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DOI: https://doi.org/10.52091/EVIK-2021/4-5-ENG

Received: March 2021 – Accepted: October 2021

Minerals in Foodstuffs – Aluminium in foodstuffs

Keywords: macro element, mezzo element, micro element, aluminium-compounds, lack of phosphorus

1. SUMMARY

The paper deals with questions of aluminium, which concentration can be significant in plants, although it is not an essential element. The concentration of aluminium of tea leaves is extremely high. The concentration of aluminium of plants strongly depends on the pH-value of the soil, if the level of acidity in the soil is high, the Al-content of the soil-solution is also high, causing P-deficiency for plants. The intake of aluminium of the humans is a function of the ratio of consumption of plant and animal origin foodstuffs. The aluminium content of animal origin foodstuffs – because of low level absorption rate of aluminium is rather low – so the concentration range of milk of aluminium is low. After the macroelements the aluminium is the metallic micro element which it's daily intake generally the highest in the human diet, approximately between 30 and 50 mg.

The too high aluminium uptake in the diet can produce various healthy disorders in the human body, and probably there is a connection between Al-intake and Alzheimer-disease and the old age dementia, as well (The association between aluminium uptake and Alzheimer's disease is disputed by several sources in the literature; the Editor).

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2. Introduction

In the previous part **[1]** of the series about the minerals the case of osmium was discussed, which is a toxic trace element. This part deals with aluminium, which is a microelement, belonging to the group of trace elements without biological importance. In some respects, it may be questionable whether there is an element at all that has no biological significance.

Of course the "boundary" between biologically significant and non significant elements is not sharp, as it has been known since Paracelsus (1493-1541) that in principle all substances – so in the case of all microelements – can be toxic, and the extent of the effect depends only on its concentration and uptake.

As the opinion of Pais **[2]** aluminium belongs to the microelements with partial biological effect. According to Pais these microelements are those, that are not have essential effect and even not stimulative for the human beings with high probability. Their concentration can be very low – therefore they do not have practically biological-physiological effect – or the concentration is not low, however the toxicity of the given microelement (and of its chemical compounds) is rather weak, so toxic effect, negative, inhibitive influence on the physiological processes can occur only in case of extremely high concentrations. Because of the limited knowledge – e.g. in consequence of the threshold values for quantitative determinations of the applied analytical techniques – it is possible, that in the future the number of essential elements will increase **[3]**. Because essentiality means, that the given microelement is a component or activator of enzymes, proving this fact in case of elements with very low concentration range is not an easy task. Mostly is difficult in that case, if the concentration of the given microelement in natural circumstances always exceeds the physiological requirement, so there are no deficiency symptoms. Theoretically the threshold can be even one atom per cell, because it is possible, that in the cell (as an anatomical and functional unit of living organism) there is only 1 molecule with physiologoical role, having 1 atom of the given trace element as a component. So, these concentrations can be really very low in the case of the agricultural products and foodstuffs (even orders of magnitude less), in comparison with the widely applied concentrations in the analytical techniques, like ppm (mg/kg or ppb (ng/g).

3. The physiological role of aluminium

Aluminium is the most abundant metal in the earth's crust (7.5%), followed by oxygen and silicon as chemical element. Most of it is found in aluminosilicate minerals (e.g. andalusite) and feldspar (e.g. orthoclase), but oxide (e.g. corundum) and hydroxide (e.g. hydrargillite) minerals are also known. However, bauxite is not a mineral, but a sedimentary rock that contains mainly boehmite and hydrargillite. Aluminium occurs in soils with a frequency of 0.2-20%, with an average concentration of 0.002 mg/liter in seawater and 0.3 mg/liter in surface freshwater **[4, 5]**.

Although Al is present in relatively high concentrations in materials of biological origin (especially plants), as the currently knowledge not to have a biological function. However, from agricultural point of view, from point of view of the nutrient supply of plants, especially the P supply, it is a very crucial element. Aluminium is probably not a vital element, it's physiological-biological function not known. According to Kőrös **[6],** the main reason for aluminium is that under physiological pH (about pH=7) is in non-ionic state, already at a much lower pH, aluminium precipitates out of solution in the form of hydroxopolymers, and since this precipitate cannot be solved by the different complexing agents, so aluminium cannot get into solution. Aluminium does not participate in redox reactions, in aqueous solution it can be present only in the +3 oxidation state. It follows that aluminium cannot be a component of either metalloenzymes or metal-activated enzymes and cannot be listed as a mobile ion. Nor could it become a component of insoluble phosphates found in significant amounts in living organisms, as biological evolution has chosen calcium for this role that is much more readily available to biological systems.

In the last 2-3 decades, plenty of scientific publications have dealt with the chemical-biochemical role of aluminium in the food chain, interactions (mainly related to the fluorine and phosphorus), possible toxic effects, environmental pollution, aluminium use and with significance, biological role, utilization and negative impact of aluminium uptake from food and other sources (e.g. medicines). Some authors believe that aluminium at an optimal concentration also has a stimulating role. I think many questions are not just waiting to be answered, but perhaps even being raised.

Some experts have recently classified aluminium as a controversial physiologically important element, not completely ruling out the possibility of essentiality, but suggesting that it is only a necessary element at very low concentrations, and therefore deficiency symptoms are not expected to occur. However, too much aluminium is also sure to disrupt the body's metabolism of Ca, P, and F. For example, due to the antagonism between fluorine and aluminium, fluorine supplementation reduces the concentration and potential adverse effects of aluminium and vice versa.

4. Aluminium turnover in the human body

With a mixed diet, the daily Al intake is approx. between 10 and 35 mg and the amount of aluminium in the human body is usually between 50 and 120 mg, and this in general increases with age **[7]**. According to other data **[8]**, the amount of stored Al in the body of an average person weighing 70 kg can be as high as 1.0 g, and the daily intake can reach 80 mg. According to the vast majority of the authors, the range of daily Al uptake is between 5 and 150 mg, however, according to some in Hungary carried out measurements **[9]**, the values from food were only between 0.3 and 19.4 mg. Of course, aluminium can come not only from solid food, but also from drinks and medicines, and even a small part of it enters the body through the lungs by inhalation.

After the macroelements, from the solid foodstuffs and beverages the aluminium and the silicon are the two elements which enter into the human gastrointestinal tract.

Thus, together with some other elements (e.g bromine, boron, possibly iron, zinc), the aluminium could even be classified as a meso element, as its prevalence in food can significantly (by an order of magnitude or even several orders of magnitude) exceed the concentration of most trace elements. The uptake of aluminium crucially depends on whether the individual is consuming food dominantly of plant or animal origin.

The various compounds and salts of aluminium are practically non-toxic to the human body, which is related to the fact that they are absorbed only slightly from the digestive tract, and thus are mainly excreted in the faeces. The amount of aluminium excreted in the urine is only around 0.1 mg/liter. The week solubility of aluminium made it possible to use aluminium utensils and technological equipment in the food industry and kitchen technology. However, it should be taken into account that aluminium ions catalyse the degradation of the vitamin C content in the food like the copper ions. It is also good for making aluminium foil, which is suitable for packaging a wide variety of foods.

As a result of inhalation, some of the aluminium that enters the body is stored in the lungs, which explains why the Al concentration in the lung tissues increases with age. However, some part of the aluminium is absorbed, as the Al content measured in the urine of Al-exposed workers was 2-3 times higher than the values measured in the control persons. In addition to the lungs, bone, liver, and spleen contain significant amounts of aluminium, and it is a well-known fact that Al levels increase in the brain as we age. In renal patients, due to decreased renal function, aluminium deposition in some organs may be very significant. Al-loading can also cause secondary phosphorus deficiency **[10]**.

5. Aluminium content of foodstuffs

There is a wealth of literature data on the Al content of various agricultural products, food raw materials and ready meals **[11. 12, 13, 14, 15, 16, 17]**. In Hungary, the experts of former OÉTI (State Institute of Food and Nutrition) and TAKI (Research Institute on Soil science and Agrochemistry) carried out several studies and published several publications or conference reports. No limit is given for aluminium in foodstuffs, but concerning the content in the foodstuffs huge differences can be detected depending on the origin, geographical environment etc. The extremely wide concentration range also suggests that Al is probably a non-essential microelement, as the aluminium content of the same healthy plant or animal tissue (product) may differ significantly, there may be several orders of magnitude differences.

The Al content of plants and food of plant origin is in general significantly higher than that of food of animal origin. If the environment is strongly acidic, about pH=4 value, the Al concentration in the groundwater can be occurred even above 1 mg/liter, which can lead to chlorosis in plants. The adverse effect of increased Al uptake can be mainly explained by the caused P-deficiency. On strongly acidic soils the unfavourable effect of aluminium can be eliminated by P-fertilization. Some the – so-called acid-tolerant plants – accumulate aluminium in a very large extent, and the Al content per dry matter content can exceed 0.1%. Such plant as e.g. the tea bush.

In plants, Al occurs mainly in the vegetative parts, in the case of subtropical and tropical acidic soils, which are rich in mobile Al, very high Al contents can be measured in tea, coffee and pineapple crops. According to Lásztity **[18]**, the average Al content of Hungarian barley grain was 3.1 mg/kg (the average value measured in straw was 27.9 mg/kg, so the difference is one order of magnitude), in the case of millet it was 4.6 mg/kg, and the average Al content measured in straw was 197 mg/kg. In the case of vegetables and greens, Al concentrations are higher than those measured in cereals can be registered, depending on the different geographical and soil conditions. Values can be even one order of magnitude higher than the range of 10 mg/kg.

Because of poor absorption the Al content of foods of animal origin is usually much lower, usually it is in the range of mg/kg. In cow's milk, some authors report only the measured Al content above 0.1 mg/liter, others above 1 mg/liter, and to Pais milk has an average value of around 0.5 mg/liter **[2]**. Thus, dairy products can be considered as foods with a particularly low Al content, and in most cases the Al content measured in fish is also low.

Many foods (e.g some cheeses, baking powders, frozen pasta, flour mixed with baking powder, pickled vegetables) are made using additives that also contain aluminium. Some of the aluminium that enters the body – not the dominant amount – comes from drinking water. According to the WHO recommendation, 0.05 mg/liter is the desired limit value and the permissible limit is 0.2 mg/liter, but the measurable Al concentration in the drinking water is often much higher. In the case of soda water stored in a aluminium cylinder, significantly higher values also occur.

Of course, consuming too much aluminium can also have adverse effects on the body. In some cases, however, it is not the amount of Al taken in with food is decisive, but the amount of aluminium used for medicinal purposes (e.g against gastric acid overload) and entering the body. It should be noted that high doses of aluminium are used to reduce high serum phosphate in renal patients **[19]**. According to Takács, the *daily* Al uptake, which was considered tolerable, is approximately 1 mg/kg body weight, while EFSA (European Food Safety Authority) considers a much lower value to be safe, with a maximum *weekly* intake of 1 mg/kg body weight. In the elderly ages, special care should be taken to ensure moderate aluminium intake, as high Al levels can cause impaired renal function, nervous system disorders, and Alzheimer's disease is likely to be associated with higher Al content in brain cells (the association between aluminium uptake and Alzheimer's disease is disputed by several sources in the literature; the Editor). The main danger is the use of acid suppressants with higher levels of aluminium hydroxide. Various chelating agents can otherwise be used successfully to reduce aluminium incorporation.

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