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MINERAL COMPOSITION OF TREE NUTS AND SEEDS

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Abstract

A growing interest has been observed globally over the last decade in nuts and seeds as significant ingredients of everyday diet. The consumption of nuts and seeds has been on the increase. A daily intake of 1 ounce (~ 28 g) of nuts and seeds has been suggested as part of a balanced diet. Many investigations have confirmed that lipids of nuts and seeds exert a positive impact on the cardiovascular system, are beneficial to the blood glucose level, and may contribute to prevention of some types of cancer. The aim of this study was to determine content of selected macro- and micronutrients as well as toxic trace elements in nuts and seeds. The concentrations of Na, K and Ca were determined with the atomic emission spectrometry method (FEAS), while those of Mg, Fe and Zn were measured with the method of atomic absorption spectrometry (FAAS). The levels of lead, cadmium and arsenic were determined with the method of graphite furnace atomic absorption spectrometry (GF-AAS). The highest content of magnesium was determined in Brazilian nuts, zinc in pumpkin seeds and iron in cashew nuts. Raw nuts and seeds were characterized by a low content of sodium and a high content of potassium, which is especially beneficial to human health. Nuts and seeds originating from Ethiopia and Hungary had the lowest content of lead and cadmium but the highest content of arsenic, compared with products from other countries. The highest amounts of cadmium and lead were determined in macadamia nuts, whereas the lowest ones were in pumpkin seeds. The content of arsenic was low and did not depend on a species. However, the content of toxic trace elements was correlated with the fat and protein content.

Keywords: nuts, seeds, minerals, cadmium, lead, arsenic.

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INTRODUCTION

A growing interest has been observed globally over the last decade in nuts and seeds as significant ingredients of everyday diet. According to the Healthy Eating Plate, developed in the Department of Nutrition at the Harvard School of Public Health in co-operation with Harvard Health Publications, nuts and seeds are placed next to legumes, fish and poultry as fine sources of plant protein with a fatty acid profile beneficial to human health (http://www.hsph.harvard.edu). Nuts are also recommended by USDA in ChooseMyPlate (https://www.choosemyplate.gov). One ounce of nuts and seeds corresponds to *ca* 1/3 daily protein demand for an adult man and 2/5 for a woman.

Many investigations have confirmed that lipids of nuts and seeds exert a positive impact on the cardiovascular system, have a beneficial influence on the blood glucose level, and reduce insulin demand in type 2 diabetes (Damavandi et al. 2013, Russell et al. 2016, Mazidi et al. 2018). Owing to their high energy value (150 - 200 kcal 28 g^{-1}), the consumption of nuts is recommended in place of a portion of red meat, poultry meet or hard cheese rather than as an extra snack. A daily intake of 1 ounce (~ 28 g) of nuts and seeds, corresponding to 80 g of red meat, poultry meat or fish, has been recommended as part of a balanced diet.

Nuts and seeds are dried products with a low water content. Owing to their evolutionary adaptation to the embryonic nutrition of the plants they originate from, they are rich in many nutrients. Individual species of nuts and seeds differ in chemical composition, mainly regarding the concentrations of proteins, carbohydrates and lipids, and in qualitative composition (Freitas 2012, Gama 2018). Nuts and seeds are characterized by a low content of saturated fatty acids (SFAs) and, simultaneously, high content of mono- and polyunsaturated fatty acids (MUFAs and PUFAs), including acids of the *n*-3 and *n*-6 families. They also contain high quantities of vitamin E and magnesium (Siriwardhana et al. 2012). Vitamin E protects the immune system by acting as one of the key antioxidants in the body. In turn, magnesium takes part in many vital processes. Investigations have shown that its deficiency may lead to arterial hypertension, diabetes, cardiac diseases and depression, whereas its low serum level may contribute to the development of the metabolic syndrome (Ros 2015). Nuts are also rich in dietary fiber implicated in reduction of postprandial glycemia (Gaetke et al. 2010, Casas-Agustench 2011).

Nuts and seeds are considered as important dietary sources of minerals because they accumulate these compounds during plant growth to be used for further development needs. The content of nutrients varies depending on a plant variety, agricultural practices, soil and climatic conditions, as well as the technological and culinary practices. Interest in these products is increasing worldwide mainly because of their fat and protein content but also because they are a good source of minerals. Nuts and seeds are products with a naturally low content of sodium and a high content of potassium. Clinical trials and metanalysis of their results suggest that a high intake of potassium is linked with blood pressure reduction in both patients with arterial hypertension and normal subjects. There is no explicit scientific evidence, however, that dietary supplementation with potassium reduces arterial pressure. Therefore, individuals not suffering from kidney dysfunctions are recommended to consume potassium-rich food products, e.g. fruit, vegetables and nuts, rather than dietary supplements containing this element (Ndanuko et al. 2017). Higher consumption of nuts and seeds has been associated with the reduction of a risk of colorectal and prostate cancer (Papanastasopoulos, Stebbing 2013).

The content of macronutrients and minerals in nuts and seeds is not the only determinant of its nutritional value. In view of increasing pollution of the natural environment, especially in developing countries which are producers of nuts and oil seeds, many elements detrimental to human health are likely to occur in these food products. Being plant products subjected to minimal technological processing (except for roasting, frying and blanching of some species), nuts and seeds may contain such elements as cadmium, lead and arsenic (both tree and ground nuts). The content of toxic elements in aerial and underground parts of plants depend on the extent of environment pollution.

Knowledge of the total content of essential nutrients as well as toxic substances is the information that enables one to identify beneficial effects or nutritional hazards for humans resulting from food consumption. Therefore, it is necessary to evaluate periodically the contamination of nuts and seeds so as to ensure there are no risks to public health.

The aim of this study was to determine the content of selected macro- and micronutrients and toxic trace elements in nuts and seeds of oil plants depending on their species and place of origin.

MATERIAL AND METHODS

The experimental material consisted of nuts (peanuts, hazel nuts, walnuts, pistachios, cashew nuts, Brazilian nuts, pine nuts and macadamia nuts) and seeds of oil plants: sunflower, pumpkin, sesame, poppy and flax. Nuts and seeds originated from three distributors, with one holding a bio-farm certi-ficate. As available, each variety of tested nuts and seeds from a given country was obtained. Before analyses, homogenate samples were prepared from at least three individual packs from each of the distributors. The homogenous bulk material was stored at a temp. of 2-6°C. Before analysis, two parallel replications from each sample were prepared. The content of nutrients and levels of toxic elements were determined in two replications.

Total proteins were determined by the Kjeldahl method (AOAC 1990). Total fat composition was determined gravimetrically after petroleum ether extraction, according to the Soxhlet procedure (AACC 2000).

The content of sodium, potassium and calcium was determined with the atomic emission spectrometry method (FEAS), whereas magnesium, iron and zinc were assayed with the method of atomic absorption spectrometry (FAAS), after dry ashing of samples at 450°C for 8 h. The levels of toxic elements, i.e. lead, cadmium and arsenic, were assayed with the method of graphite furnace atomic absorption spectrometry (GF-AAS). Analyses were conducted on a Varian AA240Z – GTA atomic absorption spectrometer.

To verify the repeatability of results and to evaluate the accuracy of the methods employed for determination of essential and toxic elements, element recovery was evaluated. To this end, 2 cm^3 of the standard with known concentration (for Na, K, Ca – 2.5 mg dm^{-3}, for Mg – 2.5 mg dm^{-3}, Fe – 5.0 mg dm^{-3} and Zn – 2.0 mg dm^{-3}; and for Pb – 0.03 mg dm^{-3}, Cd – 0.04 mg dm^{-3} and As – 0.001 mg dm^{-3}) was added to the samples (*ca* 4 g – in three replications). Due to the lack of reference material with a nut and seed matrix, CRM INCT-CF-3 - Corn Flour or Merck standard solutions for elements were used.

This allowed the following recovery of the elements: Na – 95.8%, K – 91.4%, Ca – 81.1%, Mg – 77.1%, Fe – 90.2%, Zn – 76.0%, Pb – 84.4%, Cd – 93.0%; and As – 84.0%. Recovery values achieved for all the elements were within the desired range (75-125%), which indicated good accuracy of the applied method.

Statistical analysis

The statistical analysis of the results was supported with Statistica vers.13.3 software. Normal distribution of results in groups (depending on origin and/or species) was checked with the Shapiro-Wilk test. Normal distribution was not determined for any values of determined the content of macro- and micronutrients and toxic trace elements in nuts and seeds. The Kruskal-Wallis test and median test were then used as non-parametric statistical tools. Due to the non-parametric distribution of results, they were presented as values of median (Me) and quartile deviation (Q).

In the analyzed nuts and seeds, the content of mineral components and toxic trace elements in correlation with the content of protein and fat was tested. Due to the lack of normal distribution, the Spearman's rank correlation was used. If there was no such correlation confirmed, the data obtained were subjected to logarithmic transformation, and regression was determined up to optimizing the R^2 coefficient.

RESULTS AND DISCUSSION

The content of macro- and micronutrients is presented in tables, including the division into the species of nuts and seeds; the levels of toxic trace elements are given in Table 1. The concentrations of toxic trace elements depending on the fat and protein content in nuts and seeds are shown in Figures 1-4.

Table 1

Content of arsenic, cadmium and lead in nuts and seeds

Sample		Content of Pb (mg kg^{-1})	Content of Cd (mg kg^{-1})	Content of As (mg kg^{-1})
		Me ± Q	Me ± Q	Me ± Q
Peanuts	*n*=9	0.131^{b} ± 0.011	0.063 ± 0.035	0.018 ± 0.001
Hazel nuts	*n*=9	0.149^{b} ± 0.004	0.094 ± 0.037	0.021 ± 0.003
Pistachios	*n*=9	0.118^{b} ± 0.021	0.036 ± 0.007	0.020 ± 0.000
Cashew nuts	*n*=9	0.135^{b} ± 0.003	0.047 ± 0.080	0.015 ± 0.004
Brazilian nuts	*n*=9	0.134^{b} ± 0.005	0.042 ± 0.014	0.021 ± 0.000
Macadamia nuts	*n*=9	0.267^{c} ± 0.086	0.224 ± 0.021	0.018 ± 0.000
Walnuts	*n*=9	0.150^{b} ± 0.017	0.024 ± 0.007	0.020 ± 0.001
Sunflower seeds	*n*=9	0.137^{b} ± 0.016	0.029 ± 0.003	0.026 ± 0.004
Pumpkin seeds	*n*=9	0.081^{a} ± 0.015	0.028 ± 0.007	0.018 ± 0.003
Sesame	*n*=9	0.116^{b} ± 0.006	0.076 ± 0.021	0.026 ± 0.006
Poppy	*n*=9	0.084^{a} ± 0.003	0.032 ± 0.000	0.034 ± 0.006
Flax	*n*=9	0.097^{ab} ± 0.009	0.032 ± 0.000	0.016 ± 0.000
Pine nuts	*n*=9	0.121^{b} ± 0.009	0.038 ± 0.002	0.024 ± 0.000

a,b,c – statistically homogeneous groups

Content of essential elements

The analyzed nuts and seeds had a low sodium content, but they were rich in magnesium and zinc.

In the analyzed products (except for pistachio nuts which were additionally salted), the content of sodium was low and ranged from 106 mg kg^{-1} in cashew nuts to 561 mg kg^{-1} in seeds of flax (Table 2). Raw nuts and seeds were characterized by a high content of potassium, which is particularly important in the prevention of hypertension. The highest content of potassium was determined in pumpkin seeds: 9310 mg kg^{-1} (Table 2). It was significantly higher than the lowest potassium content determined in macadamia nuts: 3550 mg kg^{-1}. Macadamia nuts also had the lowest content

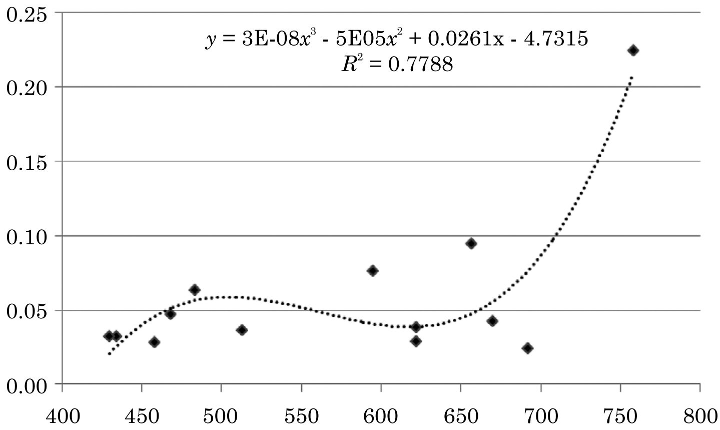

Fig. 1. Content of cadmium (mg kg^{-1}) dependent on fat (g kg^{-1})

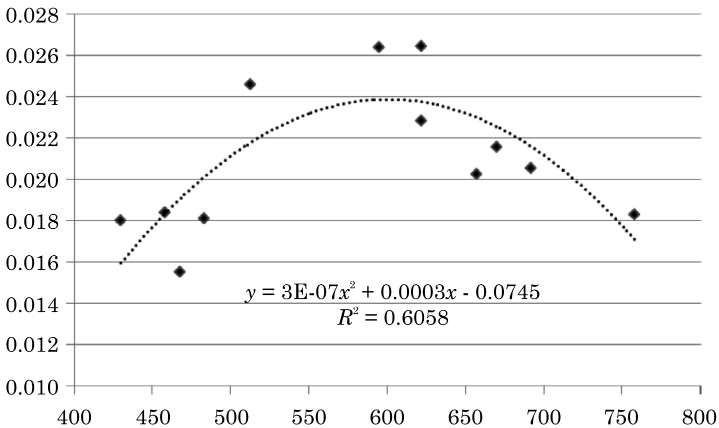

Fig. 2. Content of arsenic (mg kg^{-1}) dependent on fat (g kg^{-1})

of magnesium (532 mg kg^{-1}). This content was ten-fold lower than in Brazilian nuts (5307 mg kg^{-1}) – Table 2. A 28-gram portion of nuts provided from 10% to 99% of RDI for this element. Nuts, especially Brazilian ones, may therefore be a good source of this element in a human diet.

The content of potassium and magnesium was positively correlated with the protein content in the tested samples (Table 3). For potassium, this correlation was high and significant. This is particularly important for preventing hypertension. It has been found that the risk of hypertension does not correlate with global protein consumption, but it rises significantly with high animal protein consumption and decreases owing to the consumption of vegetable proteins. This effect may be strengthen by the potassium, magnesium and polyunsaturated fatty acid content of nuts. It has also been implicated that diets rich in potassium might be more effective in preventing hypertension than reduced salt intake (LELONG et al. 2017).

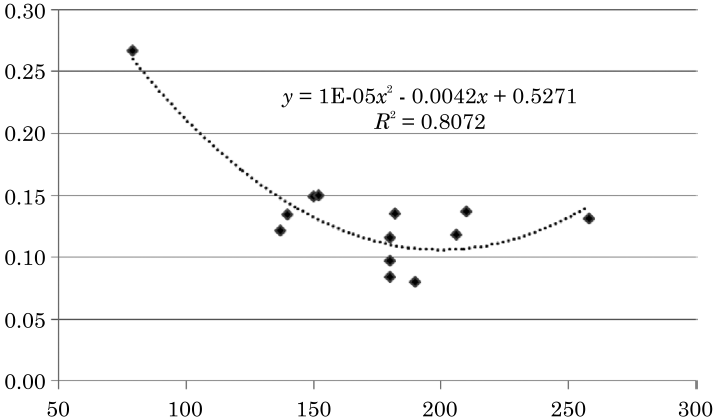

Fig. 3. Content of lead (mg kg^{-1}) dependent on protein (g kg^{-1})

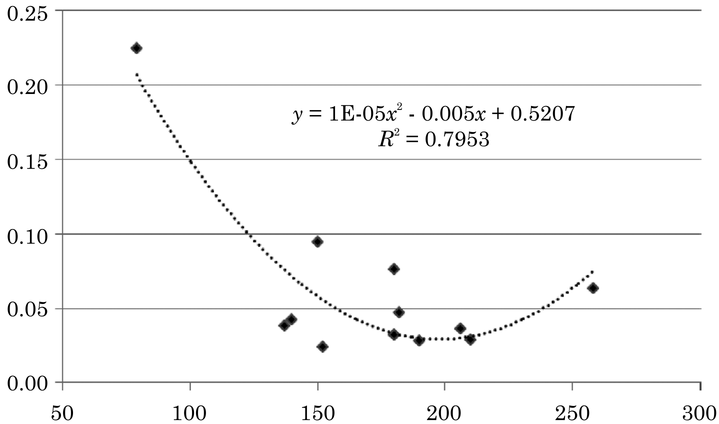

Fig. 4. Content of cadmium (mg kg^{-1}) dependent on protein (g kg^{-1})

The highest content of zinc was determined in pumpkin seeds: 91.2 mg kg^{-1}, being significantly higher than the lowest content determined macadamia nuts (Table 2). A 28-gram portion of pumpkin seeds covered 64% of RDI for this element for an adult person stipulated at 10 mg per day (Regulation of the European Parliament and Council (EU) no. 1169/2011). The nuts of macadamia contained 37.4 mg Zn kg^{-1}, which was *ca* 2.5-fold less than in pumpkin seeds, supplying 11% of RDI for this element.

Iron content in the analyzed species of nuts was diverse. The lowest content of this element was determined in peanuts, i.e. 12.7 mg kg^{-1}, and it was statistically significantly lower than in cashew nuts: 53.4 mg kg^{-1} (Table 2). Comparison of the results obtained in our study with the European Daily Reference Intakes (DRI) for Vitamins and Minerals for adults (Regulation of the European Parliament and of the Council (EU) no. 1169/2011), demon-

Table 2

Content of iron, zinc, sodium, potassium, magnesium and calcium in nuts and seeds

Sample	Fe (mg kg^{-1})	Zn (mg kg^{-1})	Na (mg kg^{-1})	K (mg kg^{-1})	Mg (mg kg^{-1})	Ca (mg kg^{-1})
	Me ± Q	Me ± Q	Me ± Q	Me ± Q	Me ± Q	Me ± Q
Peanuts	12.7* ± 0.7	65.2 ± 1.5	438^{a} ± 26	7406 ± 241	1284 ± 69	726^{ab} ± 34
Hazel nuts	20.9 ± 1.3	49.0 ± 2.0	262^{a} ± 133	7060 ± 313	807 ± 41	1327^{ab} ± 223
Pistachios	23.4 ± 0.1	46.2 ± 0.1	430^{b} ± 11	8396 ± 20	631^{x} ± 10	1140^{ab} ± 11
Cashew nuts	53.4* ± 4.8	76.2 ± 5.2	106^{a} ± 8.0	6473 ± 664	1755 ± 226	516^{ab} ± 80
Brazilian nuts	21.9 ± 2.7	61.6 ± 0.8	148^{a} ± 25	6066 ± 252	5307^{*x} ± 215	1887^{ab} ± 30
Macadamia nuts	15.6 ± 0.4	37.4* ± 0.4	314^{a} ± 28	3545* ± 188	$532^{*\#}$ ± 38	614^{ab} ± 14
Walnuts	19.2 ± 0.8	51.0 ± 0.7	172^{a} ± 49	6139 ± 838	874 ± 27	927^{ab} ± 98
Sunflower seeds	31.0 ± 14.9	78.2 ± 35.2	270^{a} ± 82	7819 ± 1269	2156 ± 127	901^{ab} ± 27
Pumpkin seeds	47.7 ± 21.5	91.2* ± 5.5	132^{a} ± 20	9315* ± 935	$2539^{\#}$ ± 260	501^{ab} ± 150
Sesame	36.4 ± 13.3	77.1 ± 15.9	183^{a} ± 70	6270 ± 534	2223 ± 429	655^{ab} ± 45
Poppy	45.2 ± 2.3	77.4 ± 4.1	538^{a} ± 45	6034 ± 1438	1836 ± 32	7222^{c} ± 1122
Flax	37.8 ± 10.8	77.2 ± 6.0	278^{a} ± 16	7281 ± 1839	2009 ± 262	2155^{ab} ± 39
Pine nuts	42.6 ± 2.55	79.7 ± 10.3	151^{a} ± 17	7684 ± 1601	1659 ± 109	286^{a} ± 12

a,*b*,*c* – statistically homogeneous groups
*# – statistically significant differences

strated that a daily portion of cashew nuts covered 11% of the recommended value of 14 mg Fe per day per portion (~28 g).

The content of calcium in particular species of nuts and seeds ranged from 286 mg kg^{-1} in pine nuts to 2155 mg kg^{-1} in seeds of flax. The highest calcium content was determined in poppy seeds, where it reached 7222 mg kg^{-1} (Table 2), thus being significantly higher than in the other nuts and seeds. A recommended 28-gram daily portion provided up to 63.2 % of RDI for calcium.

Nuts and seeds are mainly considered as a source of proteins and fats, but especially in vegetarian diets they are an important ingredient helping to achieve the targeted intake of macro- and micronutrients (Wien 2017).

A possible problem is the bioavailability of iron, zinc and calcium, lower than from animal products. Moreda-Piñeiro et al. (2016) found moderate dialyzability percentages (2.1-40.7% except Fe 0.70-3.7%) in nut and seed samples. In addition, the nut/seed food matrix influences mineral bioavailability. High bioavailability ratios were found in products with high carbohy-

Table 3

Content of mineral components and toxic trace elements related with the content of protein and fat

Trace element	Spearman's rank correlation $p < 0.05^*$	
	protein	fat
Iron	0.149	**-0.657***
Zinc	0.271	**-0.558***
Sodium	0.077	-0.105
Potassium	**0.613***	-0.371
Magnesium	0.182	-0.352
Calcium	0.000	-0.138
Lead	-0.354	**0.820***
Cadmium	-0.332	0.306
Arsenic	0.011	0.135

drate content. A good negative correlation was assessed between metal bioavailability percentages and the fat content of nuts and seeds. These results coincide with ours. Significant, good correlation with the fat content was found for iron (-0.657) and zinc (-0.558) (Table 3). The protein content was linearly related only with potassium in nuts and seeds (Table 3).

Content of toxic elements

Determinations of the content of lead, cadmium and arsenic in the investigated species of nuts and seeds are specified in Table 1.

The contamination of all analyzed nuts and seeds with lead was low. The highest lead content was determined in macadamia nuts and was significantly different form its levels in the other products (Table 1). The lowest lead content, such as 0.081 mg kg^{-1}, was determined in pumpkin seeds. Among seeds, the highest contamination with lead – at 0.137 mg kg^{-1} – was noted in sunflower seeds. Among the tested nuts, the highest content of this element occurred in macadamia nuts and reached 0.267 mg kg^{-1} (Table 1). The analyses showed a low intake of lead from low consumption of nuts and seeds. The consumption of no more 28 g per day of nuts caused a low lead intake, which for most of the species of nuts and seeds did not exceed 30% PTWI, 10% BMDL01 for adults (cardiovascular disorders), or 20% BMDL10 for adults (nephrotoxicity).

Table 1 shows the content of cadmium in particular species of nuts and seeds. The highest cadmium content – at 0.224 mg kg^{-1} – was assayed in macadamia nuts, and this value was almost 2.5-fold higher than in hazel nuts as well as being 24-fold higher than in sunflower seeds, which were characterized by the lowest contamination with this element.

The analyzed products originating from Australia and Poland contained more cadmium than the nuts and seeds from the other countries. In the products exported from the other countries, the contamination with cadmium was low and did not differ significantly between species. The lowest cadmium level (0.02 mg kg^{-1}) was reported in the products from Ethiopia and Hungary.

The level of cadmium in the analyzed seeds was low, with the highest value noted in poppy seeds (0.036 mg kg^{-1}). The differences in cadmium determined in seeds of various oil plants were probably linked to the cultivation conditions as well as the local pollution of soil, air and water. For inhabitants of areas highly contaminated with cadmium and consuming locally grown nuts and seeds (the most susceptible groups include children and vegetarians), the intake of cadmium is several times higher than in the case of persons inhabiting areas with lesser exposure to this element (RIETRA et al. 2017).

The content of arsenic in particular species of nuts and seeds is shown in Table 1. Contamination of individual species of nuts and seeds with arsenic was low and did not differ significantly between the species. The highest arsenic content at 0.034 mg kg^{-1} was determined in poppy seeds, whereas the lowest one – at 0.015 mg kg^{-1} – in cashew nuts.

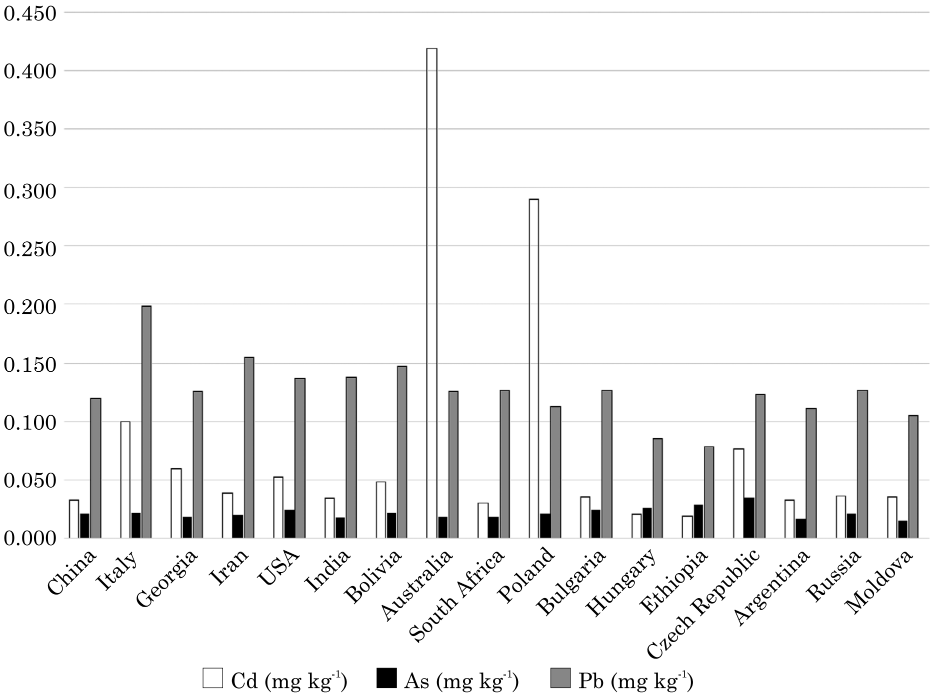

Fig. 5. Content of cadmium, lead and arsenic depending on the country of origin

Products originating from the Czech Republic and Ethiopia proved to be the most contaminated with arsenic (0.034 mg kg^{-1} and 0.029 mg kg^{-1}, respectively). In contrast, the lowest arsenic levels were demonstrated in products from Moldavia (0.015 mg kg^{-1}), Argentina and India (0.017 mg kg^{-1}).

The content of lead was positively correlated with the fat content. The Spearman's rank correlation was statistically significant (Table 3). If there was no statistically significant dependence according to the Spearman's rank correlation, the data were subjected to logarithmic transformation, and regression was determined up to optimizing the R^2 coefficient.

It was found that the content of lead and cadmium depended on the protein according to the course of the quadratic function. The minimum of this function was determined at 19.1% in both cases (Figures 4-5). Up to this value, the content of lead and cadmium decreased with an increasing protein content. The determination coefficient for this model was $R^2 \sim 0.8$. Relationships between fat and toxic trace elements were linear for lead, quadratic for arsenic and third degree polynomial for cadmium. It was found that when the fat content in the examined seeds and nuts exceeded 60%, the cadmium content increased, while the arsenic content decreased.

CONCLUSIONS

1. The analyzed nuts and seeds may be significant sources of magnesium, zinc and iron in a diet. The highest content of magnesium was determined in Brazilian nuts, zinc in pumpkin seeds and iron in cashew nuts.

2. Content of toxic trace elements in analyzed nuts and seeds depended on the fat and protein content.

3. Nuts and seeds originating from Ethiopia and Hungary were characterized by the lowest content of lead and cadmium and the highest content of arsenic, compared with products from other countries.

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