Journal of Elementology ISSN 1644-2296

Gładysz, I., Plazuk, E., Dmitrowicz, A., Szepeluk, A. and Karczewski, J. (2024)
'Aluminum content in cereal products from eastern Poland',
Journal of Elementology, 29(2), 379-385,
available: https://doi.org/10.5601/jelem.2024.29.2.3317

RECEIVED: 7 April 2024
ACCEPTED: 30 April 2024

ORIGINAL PAPER

Aluminum content in cereal products from eastern Poland*

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Abstract

Aluminum (Al) is a widespread element in the earth's crust. In large quantities, it can be toxic to both plants and herbivores. The aim of the work was to determine the aluminum content in samples of flour, groats and other cereal products available on the retail market in eastern Poland. Al determination was performed in the chemical laboratory of the Biała Podlaska University "EKO-AGRO-TECH", using a ball mill and a mineralization furnace. The assessment of the content of this element will allow determining whether the aluminum content depends on the type of product, which may be helpful in assessing exposure to aluminum. Samples of flakes and groats were ground in a Fritsh ball mill and dissolved in pure acids, nitrogen and salt (6:1), and mineralized in an Anton Paar furnace. Then, the samples were diluted with distilled water and filtered on paper filters, and the filtrates were subjected to an elemental analysis by atomic emission spectrometer with excitation using an ICP-OES Spectro-blue FME 26 apparatus. The average concentration of aluminum in all tested products does not differ significantly from the average concentrations of this element in individual groups. After averaging in individual product groups, it was found that the average content in all products combined is not statistically different in each of these products. A balanced aluminum concentration was found in the tested cereal products originating from Southern Podlasie (Lubelskie Voivodeship) and from the southern districts of the Podlaskie Voivodeship. It was found that the aluminum concentrations in the tested cereal products did not show statistically significant differences.

Keywords: aluminum, dietary exposure, cereals, metals

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* Funding source: The project is funded by the John Paul II University Scientific Support Fund No. PB/6/2021, which is intended to support and develop scientific research.

INTRODUCTION

Aluminum (Al) is a widespread element in the Earth's crust, where it ranks as the third most abundant element (7%), after oxygen and silicon. The combination of aluminum with silicon, oxygen, iron and other elements constitutes an essential part of the soil. In aluminosilicates, aluminum is bound into very durable connections, which are difficult to be affected by external factors. Until recently, aluminum has received little attention in environmental toxicology. However, the increase in soil acidification caused by acid rains and the decomposition of organic matter leads to the gradual leaching of aluminum from soils with low buffering capacity. The lower the pH, the higher the concentration of ionized aluminum in the soil (Luo et al. 2020; Carneiro de Mello et al. 2023). The content of the soluble fraction in the soil, containing aluminum ions in the form of $Al3^{+}$ or ions resulting from the dissociation of $Al_2(SiO_3)_3$ or $Al(HSiO_3)_2$, is relatively small (Squadrone et al. 2021). In large quantities, it can be toxic to both plants and animals that eat aluminum-containing plants. The presence of aluminum in the soil is related to the presence of H^{+} ions. Soluble aluminum compounds may be accumulated by some plants grown on acidic soils (Du et al. 2022). The most common methods to remove aluminum from the soil are soil deacidification and growing plants that absorb aluminum (Zaisteva et al. 2023).

Aluminum is assimilated by the liver, and does not show typical toxic features. Therefore, it is classified as a neutral metal and is consequently used widely, e.g. in cooking. However, the contact of aluminum with organic acids present in food products and the resulting reactions substantiated the systematic withdrawal of aluminum vessels from use, which started back in the 1980s (Brizio et al. 2016).

An excess of aluminum overloads the liver, and absorption of large doses of this element, especially in childhood, may result in impaired liver function. Moreover, aluminum easily combines with calcium ions to form compounds that are difficult to absorb, and therefore its consumption should be limited during the period of growth and development of the skeletal system (Bryliński et al. 2023).

Great interest in this element is revealed in the research on the impact of aluminum on health (Crisponi et al. 2013, Shaw, Tomljenovic 2013, Klotz et al. 2017, Alasfar, Isaifan 2021). The body's absorption of aluminum is low, and the mechanisms of gastrointestinal absorption are not yet fully understood (Mold et al. 2020).

Cereal products are the most common food in the Polish diet, being the main source of carbohydrates and energy. Whether in the form of flour, flakes, bread, pasta or groats, cereals dominate an everyday menu. The aluminum content in flour, groats and other cereal products may provide information about exposure to aluminum (Exley, House 2011, Liang et al. 2019). The aim of the study was to determine the aluminum content in samples of flour, groats and other cereal products available on the retail market in eastern Poland (southern part of the Podlaskie Voivodeship and northern part of the Lublelskie Voivodeship). These were products made from grain plants, based mainly on raw materials obtained from local producers. The assessment of the content of this element will resolve the question whether the aluminum content depends on the type of product, which may be helpful in evaluating the exposure to aluminum due to the type of products included in a diet.

MATERIALS AND METHODS

The materials used for the research were cereal products purchased in stores and mills in the region of Southern Podlasie (Lubelskie Voivodeship) and in the southern districts of the Podlaskie Voivodeship, in 2023. Of the 82 tested products, 43 were flours made from rye, wheat and spelt. Flours commercially designated as Type 450 and 500 were tested. These white flours are the most commonly used, next to Type 650 and 720, bread flours. Wholegrain flours are rich in fiber and are ground with hulls: type 1850 – graham and type 2000 – wholemeal. 24 products were groats, such as barley, millet, couscous, buckwheat, spelt and semolina. 13 products were food flakes, mainly oat flakes, and also millet, barley and spelt flakes. Two products were spelt and buckwheat bran.

Al determination was performed in the chemical laboratory of the Biała Podlaska University "EKO-AGRO-TECH", using a ball mill and a mineralization furnace. Cereal materials purchased in the form of flakes and groats were ground in a Fritsch Analysette 3 ball mill, afterwards, same as flour, were dissolved in nitric acids p.a. (POCH Basic) and 35-38% hydrochloric acid (Chempur) in the proportions of 6:1, and then mineralized in a microwave oven by Anton Paar (Austria). Microwave digestion was carried out using a protocol designed for microwave digestion of cereal products (temp. 110°C for 5 min, 220°C for 20 min, and 70°C for 25 min). The contents from the mineralization vessels were filtered on quality filters with a diameter of 150 mm and a weight of 80 (Chemland), and then diluted to 50 ml with distilled water. The filtrates were subjected to an elemental analysis on an atomic emission spectrometer with excitation, carried out on an ICP-OES Spectro-blue FME 26 apparatus. The element aluminum was quantitatively determined by reference to the calibration curve of the standard solution (VGH, Standard, LGC) in its linear range.

To read the results, an elemental standard containing 48 elements (including aluminum), necessary for preparing a calibration curve according to the research methodology, was used. Smart Analyzer Vision was used to read the concentrations of chemical elements in the tested samples.

Statistical analysis was performed based on IBM Statistics SPSS 24.0 computer software for Windows. Two tests were carried out to check the significance of differences ($p<0.05$) in Al content both between cereals and the types of derived products, and between their locations. The Kolmogorov--Smirnov and Shapiro-Wilk tests were used to test normality, and the Levene's test was used to test homogeneity of variances based on a mean, median, and trimmed mean. The data followed non-normal distribution, therefore the non-parametric Kruskal-Wallis test was used.

RESULTS AND DISCUSSION

When examining the content of selected minerals in cereal products, the statistical analysis did not show significant differences in the aluminum level between the tested flours, groats and other products (p=0.3634), as shown in Table 1. The average concentration of aluminum in all tested products does not differ significantly from the average concentrations of this element in individual groups. After averaging the results in individual product groups, it was found that the average content in all products combined is not statistically different in each of these products.

Table 1

Aluminum content in the tested food products

Product	n	Average (mg kg^{-1})	Median	Min	Max	Lower quartile	Upper quartile	Standard deviation SD	Standard error SE
Flour	43	71.6	76.2	5.9	124.0	44.5	98.8	30.2	4.7
Groats	24	63.3	78.4	0.6	120.0	20.7	95.2	39.6	8.1
Other	15	56.3	42.7	10.9	128.0	35.7	88.4	34.7	8.7
Total	82	66.2	74.3	0.6	128.0	37.8	95.1	34.2	3.8

* Kruskal Wallis test H=2.02, p=0.3634

The relationship between Al and health risks has been studied for at least fifty years, and this metal is certainly not neutral in the human body (Filippini et al. 2019, Rubio-Armendariz et al. 2021).

In recent years, human exposure to this metal has been studied in the context of ingested food, environmental sources, bioavailability, absorption in organisms and toxicological mechanisms, as observed in the reports presented by the Agency for Toxic Substances and Disease Registry, the Center for Food Safety and the Joint FAO/WHO Expert Committee on Food Additives in 2008, 2009 and 2016, respectively.

High aluminum content is characteristic of legumes, nuts, oil seeds and spices, as well as sugars, sweets and sweet desserts, with an average aluminum content of 28.5 mg $kg^{-1}$and 21.1 mg kg^{-1}respectively. The high content of the element in these food groups is mainly due to cocoa used as an ingredient in these products. As much as 11% of the total aluminum intake comes from instant teas. Other significant sources of exposure include vegetable salads, tea, dark chocolate and multigrain bread. The aluminum concentration values obtained in our research do not differ significantly from those reported by other authors. However, high dispersion of the results is noteworthy, as it may indicate that the accumulation of Al depends on the place of cultivation, soil conditions and processing methods.

In order to estimate the potential risk of aluminum exposure, it would be necessary to estimate the daily consumption of cereal products and, based on analytical tests, calculate Al intake depending on age and body weight.

The Al content in food available to German consumers was estimated. The average weekly dietary exposure of Al for an adult was found to be 50% of the permissible weekly threshold set by the European Food Safety Authority (EFSA), namely 1 milligram per kilogram (mg kg^{-1}) of body weight per week. The following default body weight values were used: 60 kg for adults (in accordance with Regulation EU 10/2011), 42 kg for adolescents aged 11-14, 22 kg for children aged 3-10, 12 kg for infants age 1-3 years and 6 kg for infants up to 12 months old, all values are the median according to EFSA (Tietz et al. 2019). Referring to the concentration values of the tested cereal products to the consumption standards adopted by EFSA, it can be assumed with high probability that the supply of aluminum is within safe limits.

CONCLUSIONS

A balanced aluminum concentration was found in the tested cereal products originating from Southern Podlasie (Lublin Voivodeship) and from the southern districts of the Podlaskie Voivodeship.

Author contributions

IG, JK – conceptualization, EP,AD, JK – methodology, AS – formal analysis, IG, JK writing –original draft preparation, JK – visualization, IG – editing. All authors have read and agreed to the published version of the manuscript.

Conflicts of interest

The authors declare no conflict of interest.

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