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ORIGINAL PAPER

THE CONTENT OF SELECTED ELEMENTS IN COMMON FLAX SEEDS (*LINUM USITATISSIMUM* L.) DEPENDING ON THE CULTIVAR AND WEATHER CONDITIONS*

Magdalena Kluza-Wieloch[1], Agnieszka Waśkiewicz[2], Leszek Bednorz[1], Renata Nowińska[1]

[1] Department of Botany
[2] Department of Chemistry
Poznań University of Life Sciences, Poland

Abstract

The aim of the study was to evaluate the effect of different cultivars and weather conditions on the content of minerals: K, Na, Mg, Ca, Zn, Cu, Mn and Fe in linseed (*Linum usitatissimum* L.). In total, 11 common flax cultivars of four utility types were analysed. Field experiments were carried out in Poznań (Poland) between 2003 and 2005 and between 2008 and 2014. The study showed that the chemical composition of flax seeds was determined by differences between cultivars, the weather conditions and the cultivar-year interactions. The seeds of the Alba cultivar, representing the fibre type, had the highest content of all the elements measured in our study. The results demonstrated that none of the four types of utility cultivars was distinguished by a particularly high content of minerals in the seeds. Hence, the seeds of the flax cultivars of all the types used in our study may be used as sources of valuable macro- and microelements. The content of some minerals in the seeds of different flax cultivars was significantly correlated with the average temperatures and the average rainfall during the research period. The concentrations of calcium and zinc were not correlated with the weather conditions. The content of four elements (Na, Mg, Cu, Fe) was negatively correlated with temperature, whereas the content of potassium was positively correlated with this factor. Concentrations of three elements (K, Na, Fe) were negatively correlated with rainfall, whereas the concentration of manganese was positively correlated with this factor.

Keywords: linseed, minerals, cultivars, weather conditions.

Leszek Bednorz, PhD DSc, Department of Botany, Poznań University of Life Sciences, Wojska Polskiego Str. 71c , 60-625 Poznań, Poland, e-mail: leszek.bednorz@up.poznan.pl

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INTRODUCTION

There are about 180 species in the *Linum* genus of the *Linnaceae* family (McDill et al. 2009). Common flax (*Linum usitatissimum* L.) is the most popular and thoroughly investigated cultivated flax species. It is native to western Asia and the Mediterranean region. Since at least 5000 BC, flax has been cultivated as a source of linen fibre, but today it is mainly grown for oil (Oomah 2001). Numerous common flax cultivars have commercial significance as rich sources of linseed oil, fibre and owing to their ornamental value. The total area of fibre flax plantations is over 240 000 ha (just about 100 ha in Poland). France, Belarus and Russia are the biggest producers. However, the area of plantations where flax cultivars with high content of oil are grown is over 2 250 000 ha. They are located mainly in Canada, China, Russia and India (FAOSTAT 2018).

Recently, the interest in flax has been increasing because its seeds are a significant source of bioactive compounds, and it is a valuable, health-promoting medicinal and functional food. Nowadays, greater health awareness among consumers has led to a significant growth in the consumption of functional food. Flaxseed is one of the richest vegetarian sources of α-linolenic acid (omega-3 fatty acid) and soluble mucilage. The seeds are rich in fat (41%), protein (20%) and dietary fibre (28%). Flaxseed oil contains a unique mixture of saturated and unsaturated fatty acids (Gambuś 2005, El-Betltagi et al. 2007, Vetter, Thurnhofer 2007, Zając et al. 2010, Fataneh et al. 2012). Flax seeds are also a good source of minerals, especially phosphorus, magnesium, and calcium. They have very low content of sodium (Gambuś 2005) and the highest content of potassium (5.6-9.2 g kg^{-1}) among various foods. High potassium intake is inversely related to platelet aggregation, the accumulation of free radicals in blood and stroke incidence (Carter 1993). Brown and yellow flaxseed cultivars are virtually identical in their content of nutrients (Ganorkar, Jain 2013).

Researchers studying linseed focus on the content of fatty acids, lignans, cannabinoids, podophyllotoxin, phenolic acids, flavonoids, amino acids and lutein (Oomah et al. 1996**,** Beejmohun et al. 2007, Fujisawa et al. 2008, Yousefzadi et al. 2010, Styrczewska et al. 2012, Pali, Mehta 2014, Shim et al. 2014, Wang et al. 2017). Minerals, that is macro- and microelements, are less often the subject of research. So far, researchers have mainly studied the effect of different agronomic factors on the content of minerals in linseed (Hassan, Leitch 2000, Antonkiewicz, Zając 2003, 2005, Heller, Wielgusz 2011, Klimek-Kopyra et al. 2013, Andruszczak et al. 2015, Kraska et al. 2016). Only a few studies deal with the impact of weather conditions on the concentration of minerals in the seeds (Hassan, Leitch 2000, Antonkiewicz, Zając 2005, Kraska et al. 2016).

The aim of this study was to determine the effect of different cultivars and weather conditions on the content of minerals and nutritional value of flax seeds.

MATERIAL AND METHODS

Between 2003 and 2005 and between 2008 and 2014, field experiments were carried out at the experimental garden of the Department of Botany, Poznań University of Life Sciences, Poland (52°24′ N, 16°57′ E). The experiment was conducted on lessivé soil underlain by slightly loamy sand. The humus layer was about 25 cm thick.

In total, 11 common flax cultivars of four types were analysed (Table 1). There was only one yellow linseed cultivar, namely Choresmicum, and ten brown linseed cultivars. The experiment was set up in a split-plot design with three replications for each cultivar.

Table 1

Types of cultivars and the cultivars used in the experiment of the years 2003-2005 and 2008-2014

Types of cultivars	Oil cv.	Fibre cv.	Intermediate cv.	Ornamental cv.
Name of the cultivar	1. Abby 2. Szafir 3. Opal	4. Alba 5. Artemida 6. Luna 7. Modran 8. Nike 9. Selena	10. Evelin	11. Choresmicum

The soil was prepared for seeding in line with good agricultural practices. Seeds of all the cultivars were sown manually in rows spaced at 50 cm (200 seeds per 1 m^2) in late April. Before the seeds were sown, the soil had been fertilised with NPK at respective amounts of 50 kg ha^{-1} (N), 40 kg ha^{-1} (P) and 70 kg ha^{-1} (K). The same agricultural technology was applied in each year of the experiment. No herbicide was used, and weeds were removed manually. Mature seeds were harvested in early September from the central parts of the plots. For each cultivar, one pooled sample was created from three subplots.

Weather conditions

Data such as the average air temperatures and accumulated rainfall from April to September (the growing season) in the years of the experiment were provided by the Institute of Meteorology and Water Management (IMGW), Poznań, and then compared (Table 2). The temperatures were the highest in 2011 and 2014, being the lowest in 2004. The highest total rainfall was recorded in 2010 and 2012-2014, whereas the lowest was in 2003 and 2008. The spring (April-May) of 2011 was outstanding with its warm and dry weather (Table 2).

Sample preparation

From each pooled sample, three representative samples (1.0 g each) of ground seeds were mineralised in a CEM Mars 5 Xpress microwave

Table 2

Rainfalls and mean air temperatures in the months April-September of the years 2003-2005 and 2008-2014 according to the IMGW Poznań

Years	Temperature (°C)							Rainfall (mm)						
	April	May	June	July	August	September	Mean	April	May	June	July	August	September	total
2003	8.2	15.7	19.0	19.5	19.4	14.7	16.1	20.6	6.4	24.5	116.4	7.2	14.6	189.7
2004	9.4	12.5	16.0	18.0	20.0	14.3	15.0	19.3	50.8	57.9	33.1	57.4	25.5	244.0
2005	9.1	13.6	16.5	20.1	17.3	16.2	15.2	16.4	62.2	16.8	73.2	48.6	34.6	251.8
2008	8.8	14.1	18.0	19.9	18.8	13.7	15.6	72.6	8.2	7.8	50.0	63.4	15.6	217.6
2009	11.7	13.3	15.9	19.7	19.3	16.2	16.0	16.4	82.0	96.8	92.6	13.8	27.6	329.2
2010	8.8	11.5	17.1	21.7	18.9	12.9	15.2	25.0	102.0	18.2	74.6	94.2	72.0	386.0
2011	11.7	13.9	18.8	17.9	19.3	15.7	16.2	7.2	9.4	55.0	146.4	30.0	17.4	265.4
2012	9.5	15.0	16.8	19.8	19.3	15.0	15.9	16.4	47.6	94.4	126.2	33.4	20.6	338.6
2013	8.5	15.1	17.8	20.3	19.4	13.0	15.7	15.8	65.0	127.4	39.2	33.4	69.2	350.0
2014	11.1	13.7	16.5	22.1	18.2	15.8	16.3	64.8	86.2	33.7	92.1	31.2	37.4	345.4

mineralisation system (CEM Corp., Matthews, NC, USA) in a closed system (55 mL vessels), using 6 mL of 65% HNO_3 and 1 mL of 30% H_2O_2. The plant materials were digested using a three-stage microwave programme: I – 600 W, 100°C, 3 min; II – 600 W, 120°C, 3 min; III – 1200 W, 200°C, 8 min. After digestion, the materials were filtered and then the whole contents were filled up with distilled water to a final volume of 100 mL.

Analytical method

The concentrations of minerals in the plant material were analysed by flame atomic absorption spectrometry (Cu, Fe, Mn, Zn) and atomic emission spectrometry (Ca, K, Mg, Na), using an Agilent Technologies AA Duo – AA280FS/AA280Z spectrometer (Agilent Technologies, Mulgrave, Victoria, Australia) equipped only with single-element, hollow-cathode Varian lamps (HCLs).

Statistical analyses

Untransformed data were used for all statistical analyses. The normality of the data was proved with the Kolmogorov-Smirnov test.

Two-way multivariate analyses of variance (two-way MANOVAs) and two-way analyses of variance (two-way ANOVAs) were used to examine the effect of two factors (the cultivar and the year) on the chemical composition of seeds. The significance of differences between the average content of the minerals in the cultivars was evaluated with the Tukey HSD test for unequal sample sizes.

Principal component analysis (PCA) was applied to highlight differences between the cultivars and functional groups of cultivars (oil, fibre, intermediate and ornamental) in the concentration of minerals, and to estimate how it contributed to inter-cultivar and intergroup differentiation. The principal components with eigenvalues greater than or near 1.0 were evaluated. A scatterplot of the first two components is shown in Figure 1.

The chi-square test of independence was used to determine if the minimum and maximum values of the minerals occurred independently in the years of the research.

The Spearman's rank correlation coefficient was used to measure the strength of the relationship between the concentration of individual minerals and the average monthly temperatures as well as the accumulated monthly rainfall during the growing seasons (April-September) in the years of the research (2003-2005 and 2008-2014).

Statistica v. 11 (StatSoft, Poland) and Calculation for the chi-square test (an interactive calculation tool for chi-square tests of goodness of fit and independence) were used for statistical analyses (Preacher 2001).

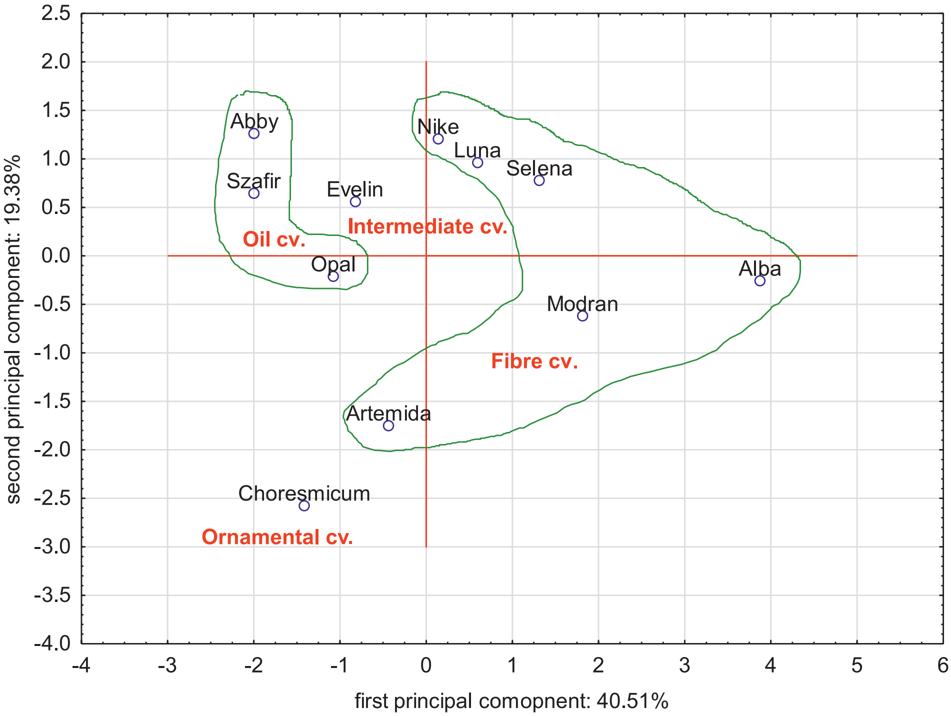

Fig. 1. PCA relationship among studied flax cultivars

RESULTS AND DISCUSSION

The content of potassium in the seeds of the flax cultivars differed significantly and ranged from 5.8 to 10.5 g kg^{-1} (Table 3). A similar content of potassium in flax seeds was also found by Khalifa et al. (2011) – 8.6-12.2 g kg^{-1}, Katare et al. (2012), Goyal et al. (2014), Kajla et al. (2015) – 7.5-8.31 g kg^{-1} and Kraska et al. (2016) in two Polish cultivars (8.41 g kg^{-1}, 8.59 g kg^{-1}). Khan et al. (2010) found a higher content of potassium (11.4-19.2 g kg^{-1}), whereas Zając et al. (2002) reported a lower content of potassium (5.7 g kg^{-1}) in the seeds of flax cultivars. As Carter (1993) emphasised, flax seeds have the highest content of potassium (5.6-9.2 g kg^{-1}) among various foods.

The content of sodium ranged from 0.3 to 7.6 g kg^{-1} (Table 3). It reached the greatest variation in the seeds of different flax cultivars (the coefficient of variation in the content of sodium in individual flax cultivars ranged from 30% to 116% in all the years of the research). The lowest value of the coefficient of variation was noted for the content of magnesium and manganese (5% $\leq$ v $\leq$ 11%). Other authors found less sodium in flax seeds, i.e. 0.27 g kg^{-1} (Goyal et al. 2014) and 0.6 g kg^{-1} (Khan et al. 2010). Flax seeds are considered to contain little sodium (Gambuś 2005).

Table 3

Minerals concentration in seeds of flax cultivars

Specification	Cultivars											ANOVA *p*-value		
	Abby	Szafir	Opal	Alba	Artemida	Luna	Modran	Nike	Selena	Evelin	Choresmicum	C	Y	C × Y
	K (g kg^{-1})													
Mean	6.8	6.7	6.8	7.3	6.8	7.0	7.0	7.4	7.5	7.2	7.8	<0.0001	<0.0001	<0.0001
Min	6.3	5.8	5.9	6.0	5.8	6.1	6.0	5.7	6.4	6.2	6.9			
Max	7.5	8.0	8.2	10.5	7.4	8.6	8.0	9.7	8.8	9.2	8.8			
CV (%)	5.4	9.5	10.1	16.1	7.0	11.3	10.2	15.7	9.2	12.4	8.0			
Tukey test	*f*	*g*	*f*	*cd*	*f*	*e*	*e*	*b*	*c*	*d*	*a*			
	Na (g kg^{-1})													
Mean	1.9	1.5	1.6	1.7	1.3	1.8	1.3	1.9	1.7	1.9	1.4	<0.0001	<0.0001	<0.0001
Min	1.0	0.3	0.3	0.5	0.4	0.8	0.7	0.9	0.9	0.6	0.8			
Max	4.7	2.9	3.3	4.4	2.5	2.4	2.3	4.6	4.2	7.6	2.0			
CV (%)	56.0	53.3	52.7	64.0	48.2	29.7	46.3	55.2	57.6	116.4	30.4			
Tukey test	*a*	*f*	*e*	*d*	*h*	*c*	*i*	*b*	*d*	*a*	*g*			
	Mg (g kg^{-1})													
Mean	4.3	4.0	4.2	4.7	4.4	4.4	4.7	4.4	4.8	4.4	4.3	<0.0001	<0.0001	<0.0001
Min	3.7	3.5	3.4	4.1	3.5	3.3	4.3	3.8	4.3	3.9	3.7			
Max	4.6	4.5	4.6	5.2	4.9	5.2	5.2	4.8	5.6	4.8	4.6			
CV (%)	5.3	7.0	8.9	7.7	7.0	10.7	5.2	6.2	7.3	5.7	6.2			
Tukey test	*d*	*f*	*e*	*b*	*c*	*c*	*b*	*c*	*a*	*c*	*d*			

cont. Table 3

Specification	Cultivars											ANOVA p-value		
	Abby	Szafir	Opal	Alba	Artemida	Luna	Modran	Nike	Selena	Evelin	Choresmicum	C	Y	C × Y
	Ca (g kg^{-1})													
Mean	4.5	3.8	3.9	3.6	3.6	3.6	3.3	3.3	3.8	4.1	4.0	<0.0001	<0.0001	<0.0001
Min	3.7	2.6	2.4	2.9	2.6	2.4	1.7	2.5	2.8	2.5	2.7			
Max	6.1	5.7	5.7	4.4	4.7	4.5	4.1	4.1	4.7	5.4	5.5			
CV (%)	16.8	22.6	21.8	12.8	15.7	15.7	20.8	14.9	15.5	23.8	19.7			
Tukey test	*a*	*c*	*c*	*d*	*d*	*d*	*e*	*e*	*c*	*b*	*b*			
	Zn (mg kg^{-1})													
Mean	58.0	57.9	60.5	71.0	59.6	62.0	66.8	60.8	62.7	58.8	59.1	<0.0001	<0.0001	<0.0001
Min	49.9	49.3	48.1	60.2	48.5	48.4	53.5	51.9	53.9	47.6	52.7			
Max	70.8	66.3	70.0	77.7	70.0	75.2	78.0	70.3	72.8	71.7	66.0			
CV (%)	10.9	9.4	10.0	7.2	9.7	10.7	8.2	8.1	8.8	14.1	7.8			
Tukey test	*gh*	*h*	*e*	*a*	*f*	*d*	*b*	*e*	*c*	*fg*	*f*			
	Cu (mg kg^{-1})													
Mean	12.9	11.9	12.7	14.9	11.3	12.8	13.3	12.1	13.3	12.2	9.8	<0.0001	<0.0001	<0.0001
Min	5.9	6.5	8.2	9.8	5.8	7.9	7.8	7.9	8.6	7.2	5.9			
Max	21.3	21.3	24.6	24.0	18.9	22.7	25.2	20.5	25.6	20.5	17.4			
CV (%)	31.7	36.4	37.0	29.1	35.1	35.0	36.9	32.9	38.7	43.4	39.6			
Tukey test	*d*	*e*	*d*	*a*	*f*	*d*	*c*	*e*	*b*	*e*	*g*			

cont. Table 3

Specification	Cultivars											ANOVA p-value		
	Abby	Szafir	Opal	Alba	Artemida	Luna	Modran	Nike	Selena	Evelin	Choresmicum	C	Y	C × Y
	Mn (mg kg^{-1})													
Mean	19.3	18.4	19.6	19.8	19.9	18.5	18.8	18.0	18.7	19.3	20.2	<0.0001	<0.0001	<0.0001
Min	17.6	15.2	17.0	16.9	17.9	16.4	17.1	15.7	16.9	16.5	17.9			
Max	24.1	23.0	23.3	23.8	21.8	21.1	20.9	21.0	20.2	22.3	24.8			
CV (%)	9.3	10.8	8.7	9.9	6.8	7.8	5.5	7.9	5.4	7.8	10.6			
Tukey test	*d*	*f*	*cd*	*bc*	*ab*	*f*	*e*	*g*	*e*	*d*	*a*			
	Fe (mg kg^{-1})													
Mean	92.9	93.8	96.3	111.3	101.1	102.2	96.6	95.6	97.6	96.2	97.2	<0.0001	<0.0001	<0.0001
Min	74.4	81.6	79.3	98.2	85.3	86.1	86.8	80.2	84.7	88.1	78.7			
Max	127.5	111.5	113.6	129.4	114.7	124.1	109.4	119.3	127.0	113.8	120.3			
CV (%)	15.0	8.4	10.3	8.0	9.0	8.7	7.2	11.9	11.5	7.7	12.3			
Tukey test	*e*	*e*	*d*	*a*	*b*	*b*	*d*	*d*	*c*	*d*	*cd*			

Mean – arithmetic mean; Min, Max – minimum and maximum values, CV – coefficient of variation (%). Two-way ANOVA's were performed for each chemical component to determine the effect cultivar (C), year of seeds collection (Y) and interaction among the variables studied (C × Y). Tukey post-hoc tests were performed to determine the chemical differences of seeds between each pair of cultivars (the same letters indicate a lack of statistically significant differences between cultivars).

The content of magnesium in the seeds was significant and ranged from 3.3 to 5.6 g kg^{-1}. The content of calcium ranged from 1.7 to 6.1 g kg^{-1} (Table 3). In our study, the content of magnesium in the seeds of the flax cultivars under analysis was higher than in other studies (Zając et al. 2002, Khan et al. 2010, Khalifa et al. 2011, Kraska et al. 2016). The content of calcium in our study was similar to the content measured by other researchers, except for Kajla et al. (2015) and Zając et al. (2002), who found slightly or significantly less of this element. In the studies by Katare et al. (2012) and Goyal et al. (2014), the content of both magnesium and calcium was within the ranges given above. According to Gambuś (2005), flax seeds are a good source of magnesium and calcium. Gambuś (2005) emphasised that the addition of linseed with a high content of magnesium to gluten-free bread is especially important for patients suffering from the coeliac disease because they cannot consume cereal products rich in this element, e.g. dark bread or coarse cereals.

Two of the eleven cultivars used in our experiment were also tested by other authors. Kraska et al. (2016) measured the content of K, Mg and Ca in the Szafir cultivar. The content of potassium (8.41 g kg^{-1}) in the seeds of this cultivar was higher than in our study. The content of calcium was similar (3.25 g kg^{-1}), whereas the content of magnesium was lower (2.24 g kg^{-1}). Khalifa et al. (2011) measured the content of K, Mg and Ca in the seeds of the Opal cultivar. The content of potassium (8.7 g kg^{-1}) and magnesium (4.7 g kg^{-1}) was higher than in our study, whereas the content of calcium (2.0 g kg^{-1}) was within the range of the minimum and maximum values for this cultivar. Gambuś et al. (2003) studied the same cultivar and found that its content of potassium was 9.5 g kg^{-1} (higher than in our study), whereas the content of magnesium was 1.9 g kg^{-1} (lower than in our study). Zając et al. (2002) also conducted experiments on the Opal cultivar. The content of K (5.7 g kg^{-1}), Na (0.09 g kg^{-1}), Mg (3.2 g kg^{-1}) and Ca (1.0 g kg^{-1}) was lower than in our study (Table 3).

The flax cultivars had the following content of microelements in their seeds: zinc 47.6-78.0 mg kg^{-1}, copper 5.8-25.6 mg kg^{-1}, manganese 15.2-24.8 mg kg^{-1}, and iron 74.4-129.4 mg kg^{-1} (Table 3). The content of zinc in studies conducted by other authors ranged from 11.72 mg kg^{-1} (Khan et al. 2010) to 77.0 mg kg^{-1} (Khalifa et al. 2011). Other authors noted lower content of copper in their studies, where it ranged from 2.31 mg kg^{-1} (Khan et al. 2010) to 14.0 mg kg^{-1} (Khalifa et al. 2011). According to scientific reports, the content of manganese in flax seeds ranged from 6.85 mg kg^{-1} (Khan et al. 2010) to 41.02 mg kg^{-1} (Kraska et al. 2016), whereas the content of iron ranged from 23.32 mg kg^{-1} (Kraska et al. 2016) to 240 mg kg^{-1} (Khalifa et al. 2011).

Kraska et al. (2016) found that the content of zinc in the Szafir cultivar amounted to 52.09 mg kg^{-1} and it was within the limits given in Table 3. The content of manganese (35.72 mg kg^{-1}) was higher than in our study, whereas the copper (4.92 mg kg^{-1}) and iron (24.99 mg kg^{-1}) levels were lower. Khalifa et al. (2011) found that the content of zinc in the Opal cultivar was

46.0 mg kg^{-1}, whereas the content of manganese was 16.67 mg kg^{-1}. These levels were lower than in our study. The content of iron (160.33 mg kg^{-1}) was higher, whereas the content of copper (12.67 mg kg^{-1}) was within the minimum and maximum levels for this cultivar. Gambuś et al. (2003) found that the content of zinc in the same oil cultivar was 74.5 mg kg^{-1}, whereas it was much lower in our study. The content of copper (11.3 mg kg^{-1}) was within the limits for this cultivar, whereas the content of iron (66.6 mg kg^{-1}) was much lower. Zając et al. (2002) reported the levels of zinc (69.6 mg kg^{-1}), copper (10.22 mg kg^{-1}) and manganese (19.5 mg kg^{-1}) in the seeds of the Opal cultivar that were similar to those measured in our study, but the content of iron was much higher (59.9 mg kg^{-1}) – Table 3.

The chemical composition of the seeds was determined by differences between the cultivars (represented cultivar), environmental factors (year), and cultivar-year interactions (MANOVAs: Wilks' λ <0.00001; p<0.0001). These three variables significantly affected the content of each of the tested minerals in the seeds (Table 3, ANOVA, p<0.0001).

The Tukey post-hoc tests showed that the seeds of the Alba cultivar (cv.) were particularly abundant in minerals. This cultivar had the highest average concentration of copper, iron and zinc. The average content of other elements in the seeds of this cultivar was high (Mg, Mn, K) or medium (Ca, Fe), but never low. The Abby cultivar had the highest content of calcium and sodium. The content of sodium was equally high in cv. Evenlin. The Choresmicum cultivar was distinguished by the highest content of potassium and manganese, whereas cv. Selena had the highest content of magnesium (Table 3; Tukey tests, p<0.05).

With their content of minerals, plants in the taxa representing oil cultivars and fibre cultivars form separate groups and occupy separate spaces in the course of the first principal component in PCA. The intermediate cultivar, i.e. cv. Evelin, separates both groups (Figure 1). The concentrations of Zn, Mg, Fe and Ca were the most strongly correlated with the first component (Figure 2, Table 4). The group of oil cultivars had higher content of calcium in the seeds, whereas the group of fibre cultivars had higher concentrations of zinc, magnesium and iron. The second principal component separates the ornamental Choresmicum cultivar from all the other taxa (Figure 1), mainly due to the high content of manganese and low content of sodium in its seeds (Figure 2, Table 4). The third principal component above all separates the fibre group from the intermediate cultivar due to the diversified content of calcium in the seeds (there were noticeably lower concentrations of this element in the fibre group) – Table 4.

The research showed that seeds of the same cultivar harvested in different years differed significantly in their chemical composition (Table 3). For this reason, it was necessary to find whether during the research period there were years with a particularly large number of the minimum and maximum concentrations of elements in seeds. The pattern in which the minimum and maximum values appeared varied significantly during the

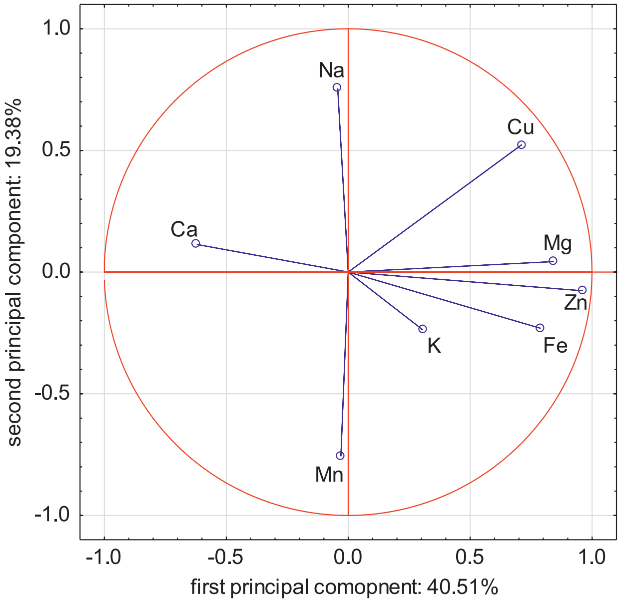

Fig. 2. PCA relationship among concentration of minerals in flax seeds

Table 4

PCA component loadings for eight minerals and first three principal components

Specification	PC1	PC2	PC3
Eigenvalues	3.24	1.55	1.35
Cumulative total variance explain.	40.51	59.89	76.82
Minerals	component loadings		
K	0.31	-0.24	-0.37
Na	-0.04	**0.76**	-0.57
Mg	**0.84**	0.04	-0.10
Ca	**-0.62**	0.11	**-0.69**
Zn	**0.96**	-0.08	0.02
Cu	0.71	0.52	-0.11
Mn	-0.03	**-0.76**	-0.56
Fe	**0.79**	-0.23	-0.26
Groups	mean PC scores		
Oil cv.	-1.69	0.57	0.03
Fibre cv.	1.22	0.05	0.34
Intermediate cv.	-0.82	0.56	-1.18
Ornamental cv.	-1.41	-2.58	-0.93

The highest values of component loadings are bolded.

research period (Chi^2 = 76.182; df=9; p=0). Most of the maximum values of the content of minerals was observed in 2010 (24 cases) and 2011 (19 cases); the share of minimum values observed in these years was very low, i.e. 2 and 1 cases, respectively (Figure 3). The analysis of the weather conditions in these years showed that 2010 was characterised by the highest rainfall between April and September (386.0 mm), whereas in 2011 there were some of the highest average temperatures in these months (16.2°C). The largest number of the minimum values of the content of elements was observed in 2013 (24 cases) and 2008 (18 cases). The maximum values were observed rather rarely in these years, i.e. 4 and 3 cases, respectively (Figure 3). These findings cannot be fully explained by the weather conditions.

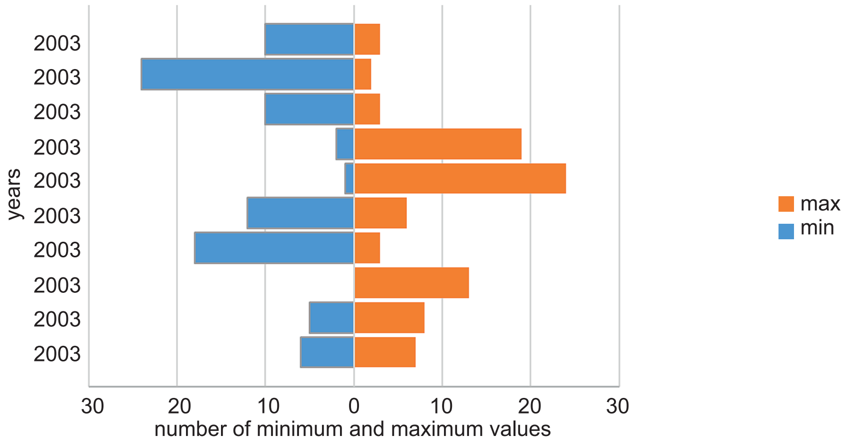

Fig. 3. The frequency of occurrences of minimum (N = 88) and maximum (N = 88) concentrations of eight minerals in the seeds of 11 flax cultivars in 2003-2005 and 2008-2014

The content of some minerals in the seeds of different flax cultivars was significantly correlated with the average temperatures and the average rainfall during the research period. The concentrations of calcium and zinc were not correlated with the weather conditions. The content of four elements (Na, Mg, Cu, Fe) was negatively correlated with temperature, whereas the content of potassium was positively correlated with it. The concentrations of three elements (K, Na, Fe) were negatively correlated with rainfall, whereas the concentration of manganese was positively correlated with this factor (Table 5). Differences in the content of some minerals in flax seeds in consecutive years of observations were also detected by others (Hassan, Leitch 2000, Antonkiewicz, Zając 2005, Kraska et al. 2016). However, the researchers did not indicate any specific relations with the weather conditions. It was only Kraska et al. (2016) who noticed that one of the reasons of different concentrations of some elements in seeds in subsequent years could have been the high variation in rainfall in particular months of the growing season.

Table 5

Spearman's rank correlation matrix for the analyzed minerals concentrations in flax's seeds vs monthly mean temperatures and the accumulated rainfall

Minerals	Temperature	Rainfall
K	**0.23**	**-0.26**
Na	**-0.16**	**-0.24**
Mg	**-0.11**	0.05
Ca	0.03	0.11
Zn	0.07	0.00
Cu	**-0.23**	-0.07
Mn	0.05	**0.14**
Fe	**-0.13**	**-0.16**

Significant (p<0.05) correlation coefficients (r) are bolded.

In the studies concerning other crop plants, for example soybean cultivars (LORENC-KOZIK et al. 2011) and milk thistle (SADOWSKA et al. 2011), researchers revealed the impact of weather conditions on the content of macro- and microelements in seeds. SADOWSKA et al. (2011) even stated that weather conditions demonstrated a greater effect on the chemical composition of seeds than agrotechnological conditions did.

CONCLUSIONS

1. The content of the macro- and microelements in the flax seeds was dependent on the cultivar, and the weather conditions in the subsequent years of observations.

2. The concentration of magnesium in the seeds of the cultivars was higher than the content observed in earlier studies on other flax cultivars. The seeds of the Alba cultivar, representing the fibre type, had the highest content of all the elements measured in our study.

3. None of the four types of cultivars was distinguished by a particularly high content of minerals in seeds. The seeds of the flax cultivars of all the types used in our study may be used as sources of valuable macro- and microelements.

4. The concentration of some minerals in the seeds of different flax cultivars was significantly correlated with the weather conditions during the research period. The content of four elements (Na, Mg, Cu, Fe) was negatively correlated with temperature, whereas the content of potassium was positively correlated with this factor. The concentration of three elements (K, Na, Fe) was negatively correlated with rainfall, whereas the concentration of manganese was positively correlated with this weather element. Neither the concentration of calcium nor that of zinc was correlated with the weather conditions.

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