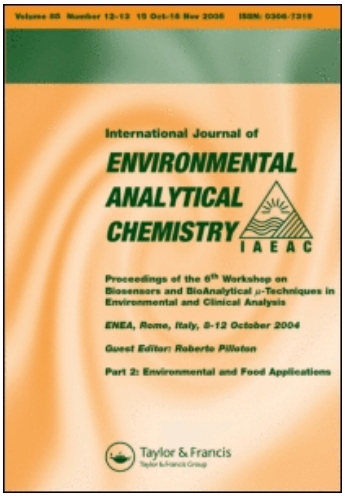

International Journal of Environmental Analytical Chemistry
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713640455

Inorganic micronutrients in food products of plant origin used for breakfast in Poland

Anna Leśniewicz[a]; Mariola Kretowicz[a]; Kamila Wierzbicka[a]; Wiesław Żyrnicki[a]
[a] Analytical Chemistry Division, Faculty of Chemistry, Wrocław University of Technology, 50-370 Wrocław, Poland

Online publication date: 22 September 2010

To cite this Article Leśniewicz, Anna , Kretowicz, Mariola , Wierzbicka, Kamila and Żyrnicki, Wiesław(2009) 'Inorganic micronutrients in food products of plant origin used for breakfast in Poland', International Journal of Environmental Analytical Chemistry, 89: 8, 621 — 634
To link to this Article: DOI: 10.1080/03067310902962494
URL: http://dx.doi.org/10.1080/03067310902962494

Intern. J. Environ. Anal. Chem.
Vol. 89, Nos. 8–12, 15 July–15 October 2009, 621–634

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Inorganic micronutrients in food products of plant origin used for breakfast in Poland

Anna Leśniewicz*, Mariola Kretowicz, Kamila Wierzbicka and Wiesław Żyrnicki

Analytical Chemistry Division, Faculty of Chemistry, Wrocław University of Technology, Wybrzeże Wyspiańskiego 27, 50-370 Wrocław, Poland

(*Received 18 July 2008; final version received 31 March 2009*)

The mineral compositions and nutritional properties of 22 breakfast cereals available at the local market in the Wroclaw agglomeration were studied. Products of popular brands widely distributed to the international market were selected for the investigation. The total concentrations of micronutrients were measured using the ICP-OES method in samples mineralised in a microwave system. The macroelement contents ranged from 0.02 to 4.60, 0.07 to 0.82 and 0.22 to 1.81 mg g^{-1} for Ca, Mg, and P, respectively. The contents of the Ba, Cd, Cr, Cu, Fe, Mn, Ni, Pb, Sr, Ti, V and Zn were found to be 0.08 to 1.73, 0.07 to 0.38, 0.12 to 0.24, 0.10 to 3.67, 1.67 to 167, 0.34 to 15.8, 0.19 to 2.30, 1.10 to 2.02, 0.03 to 4.01, 0.03 to 0.38, 0.05 to 7.28 and 0.21 to 14.4 μg g^{-1}, respectively. The mineral contents in breakfast cereals based on wheat, rice, oats and barley, multigrain cereals and ready-to-eat breakfast cereals with taste additives were higher than in corn-based breakfast cereals, with the Ca, Mg and P concentrations being 3/4, 1/2 and 1 times higher, respectively, on average. The contents of the essential minerals were compared to the human nutritional requirements and daily permissible doses. The results are discussed in terms of the utility of breakfast cereals as a source of indispensable minerals for proper human function.

Keywords: breakfast cereals; mineral composition; micronutrients; trace elements; ICP-OES

1. Introduction

Micronutrients (vitamins and minerals) are substances required by the human body in small but steady amounts for growth, normal physiological function, and survival. Micronutrients must be supplied by food or, in some cases, by dietary supplements since they cannot be synthesised by the body. According to the World Health Organization, more than two billion people in the world today suffer from micronutrient deficiencies caused mainly by vitamin and mineral dietary deficiencies [1]. The best way to prevent micronutrient malnutrition is to ensure the consumption of a balanced diet that is adequate in every nutrient. The majority of foods consumed by animals and humans is of plant origin. Breakfast cereals that are made of corn, wheat, rice, oats and barley play an important role in the diets of children and adolescents, not only at breakfast, but also as

*Corresponding author. Email: anna.lesniewicz@pwr.wroc.pl

ISSN 0306–7319 print/ISSN 1029–0397 online

DOI: 10.1080/03067310902962494
http://www.informaworld.com

snack foods eaten at other times of the day. In many countries, breakfast cereals are fortified with micronutrients. Therefore, quality control of ready-to-eat breakfast cereals is necessary to ensure both quality and safety.

Cereal-derived breakfast products are increasingly being consumed, and various studies comprising quality of ready-to-eat breakfast cereals, focused mainly on macronutrients concentration, have been undertaken all over the world. It has been reported that the consumption of breakfast cereals improves overall nutrition and reduces the risk of obesity [2]. Also, the influence of whole-grain cereal ingestion, and the subsequent increases in the intakes of soluble and insoluble fibre, vitamin B-6 and magnesium, on weight loss during weight-management programs has been examined [3]. The studies confirmed that high-fibre carbohydrate-rich breakfasts reduced daily energy consumption. The relationships between breakfast cereal ingestion, nutrient intake and Body Mass Index have also been examined for American children aged 4 to 12 [4] and girls between 9 and 19 years [5]. The high nutrient contents of the breakfast cereals allows for a substantial contribution to intakes of B vitamins, vitamin D and Fe for children aged 4 to 18 [6]. The association between the intake of products derived from cereals and non-milk extrinsic sugars was probed for its possible implications for caries in young British children (aged 1.5 to 4.5) [7]. The results showed that consumption of sweetened cereals was associated with non-milk extrinsic sugars intake; however, no relationship between breakfast cereal consumption and caries experience was observed. Total folate contents [8] and dietary antioxidants [9] have also been a subject of the investigation of ready-to-eat breakfast cereals.

Phytate and the other inositol phosphate compounds concentrations were determined in breakfast cereals available in Beltsville (Meryland area) [10]. Additionally, calcium, zinc and magnesium concentrations in the examined cereals were determined. Wheat and oat cereals contained higher concentration of the inositol phosphate species. Ca, Zn and Mg contents were highest in whole-grain and bran cereals. Corn and rice cereals contained the lowest amounts of both inositol phosphates and elements. Among mineral micronutrients, Ca content and its intake was examined as a rule [10,11,12]. Also, the quantities of other essential macroelements, such as Na, K and Mg, were quantified [13]. Concentrations of some essential trace elements, such as Cr [14,15] and Zn [10], and their availabilities in selected breakfast cereals were determined. All of the publications referenced above explicitly indicate that breakfast cereal consumption had the effect of increasing of the daily intake of micronutrients. The presented results have also shown that the cereal grain used to make breakfast cereals had a considerable influence on the macro- and microelement contents. As a general trend, the highest mineral content was observed in wheat-based cereals and the lowest macroelement concentration was observed in corn-based cereals. The addition of honey, crushed nuts, cocoa or sugar to cereals generally caused an increase in element content. Although many nutrients have been determined in ready-to-eat breakfast cereals, hardly any studies have focused on mineral composition of such products [16].

The main objective of the present study was a broad and systematic investigation of the mineral compositions of ready-to-eat breakfast cereals, which are products of plant origin that contribute a number of nutrients to the human diet. Different breakfast cereals available on the Polish market were analysed to determine their contents of Ba, Ca, Cd, Cr, Cu, Fe, Mg, Mn, Ni, P, Pb, Sr, Ti, V and Zn. By comparison of experimentally determined element contents and Recommend Daily Intakes of the micronutrients, the nutritive values of the examined cereals were determined.

2. Experimental

2.1 *Samples*

Twenty-two popular brands of breakfast cereal that are widely distributed on the international market were purchased in a local market in the Wroclaw agglomeration and studied. For each brand of examined breakfast cereal, several samples from randomly selected packages were taken for analysis. Five parallel analyses were performed. A detailed description of the analysed products is presented in Table 1.

The Standard Reference Material – Corn Flour, INCT-CF-3 – was used for assessment of measurement accuracy and as a repeatability control for the analytical procedures used.

2.2 *Reagents, glassware and plastics*

All chemicals employed in this study were of analytical grade. For sample digestion, concentrated HNO_3 (Merck KGaA, Germany) and 30% (m/v) H_2O_2 (Polish Chemical

Table 1. Ready-to-eat breakfast cereals analysed here and their composition.

Brand name	Producer	Composition – main compounds
Corn flakes		
Corn flakes MLEKOŁAKI	Lubella S.A., Lublin, Poland	corn flour (91.7%), barley malt, fructose, glucose, salt, emulsifier
Płatki kukurydziane ECO +	Brüggen Polska Sp. z.o.o., Wilga, Poland	grits, sugar, salt, malt
Corn flakes Płatki kukurydziane	CENOS Sp. z.o.o., Września, Poland	corn grits, sugar, malt, salt, vegetable oil
Corn flakes Flips "Myrcha's"	K & D KADAR, Sładzew, Poland	corn (91%), sugar, salt, barley malt
Corn flakes "Funny Morning"	Brüggen Polska Sp. z.o.o., Wilga, Poland	broken corn (94%), sugar, salt, barley malt, emulsifier
Corn flakes OTMUCHÓW	Zakłady Przemysłu Cukierniczego "OTMUCHÓW" S.A., Otmuchów, Poland	corn grits (91%), sugar, salt, malt
Corn flakes Nestlé	Cereal Partners Poland Toruń–Pacific Sp. z o.o., Toruń, Poland	corn (97%), sugar, salt, glucose, barley malt, emulsifier
Płatki kukurydziane TESCO	PIFO EKO – STREFA Sp. z.o.o., Łódź, Poland	corn grits (92%), sugar, salt
Corn flakes Hanne	C. Halne Mühlenwerke GmbH & Co KG, Bad Oeynhaus, Germany	corn (91%), sugar, salt, barley malt
Płatki kukurydziane Corn flakes	POLGRUNT Sp. z.o.o., Kluki, Poland	corn grits (91%), sugar, salt, malt
Corn flakes Lidl	Manufactured for Lidl Stiftung & Co. KG, Neckarsulm, Germany	corn (94%), sugar, salt, barley malt, emulsifier

(*Continued*)

Table 1. Continued.

Brand name	Producer	Composition – main compounds
Flavoured and multigrain flakes		
Fitness & Yoghurt	**Manufactured for NESTLÉ** Cereals Partners Poland, Toruń-Pacific Sp. z o.o.' Toruń, Poland	fitness flakes (77.5%): cereal grains – wheat (39.1%), rice, sugar, brown sugar syrup, emulsifier, acidity regulator, antioxidant fitness flakes in yoghurt (22.5%): fitness flakes, yoghurt coating glaze (66.8%), sugar, brown sugar syrup, powdered whey, low-fat powdered milk, powdered yoghurt (2%), emulsifier, antioxidant
Fitness		fitness flakes (97%): cereal grains – wheat (39.1%), rice, sugar, brown sugar syrup, emulsifier, acidity regulator, antioxidant
Gold Flakes		corn (62%), sugar, peanuts (7.6), glucose, honey (1.8%), salt, barley malt, emulsifier, acidity regulator
Kangus		wheat (57%), sugar, honey (6.1%), glucose syrup, palm oil
Cookie Crisp		flour (58.6%): wholemeal wheat (31.7%), corn, wheat, sugar, wheat starch, glucose syrup, palm oil, chocolate (1.57%), brown sugar, salt, raising agent, acidity regulator
Chocapic Duo		flour (52.9%): wholemeal wheat, wheat, rice, white chocolate (10.7%), cocoa (6.4%), glucose, barley malt, palm oil, emulsifier
Nesquik		flours (62.5%): wholemeal wheat, corn, rice, sugar, cocoa (5.6%), glucose, palm oil, salt, low-fat cocoa, acidity regulator
Cheerios Honey & Nut		wholemeal flours (62%): oat, barley, rice, wheat, corn, sugar, honey (4.1%), wheat starch, brown sugar syrup, grinded almonds, salt, palm oil, acidity regulator, emulsifier
Cheerios multigrain		wholemeal flours: oat (20.2%), barley (16.2%), rice (9.7%), wheat (10%), corn (21.7%), sugar, wheat starch, brown sugar syrup, salt, palm oil, acidity regulator, emulsifier

(*Continued*)

Table 1. Continued.

Brand name	Producer	Composition – main compounds
Cini Minis		wholemeal wheat flour (31%), rice flour, sugar, palm oil, corn starch, glucose, glucose syrup, maltodextrine, salt, cinnamon (0.5%), acidity regulator, emulsifier
Snow Flakes		corn (64%), sugar, salt, glucose, barley malt, acidity regulator, emulsifier

Reagents, Poland) were used. Aqueous standard solutions were prepared by dilution of the ICP multi-element standards (Merck KGaA, Germany). All dissolutions and dilutions were performed with water with a specific resistance of 18.3 $M\Omega cm^{-1}$ (EASYpure™ system, Barnstead, Thermolyne Corporation, USA).

Glassware, plastic test-tubes and bottles were washed with distilled water, cleaned with diluted nitric acid in an ultrasonic bath and finally rinsed several times with deionised water.

2.3 *Microwave assisted-acid digestion procedure*

Approximately 0.5 g of powdered material was weighted directly into PTFE bombs, followed by addition of 6 ml of concentrated nitric acid and 1 ml hydrogen peroxide. Similar procedures for mineralisation were reported for the quantification of minerals in Australian and Brazilian breakfast cereals [16,17]. The samples (five parallel samples) were subjected to microwave heating (microwave digestion system, Milestone, MLS-1200, MEGA) with a maximum power of 650 W for 20 minutes. After cooling, the acid digests obtained, i.e. completely clear and colourless solutions, were made up to 25 ml with the deionised water and stored in polyethylene vials at 4°C. Before analysis, all of the solutions were filtered through hard filter paper.

With each set of digests, a blank sample was prepared through the complete procedure, analysed and then used for correction of analytical signals. Analysis of Standard Reference Material, performed for evaluation of measurement accuracy and validation of the procedure from digestion to data evaluation, was done separately.

2.4 *Measurement of element content*

The element concentrations (Ba, Ca, Cd, Cr, Cu, Fe, Mg, Mn, Ni, P, Pb, Sr, Ti, V and Zn) in the digests were measured by atomic emission spectrometry with inductively coupled argon plasma as the excitation source. A Jobin-Yvon 38S spectrometer was equipped with a cross-flow nebuliser and Scott-type spray chamber. The instrument operating parameters and analytical line wavelengths used here are shown in Table 2.

Table 2. Instrumental and operating conditions for ICP-OES.

Discharge parameters			
Forward power			1000 W
Frequency			27.3 MHz
Plasma gas flow rate			13 L min^{-1}
Sheath gas flow rate			0.2 L min^{-1}
Nebuliser gas flow rate			0.3 L min^{-1}
Sample uptake			1.0 mL min^{-1}
Monochromator			
Gratings			1m Czerny-Turner
Slit width (entrance/exit)			type: HR 1000
Photomultiplier			4320 and 2400 grooves mm^{-1}
Plasma observation zone:			20 μm/50^{-1} μm R 955 radial, 12 mm above load coil
Analytical lines (wavelengths in nm)			
Ba	233.527	Mn	259.373
Ca	317.933	Ni	221.647
Cd	226.502	P	213.618
Co	228.616	P	214.914
Cr	267.716	Pb	220.353
Cu	324.754	Sr	407.771
Fe	259.940	Ti	334.941
Mg	280.270	V	292.402
Mg	285.213	Zn	202.548

3. Results and discussion

Analysis of the Standard Reference Material (Corn Flour, INCT-CF-3) was performed for validation of the applied analytical procedure. The concentrations of elements were measured in samples mineralised by a mixture of nitric acid and hydrogen peroxide according to the method applied for the samples of breakfast cereals [16,17]. The results of the analysis are shown in the Table 3. The determined total concentrations of the elements analysed in the breakfast cereals were compared to the certified values and showed a very good agreement for the majority of elements, thereby indicating good accuracy and high precision for the experimental results.

The best agreement between determined and certified concentration values was observed for Mg, where the recovery was 99.6%. Very high accuracies were also observed for Ba, Ca, Fe, Ni, P and Zn, with our results differing from the certified values by only a few percent (91, 98, 92, 95, 91 and 91% recovery for the elements, respectively). For elements such as Cr, Mn, Sr and Ti, the agreements were also satisfactory if one takes into account standard deviation uncertainties of the measurements. A relatively high disagreement between the experimentally measured and certified element contents was observed for Cu.

The precision of the SRM measurements was determined by analysis of five parallel samples in two runs, and for the most of the elements the relative standard deviations were found to be lower than 5%. In cases of elements appearing at very low levels, e.g. Ba, Cr, Cu and Ni, the RSD values exceeded 10%. The results achieved for the Standard Reference Material indicate that the use of the nitric acid and hydrogen peroxide mixture

Table 3. Experimental and certified element concentrations – Corn flour (INCT-CF-3) Reference Material analysis.

Element	Certified value [$\mu g\,g^{-1}$]	Experimental data ($n = 10$) [$\mu g\,g^{-1}$]
Ba	0.117[1]	0.18 ± 0.05
Ca	40[1]	39.2 ± 1.5
Cd	0.007[1]	<0.09
Cr	0.137[1]	0.12 ± 0.04
Cu	1.63 ± 0.13	1.1 ± 0.1
Fe	32.0 ± 1.4	29.4 ± 0.4
Mg	1066 ± 37	1062 ± 31
Mn	4.96 ± 0.22	4.40 ± 0.14
Ni	0.383 ± 0.039	0.36 ± 0.16
P	2831 ± 97	2576 ± 34
Pb	0.052[1]	<0.45
Sr	0.103[1]	0.09 ± 0.01
Ti	0.40[1]	0.30 ± 0.01
V	–	0.02 ± 0.01
Zn	20.09 ± 0.76	18.3 ± 0.2

[1] – information value (according to certificate).

and microwave energy for breakfast cereal mineralisation is appropriate and allows for correct determination of element concentrations, especially for macroelements such as Ca, Fe, Mg, Mn, P and Zn.

Total concentrations of the elements determined in corn flakes manufactured for a domestic market by different producers were calculated as arithmetic means and with the associated standard deviations shown in Table 4. In Table 5, the results of element determinations in multigrain breakfast cereals produced by Nestlé Corporation are given.

Generally, all of the examined corn flakes contained less micronutrients than multigrain breakfast cereals enriched with different taste additives. A similar tendency was observed by Villanueva, Maquina, de Diego, Abellán (2000) and Booth, Reilly, Framakalidis (1996), who reported that the lowest mineral concentrations were measured in corn flakes. Among the studied corn flakes, Mlekołaki produced by Lubella S.A. and Corn flakes Hanne contained the greatest amounts of all micronutrients. The lowest micronutrient concentrations were found in ECO+, Funny Morning and Corn flakes Otmuchów breakfast cereals. Comparison of the micronutrient contents determined in the examined multigrain and flavoured breakfast cereals manufactured by Nestlé Corporation revealed that the Chocapic Duo and Nesquik brands are nutrient-rich. The lowest macro- and microelement levels were observed in Snow flakes (sweetened corn flakes) and Gold flakes (corn flakes with added honey and peanuts).

As it can be seen in Tables 4 and 5, concentrations of elements considered to be macronutrients (i.e., Ca, Mg, and P) were observed in the highest concentrations among the analysed nutrients. The highest Ca content was found in Mlekołaki Corn flakes and in Nestlé Fitness cereals. Mlekołaki corn flakes also had the highest Mg and P concentrations. Among multigrain and flavoured breakfast cereals, the Chocapic Dou brand was distinguished by very high Fe and Mg concentrations, whereas the P amount in Cookie Crisp was the highest.

Table 4. Content of the macro- and microelements in the analysed corn flakes manufactured by different producers – mean value ± standard deviation [$\mu g\, g^{-1}$].

Element \ Brand	Mlekołaki	ECO+	Corn flakes CENOS	Myrcha's Filips	Funny Morning	Corn flakes Otmuchów	Corn flakes Nestlé	Płatki kukurydziane Tesco	Corn flakes Hanne	Corn flakes POLGRUNT	Corn flakes Lidl
Ba	0.34 ± 0.14	$<1.0 \times 10^{-4}$	0.08 ± 0.03	0.12 ± 0.03	$<1.0 \times 10^{-4}$	0.08 ± 0.03	$<1.0 \times 10^{-4}$	$<1.0 \times 10^{-4}$	$< 1.0{\cdot}10^{-4}$	$<1.0{\cdot}10^{-4}$	$<1.0{\cdot}10^{-4}$
Ca	1061 ± 33	24.7 ± 2.8	43.4 ± 6.5	30.2 ± 5.1	24.9 ± 5.3	21.8 ± 1.5	30.5 ± 2.7	36.8 ± 6.9	54.7 ± 3.1	47.4 ± 9.9	48.8 ± 4.2
Cd	$<1.8 \times 10^{-4}$	$<1.8 \times 10^{-4}$	0.20 ± 0.07	$<1.8 \times 10^{-4}$	0.14 ± 0.01	$<1.8 \times 10^{-4}$	0.40 ± 0.09	$<1.8 \times 10^{-4}$	0.33 ± 0.08	0.29 ± 0.03	0.34 ± 0.08
Cr	0.23 ± 0.06	$<5.0 \times 10^{-5}$	$<5.0 \times 10^{-5}$	0.14 ± 0.03	0.12 ± 0.03	0.13 ± 0.09	0.24 ± 0.04	$<5.0 \times 10^{-5}$	$<5.0{\cdot}10^{-5}$	$<5.0{\cdot}10^{-5}$	$<5.0{\cdot}10^{-5}$
Cu	0.20 ± 0.06	$<1.5 \times 10^{-4}$	0.33 ± 0.06	0.27 ± 0.08	0.27 ± 0.03	0.73 ± 0.1	0.30 ± 0.06	0.16 ± 0.04	0.32 ± 0.10	0.10 ± 0.01	0.89 ± 0.04
Fe	39.8 ± 4.6	1.67 ± 0.07	5.92 ± 0.82	6.44 ± 0.42	2.21 ± 0.39	2.97 ± 0.22	165 ± 5	6.10 ± 0.16	10.9 ± 0.8	9.56 ± 0.46	72.9 ± 2.2
Mg	466 ± 12	112 ± 8	202 ± 9	237 ± 8	116 ± 9	154 ± 4	73.9 ± 4	169 ± 4	363 ± 12	169 ± 4	106 ± 2
Mn	1.87 ± 0.06	0.34 ± 0.01	0.92 ± 0.03	1.00 ± 0.04	0.44 ± 0.04	0.78 ± 0.01	0.36 ± 0.07	0.87 ± 0.09	1.57 ± 0.08	0.96 ± 0.04	0.71 ± 0.08
Ni	$<8.6 \times 10^{-4}$	$<8.6 \times 10^{-4}$	$<8.6 \times 10^{-4}$	0.28 ± 0.13	$<8.6 \times 10^{-4}$	1.13 ± 0.52	0.74 ± 0.28	1.05 ± 0.50	$< 8.6{\cdot}10^{-4}$	2.30 ± 0.28	$<8.6{\cdot}10^{-4}$
P	1419 ± 26	519 ± 16	717 ± 36	807 ± 38	453 ± 12	642 ± 24	341 ± 17	606 ± 28	1161 ± 62	605 ± 31	465 ± 27
Pb	1.92 ± 0.50	1.30 ± 0.02	<0.05	<0.05	<0.05	<0.05	2.02 ± 0.92	1.10 ± 0.09	< 0.05	<0.05	<0.05
Sr	0.70 ± 0.01	0.03 ± 0.01	0.20 ± 0.02	0.03 ± 0.01	0.05 ± 0.01	0.03 ± 0.01	1.72 ± 0.10	4.01 ± 0.12	0.13 ± 0.03	0.08 ± 0.02	0.07 ± 0.02
Ti	0.08 ± 0.01	<0.03	0.15 ± 0.06	0.38 ± 0.07	0.27 ± 0.05	0.10 ± 0.02	<0.03	0.23 ± 0.02	0.27 ± 0.03	0.08 ± 0.01	0.35 ± 0.01
V	<0.03	<0.03	<0.03	<0.03	<0.03	0.06 ± 0.01	<0.03	<0.03	< 0.03	0.05 ± 0.03	0.14 ± 0.06
Zn	6.95 ± 0.78	2.07 ± 0.21	3.63 ± 0.27	4.83 ± 0.41	2.03 ± 0.24	3.57 ± 0.29	0.44 ± 0.24	2.06 ± 0.53	9.26 ± 0.72	6.45 ± 0.60	0.76 ± 0.24

Table 5. Content of the macro- and microelements in the analysed breakfast cereals produced for Nestlé – mean value ± standard deviation [$\mu g\,g^{-1}$].

Element \ Brand	Fitness &Yoghurt	Nestlé Fitness	Gold flakes	Kangus	Cookie Crisp	Chocapic Duo	Nesquik	Cheerios Honey Nut	Cheerios multigrain	Cini Minis	Snow fakes
Ba	0.47 ± 0.06	0.20 ± 0.05	0.37 ± 0.02	0.85 ± 0.14	0.92 ± 0.06	1.73 ± 0.08	0.46 ± 0.09	0.23 ± 0.04	0.31 ± 0.06	0.35 ± 0.04	0.07 ± 0.02
Ca	4336 ± 108	4604 ± 91	50.7 ± 3.4	2462 ± 68	2559 ± 28	2657 ± 122	2731 ± 50	2259 ± 61	1481 ± 46	2980 ± 61	2763 ± 51
Cd	0.07 ± 0.02	$<1.8 \times 10^{-4}$	$<1.8 \times 10^{-4}$	$<1.8 \times 10^{-4}$	$<1.8 \times 10^{-4}$	$<1.8 \times 10^{-4}$	0.38 ± 0.08	0.11 ± 0.04	0.37 ± 0.04	$<1.8{\cdot}10^{-4}$	$<1.8{\cdot}10^{-4}$
Cr	$<5.0 \times 10^{-5}$	$<5.0 \times 10^{-5}$	$<5.0 \times 10^{-5}$	$<5.0 \times 10^{-5}$	$<5.0 \times 10^{-5}$	$<5.0 \times 10^{-5}$	0.18 ± 0.01	$<5.0 \times 10^{-5}$	$<5.0{\cdot}10^{-5}$	$<5.0{\cdot}10^{-5}$	$<5.0{\cdot}10^{-5}$
Cu	1.54 ± 0.07	1.86 ± 0.06	0.44 ± 0.01	1.88 ± 0.15	1.98 ± 0.12	3.67 ± 0.14	3.39 ± 0.09	0.95 ± 0.13	1.30 ± 0.29	0.87 ± 0.06	0.20 ± 0.05
Fe	93.2 ± 6.1	117 ± 5	117 ± 4	15.0 ± 0.9	110 ± 7	167 ± 4	123 ± 5	146 ± 1	102 ± 2	123 ± 2	118 ± 4
Mg	509 ± 17	534 ± 20	189 ± 4	467 ± 6	552 ± 12	818 ± 29	664 ± 13	559 ± 21	530 ± 12	256 ± 7	62.7 ± 1.1
Mn	14.3 ± 0.6	15.4 ± 0.2	2.02 ± 0.11	9.47 ± 0.27	11.5 ± 0.2	15.8 ± 0.4	12.5 ± 0.4	12.3 ± 0.4	11.4 ± 0.5	7.42 ± 0.24	1.20 ± 0.06
Ni	0.19 ± 0.06	$<8.6 \times 10^{-4}$	$<8.6 \times 10^{-4}$	$<8.6 \times 10^{-4}$	$<8.6 \times 10^{-4}$	1.46 ± 0.40	0.81 ± 0.04	0.94 ± 0.11	1.20 ± 0.42	$<8.6{\cdot}10^{-4}$	$<8.6\ 10^{-4}$
P	1651 ± 68	1761 ± 133	407 ± 45	1172 ± 86	1810 ± 87	1700 ± 116	1330 ± 75	1680 ± 53	1320 ± 74	919 ± 40	219 ± 44
Pb	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	1.53 ± 0.25
Sr	1.40 ± 0.07	1.36 ± 0.05	0.44 ± 0.03	1.06 ± 0.06	1.85 ± 0.05	1.94 ± 0.08	1.65 ± 0.05	1.04 ± 0.04	0.90 ± 0.03	0.82 ± 0.02	0.42 ± 0.08
Ti	<0.03	0.03 ± 0.02	<0.03	<0.03	0.20 ± 0.04	<0.03	0.18 ± 0.03	<0.03	<0.03	<0.03	<0.03
V	<0.03	<0.03	2.24 ± 0.57	3.05 ± 0.21	3.75 ± 0.26	<0.03	7.28 ± 0.48	<0.03	2.38 ± 0.29	<0.03	<0.03
Zn	10.7 ± 0.6	14.4 ± 1.1	2.39 ± 0.35	10.2 ± 0.3	7.98 ± 0.45	13.2 ± 0.7	10.7 ± 0.4	10.3 ± 0.4	10.2 ± 0.3	7.72 ± 0.28	0.21 ± 0.03

Exceptionally high Ca and Fe contents in some of the analysed brands of breakfast cereals are a consequence of foodstuff fortification with macroelements. The cereals with the lowest contents of macroelements were: for Ca – Corn flakes Otmuchów and Gold flakes (containing corn flour, peanuts and honey); for Fe – ECO + corn flakes and Kangus (produced from wheat); for Mg – Corn flakes Nestlé and Snow flakes; for P – Corn flakes Otmuchów and Gold flakes. The results measured for macronutrients are in accordance with those published by Villanueva, Maquina, Diego, Abellán (2000), who determined that the Ca, Mg and P contents of Spanish breakfast cereals ranged from 150–2476, 75–670 and 149–3258 $\mu g\,g^{-1}$, respectively.

Concentrations of essential trace elements such as Cr, Cu, Fe, Mn, V and Zn differed considerably depending on the kind of breakfast cereal as well as on the element. Generally, iron was observed in the highest concentration, probably due to flake enrichment. The highest concentration of Fe was observed in Nestlé Corn flakes and in Chocapic Duo, which are flakes made of wheat and rice flour with added chocolate. The Zn concentration, nearly two orders of magnitude lower than the iron concentration, varied from 0.44 $\mu g\,g^{-1}$ (Corn flakes Nestlé) to 9.26 $\mu g\,g^{-1}$ (Corn flakes Hanne) in corn flakes and from 0.24 $\mu g\,g^{-1}$ (Snow flakes) to 14.8 $\mu g\,g^{-1}$ (Nestlé Fitness) in multigrain cereals. The manganese concentration reached 1.87 $\mu g\,g^{-1}$ in Mlekołaki corn flakes and 15.8 $\mu g\,g^{-1}$ in Chocapic Duo cereals. The lowest Cu content was observed for Corn flakes Lidl (0.89 $\mu g\,g^{-1}$), whereas Chocapic Duo and Nesquik breakfast cereals had Cu contents of 3.67 and 3.39 $\mu g\,g^{-1}$, respectively. The Cr and V contents were below or close to their detection limit levels. Similar trace element contents in Australian ready-to-eat breakfast cereals were reported by Booth, Reilly, Framakalidis (1996), who found Cu, Fe, Mn and Zn concentration ranging from 0.51–9.52, 49.5–290, 1.24–115 and 2.19–43 $\mu g\,g^{-1}$, respectively.

Concentrations of Ba and Ti in corn flakes ranged from 0.34 $\mu g\,g^{-1}$ (Mlekołaki corn flakes) to 0.38 $\mu g\,g^{-1}$ (Myrcha's Filips corn flakes) to 1.73 $\mu g\,g^{-1}$ (Chocapic Duo) and 0.20 $\mu g\,g^{-1}$ (Cookie Crisp) for multigrain cereals produced by Nestlé Corporation. The contents of hazardous or toxic elements such as Cd, Ni and Pb did not reach dangerous levels, but their mere presence in foodstuffs is alarming.

The determined Sr concentrations varied from 0.03 $\mu g\,g^{-1}$ (ECO +; Myrcha's Filips; Corn flakes Otmuchów) to 4.01 $\mu g\,g^{-1}$ (Płatki kukurydziane Tesco) in cereals made of corn, and from 0.42 $\mu g\,g^{-1}$ (Snow flakes) to 1.85 $\mu g\,g^{-1}$ in Chocapic Duo flavoured Nestlé flakes.

The micronutrient contents measured in all of the examined breakfast cereals were compared with the Recommended Daily Intakes established by the Polish National Food and Nutrition Institute (see Table 6). Reference values for micronutrient intake by adults acquired from the literature are also shown. As can be deduced from the submitted data (Recommended Dietary Allowances, Adequate Daily Dietary Intake, Tolerable Upper Intake Level and Maximum level of daily intake without detriment to health), the concentrations of all of the determined elements were within safety baseline levels for human consumption. These results indicate that the analysed breakfast cereals are a meaningful source of dietary micronutrients. It is clear that the examined corn and multigrain flakes should be considered as trace element supplements. Breakfast cereals are strongly recommended as a healthy and nutritious food for children due to the required micronutrient doses required for child health. Regular verification of the quality of these products is also indispensable due to the possibility of element accumulation and the subsequent harmful effects if the toxicity limits are exceeded.

Table 6. Dietary value of analysed breakfast cereals estimated here compared to recommended values.

	Reference data for adults acquired from literature				
Element	Recommended daily intake [mg day^{-1}] [18,19]	*Recommended Dietary Allowances*/ Adequate daily dietary intake [mg day^{-1}] [19–21]	Tolerable Upper intake level [mg day^{-1}] [19,20]	Maximum level of daily intake without detriment to health [mg] [22]	Intake calculated for this study min-max [μg/30^{-1} g]; [1] – [mg/30^{-1} g]
Ba				16	(*Snow flakes*) **2.06 ÷ 51.9** (*Chocapic Duo*)
Ca	800–1200	1000–1200	2500		(*Corn flakes, OTMUCHÓW*) **0.65 ÷ 138** [1] (*Nestlé Fitness*)
Cd		3.5×10^{-5}		0.018–0.20	(*Fitness & Yoghurt*) **2.10 ÷ 12.0** (*Corn flakes, Nestlé*)
Cr		0.025–0.035	0.050–0.200	0.06	(*ECO +*) **3.60 ÷ 7.20** (*Corn flakes, Nestlé*)
Cu	1.5–2.5	1.5–3.0	8–10	3.2	(*ECO +*) **3.00 ÷ 110** (*Chocapic Duo*)
Fe	11–26	*12–30*	45	15	(*ECO +*) **0.05 ÷ 5.01** [1] (*Chocapic Duo*)
Mg	270–400	*240–400*	350	500	(*Snow flakes*) **1.88 ÷ 24.4** [1] (*Chocapic Duo*)
Mn	1.5–2.6	2.0–5.0	11	5	(*ECO +*) **10.2 ÷ 474** (*Chocapic Duo*)
Ni		1.0×10^{-4}	1.0	0.45	(*Fitness & Yoghurt*) **5.66 ÷ 69.0** (*Corn flakes, POLGRUNT*)
P	650–1200		4000		(*Snow flakes*) **6.57 ÷ 54.3** [1] (*Cookie Crisp*)
Pb		1.0×10^{-4}	0.25	0.3	(*Corn flakes,CENOS*) **33.0 ÷ 60.6** (*"Corn flakes" Nestlé*)
Sr				2	(*ECO +*) **0.90 ÷ 120** (*Platki kukurydziane, Tesco*)
Ti				0.3	(*Nestlé fitness*) **0.81 ÷ 11.4** (*Myrcha's Flips*)
V		1.0×10^{-4}	1.8	2.5	(*Mlekołaki*) **1.50 ÷ 218** (*Nesquik*)
Zn	10–21	*15–19*	34	17	(*Snow flakes*) **6.29 ÷ 432** (*Nestlé Fitness*)

Recommended dietary allowances: These are set to meet the needs of almost all (97 to 98%) individuals in a group.
Adequate daily dietary intake: This is believed to cover the needs of all individuals in a group, but a lack of data prevented being able to specify with confidence the percentage of individuals covered by this intake.
Tolerable upper intake level: The maximum level of daily nutrient intake that is likely pose no risk of adverse effect.

As can be seen from Table 6, the daily intakes of the micronutrients examined here did not exceed 10% of the recommended daily doses if a typical breakfast portion of cereals (30 g) was consumed. For some of the analysed brands, for example Nesquic, Snow flakes, Cini Minis, Fitness & Yoghurt and Nestlé Fitness, the maximal daily Ca intake was higher than 10% and could even reach 20%. Consumption of Mlekołaki Corn flakes provides over 10% of the Fe recommended daily dose. Over 20% and even 30% of Fe daily needs could be satisfied with ingestion of Corn flakes Lidl, Fitness & Yoghurt, Cheerios multigrain, Cookie Crisp, Nestlé Fitness, Gold flakes, Nesquik, Cheerios Honey Nut, Cini Minis and Snow flakes. The iron dosage could even increase to 45% of the recommended daily dose by eating Corn flakes, Nestlé and Chocapic Duo for breakfast. Over 10% of the daily human needs for phosphorus can be attained by eating Kangus and Cini Minis. The supplied P rises to over 20% (from 23 to 32%) after having Cheerios multigrain, Cookie Crisp, Nesquik, Cheerios Honey Nut, Fitness & Yoghurt, Nestlé Fitness and Chocapic Duo breakfast cereals. Corn flakes meet the nutritional needs of the body the least. The consumption of a typical breakfast portion of corn cereals meets at most 5% of the daily requirements for each of the analysed elements. The ECO+, Funny Morning and Corn flakes Otmuchów are the most elementally deficient. The highest micronutrient intakes were observed with multigrain and flavoured breakfast cereal consumption. The Nestlé Fitness, Cookie Crisp, Chocapic Duo, Nesquik and Cheerios Honey Nut brands have been found to be the most nutrient-rich. Micronutrient intake by consumption of breakfast cereals cannot be definitely ignored because ready-to-eat breakfast cereal consumption is becoming increasingly common.

Comparison of the analysed ready-to-eat cereals' mineral compositions to the natural concentrations of macro- and microelements in corn, wheat, barley, rye and oat grains (see Table 7) undoubtedly proves fortification of cereals with Ca and Fe. Some of these food products contain less Mg, Mn, P, V and Zn than raw materials. The Pb level in ready-to-eat breakfast cereals is comparable to its content in corn, wheat, barley, rye and oat grain, thereby suggesting that the Pb contamination originates from the raw materials.

4. Final remarks

For the first time, a systematic study of the mineral compositions of a significant number of various breakfast cereals produced by well-known brands was presented. In general, the concentrations of macro- and microelements differed considerably for various grain-origin ready-to-eat cereal products. As a rule, corn-based breakfast cereals had lower mineral contents than those based on wheat, rice, oats and barley. The maximum Ca, Mg, Mn and Cu concentrations were 32,000, 14,000, 56 and 27 $\mu g\,g^{-1}$, respectively, in corn flakes. For the multi-grain cereals, the highest values were 140,000, 25,000, 470 and 110 $\mu g\,g^{-1}$, respectively. Multigrain products with added yogurt, honey, nuts and chocolate contained much greater mineral levels than corn flakes. The nutritive values of the examined breakfast cereals with respect to mineral intake were evaluated. Based on the determined mineral compositions of the breakfast cereals, it was determined that the examined corn and multigrain flakes are good source of micronutrients. Consumption of 30 g of the analysed cereals provides up to 10% of daily human needs for almost all of the examined elements and satisfies up to 20% of Ca, 45% of Fe and 30% of P recommended daily doses. The microwave digestion technique used in connection with ICP-OES is a good

Table 7. Content of the macro- and microelements in corn, multigrain and flavoured breakfast cereals in comparison to reference data for different grains [$\mu g\,g^{-1}$].

	Experimental data		Reference data acquired from literature [23,24]*				
Element	Corn flakes	Multigrain and flavoured breakfast cereals	Corn	Wheat	Barley	Rye	Oat
Ba	0.08 ÷ 0.34	0.07 ÷ 1.73					
Ca	21.8 ÷ 1061	50.7 ÷ 4604	*20–250**	*250–340*	*290–370*	*210–560*	*540–580*
Cd	0.14 ÷ 0.4	0.07 ÷ 0.38		0.001–0.26	0.006–0.12	0.02–0.15	0.02 - 0.30
Cr	0.12 ÷ 0.24	0.18		0.2–0.7	0.3–0.8	0.07–1.2	0.2 -2.8
Cu	0.10 ÷ 0.89	0.2 ÷ 3.67	1.4–2.1 *0.54–3.14*	0.6–10.35 *2.61–5.53*	1.8–15 *2.70–4.98*	1.4–8 *2.50–7.50*	1–5.2 *4.03–6.26*
Fe	1.67 ÷ 165	15.0 ÷ 167	17 5.2–27.1	15–69 21.4–53.7	16–160 25.0–47.1	34–43 18.0–64.5	54–140 40.0–54.1
Mg	73.9 ÷ 466	62.7 ÷ 818	*370–1490*	*820–1440*	*790–1330*	*700–2480*	*1440–2350*
Mn	0.34 ÷ 1.87	1.20 ÷ 15.8	3.6 *1.61–9.00*	7.5–103 *18.58–43.91*	12–30 *11.93–19.43*	17–121 *19.70–67.30*	9–87 *40.19–56.30*
Ni	0.28 ÷ 2.3	0.19 ÷ 1.46	0.22–0.34	0.2–0.67	0.10–0.67	0.2–8	0.14–1
P	341 ÷ 1419	219 ÷ 1810	*890–3440*	*2000–5080*	*2210–3030*	*1940–6320*	*4520–7340*
Pb	1.10 ÷ 2.02	1.53	0.3–3	0.07–2.2	0.1–1.57	0.06–1.3	0.05–2
Sr	0.03 ÷ 4.01	0.42 ÷ 1.94	0.06–0.4	0.48–2.3			1.8–3.2
Ti	0.08 ÷ 0.38	0.03 ÷ 0.20					
V	0.05 ÷ 0.14	2.24 ÷ 7.28		7–10	60		
Zn	0.44 ÷ 9.26	0.21 ÷ 14.4	25–36 *4.5–30.6*	6–67 *16.5–41.6*	14 - 51 *20.6–27.7*	14–73 *17.5–56.2*	12–75 *31.1–3.97*

*Values from ref. [24] are in italics.

method for determination of macroelements and microelements such as Ca, Cr, Fe, Mg, Mn, Ni, P, Sr, and Zn.

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