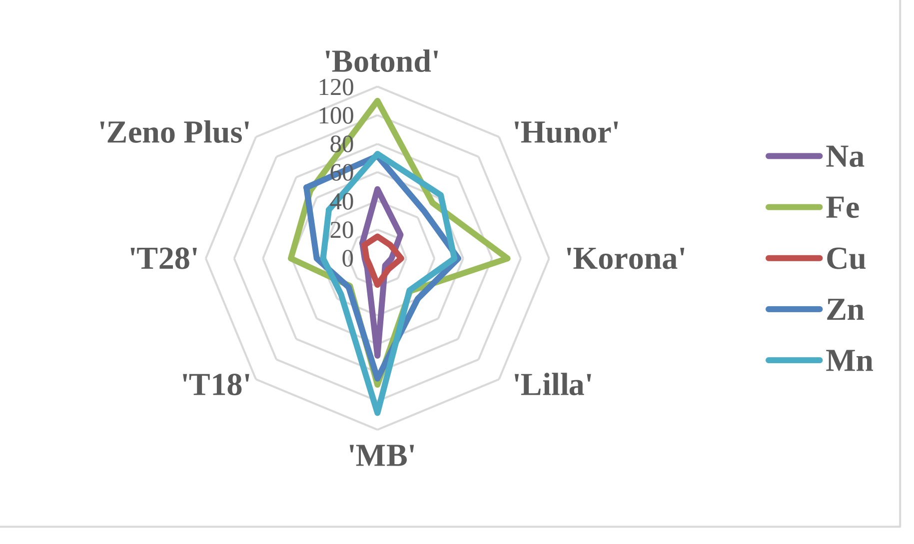

Figure 2: Mean values of mineral contents (Zn, Cu, Fe, Na and Mn, mg/kg d.w.) of the eight investigated poppy accessions

KÜLÖNBSÉGEK MÁK (*PAPAVER SOMNIFERUM* L.) MAG TÉTELEK ÁSVÁNYIANYAG-TARTALMÁBAN

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ÖSSZEFOGLALÓ

Speciális fitokémiai összetételének köszönhetően a mák értékes növényi alapanyag mind az élelmiszer- mind a gyógyszeripar számára. Kutatásunk célja nyolc hazai nemesítésű mák magtétel ásványianyag-tartalmának meghatározása volt. ICP-OES módszerrel vizsgáltuk négy fajtajegyzékben elismert, köztük egy étkezési- ('Zeno Plus') és három ipari ('Botond', 'Hunor', 'Korona') fajta, valamint négy tájfajta ('Lilla', 'MB', 'T18', 'T28') ásványianyag-tartalmát az élelmiszer dúsítási potenciál felmérése érdekében. Erősen szignifikáns különbségeket figyeltünk meg a vizsgált fajták ásványianyag-tartalma között. A 'Zeno Plus' fajta esetén figyeltük meg a legnagyobb makroelem-tartalmat (Ca - 15976.667±440.038 mg/kg sz.a.; Mg - 3733.000±78.689 mg/kg sz.a.; K - 8219.333±47.648 mg/kg sz.a.), a 'Botond' halmozta fel a legtöbb vasat (110.043±3.966 mg/kg sz.a.), miközben az 'MB' bizonyult a leghatékonyabbnak a Zn (84.233±1.478 mg/kg sz.a.), Cu (18.660±0.897 mg/kg sz.a.), Na (68.237±1.410 mg/kg sz.a.) és az Mn (108.267±2.706 mg/kg sz.a.) elemek akkumulációjában. Mindhárom tétel kifejezetten ígéretes alapanyagnak bizonyul élelmiszer dúsítás célú élelmiszerfejlesztések és nemesítési programok megvalósításához.

Kulcsszavak: élelmiszer dúsítás; ásványi anyag; olajpogácsa

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