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Bioavailable silicon forms in dietary supplements

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Abstract. Silicon (Si) is an element necessary for the proper functioning of the body. It affects cell viability, osteoblast differentiation, blood vessel elasticity, type I collagen synthesis, as well as the condition of the skin, hair, and nails. It is also considered an antiatherosclerotic agent. The silicon content in the human body is 6-7 g, and the only absorbable form is orthosilicic acid. The average daily requirement of the body for this element is in the range of 20 to 40 mg, whose diet does not fully provide. In addition, the silicon content in the body decreases with age, so there is a need for its supplementation.

There are many liquid, gel, and spray diet supplements available that vary in concentration and silicon compound. The aim of the research was to determine the content of orthosilicic acid in liquid diet supplements. Thirteen preparations were selected for the study, in which concentration of available silicon was determined by a spectrophotometric method. This method was based on reaction in the acidic environment of dissociated silicon with ammonium molybdate. Among the selected products, the highest concentration of available silicon form was obtained for pharmaceuticals composed of choline stabilized orthosilicic acid, which is in the range of 50-2000 ppm. However, its concentration in preparations containing monomethylsilanetriol (MMST) did not exceed 50 ppm.

Keywords: chemical sciences, orthosilicic acid, Uv-Vis spectroscopy
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1. Introduction

Silicon is the second most common element in the Earth's crust (28% by weight). It does not exist in an elemental form, but in the form of chemical compounds (for example: silica, salts, and silicic acids). In everyday life, a person is in contact with many silicon compounds, through cosmetics, medical implants, and devices. However, the most important source of this microelement is food.

Unlike other elements, silicon does not accumulate in the body, and its content is from 6 to 7 g and decreases with age [1]. The average daily requirement of the body for silicon is 20-40 mg, however, the need for this substance is greater for people after surgery, pregnant women, and the elderly people. The deficiency of this microelement also may cause many ailments (hair loss, nail fragility or faster skin aging) and diseases (intestinal dysbacteriosis, osteoporosis, atherosclerosis) [2-6].

In the human body, the highest concentration of silicon is found in the walls of blood vessels, tendons, skin, hair, and nails [7-9]. It also plays a key role in the process of skeleton mineralization, regeneration, and collagen synthesis [10, 11]. Furthermore, studies in rats have shown that silicon effectively inhibits the absorption of aluminum through the gastrointestinal tract [12, 13]. According to some sources, silicon is recognized as an anti-atherosclerotic agent, because silicon compounds can prevent the accumulation of lipid deposits in the lumen of arteries.

Ferreira et al. [15] investigated the dermatological effects of oral silicon ingestion of two forms: maltodextrin-stabilized silicic acid (powder) and monomethylsilanetriol on a group of women aged 40-60. As a result of the research, a decrease in aluminum content, a reduction in wrinkles and skin discoloration was observed, which was comparable when using both preparations. It was also shown that silicon in the form of OSA (orthosilicic acid) stimulates prolyl hydroxylase activity, and thus the synthesis of type I collagen [15, 16].

There are many commercially available silicon dietary supplements that differ in the degree of bioavailability and the concentration of silicon compound does not exceed 20%. The aim of the study was to compare the assimilable form of selected preparations with the spectrophotometric method.

2. Material and methods

The test material was diet supplements from 3 different manufacturers, which contained silicon in the form of orthosilicic acid stabilized with choline (P1, P2A, P2B, P2C, P2D and P3) or monomethylsilanetriol (MMST) (P4-P8). Preparations P2A, P2B, P2C, and P2D are from one producer, but they have been obtained according to different production methods. Preparations 7 and 8 are in the form of aerosol, P9 is a gel, and P10 is a tablet. Moreover, preparations with MMST are from one producer.

The silicon content of the preparations was determined by the Uv-Vis method using Thermo Scientific Evolution 220 spectrometer in the visible light range. The spectrophotometric method is based on reaction in a strongly acidic environment of dissociated silicon with ammonium molybdate [17].

Each dietary supplement was first diluted to a concentration of 0.2 μg g^{-1} and then taken 3 ml into a 25 ml flask, 0.25 ml of 1.25 M sulfuric acid (VI) and 1.25 ml of a 5% aqueous solution of ammonium molybdate were added. After 20 minutes, 5 ml of distilled water, 1.25 ml of a 5% aqueous solution of oxalic acid and 0.75 ml of 0.25% aqueous solution of Mohr's salt are added, followed by distilled water to a bar. After 30 minutes, the absorption was measured at the analytical wavelength λ = 814 nm.

3. Results and discussion

The determined content of an available silicon form in the analyzed diet supplements is presented in Table 1. In the group of silicon containing orthosilicic acid pharmaceuticals, the highest concentration of the compound was determined for the P2 C preparation (1947.5 μg g^{-1}) and the lowest for P3 (56.29 μg g^{-1}). However, in the case of supplements containing this microelement in the form of monomethylsilanetriol (MMST), the highest concentration of bioavailable form was obtained for the preparation P9 (23.35 μg g^{-1}). Preparations P5 and P6 contain almost 40 times lower concentration than P9. Among dietary supplements containing silicon in the form of MMST, its highest concentration was determined in the case of tablets (P10). The silicon content in this case is comparable to supplements containing orthosilicic acid.

Elemental analysis by ICP-OES method showed that 2a-d dietary supplements contain 2000 μg g^{-1} Si. The manufacturer of supplement 1 declares that it contains 2.8 mg of $Si(OH)_4$ per 1 ml and manufacturer of supplement 3 3.9 mg of $Si(OH)_4$ per 1 ml. Whereas, in the case of 4-9 supplements the manufacturer declares 0.144 mg of MMST per 1 ml of the product and 8% of the active substance in tablets. In the analyzed products, the average content of an available form of silicon was below 30% declared by the producers. The results suggest that the silicon compounds may have polymerized.

The studies show that the content of the available form in the preparation depends largely on the optimization of the method of producing a dietary supplement. Extending the time of mixing components before the concentration process, as well as gradual concentration is one of the key elements of production. In this way, the concentration of bioavailable silicon forms in the pharmaceutical can be doubled.

Food and plants contain less silicon when compared to diet supplements (Table 2). Of the fruits, most of this microelement contains bananas, pineapple, and mangoes at the level of 1.34 ±1.3 mg per 100 g of product. In comparison, green beans, spinach or coriander contain 1.79 ±2.42 mg Si per 100 g [12]. Moreover, fertilization of SiO_2 crops improves the fertility of fields, increases the yield and the content of available silicon in plants [12, 18-21].

Table 1

The results of determination of silicon in the available form in selected preparations using UV-Vis technique

Type of compound	Type of diet supplement	Name of preparation	Concentration of available Si form in preparation [μg g^{-1}]
Orthosilic acid	Liquid	P1	66 ±1
		P2 A	1672 ±16
		P2 B	915 ±12
		P2 C	1947.5 ±2.5
		P2 D	1760.0 ±7.5
		P3	56.29 ±5.35
Monomethylsilanetriol (MMST)		P4	0.87 ±0.03
		P5	0.54 ±0.06
		P6	0.45 ±0.04
	Aerosol	P7	6.95 ±0.08
		P8	4.57 ±0.05
	Gel	P9	23.35 ±0.07
	Tablet	P10	650 ±11

Table 2

Silicon content in food product [12, 22-24]

Food products	**Si [mg per 100g]**
Bread	2.87
Rice	1.54
Milk (human)	0.05
2% Milk	2.50
Soy milk	1.21
Mozzarella cheese	1.33
Butter	1.43
Buckwheat noodles	3.60
Maize	2.52
Chocolate (35% Cocoa)	6.41
Honey	1.16
Sugar	3.43
Red bean	1.78
Sesame seeds (roasted)	3.93

cont. of the tab. 2

Spinach	3.96
Tomato	0.55
Oyster	2.92
Tatsoi	0.84
Chicory	1.12
Mizuna	0.84
Swiss Chard	0.84

Knowing that the human body's daily requirement for orthosilicic acid ranges from 20 to 40 mg, it can be concluded that the daily diet is not able to fully deliver the right amount of this compound. In addition, people who have undergone bone surgery, pregnant women, and the elderly persons have a significantly increased demand for this element. Even balanced diet cannot provide an adequate dose of Si, hence the need for supplementation. The research shows that among dietary supplements, available on the Polish market, it is better to reach for a supplement containing orthosilicic acid or a tablet with MMST.

4. Conclusions

In summary, silicon plays an important role in the human body, and the best source of its assimilable form is dietary supplements. The results of the research show that the highest concentration of available silicon formulations contain preparations that contain this microelement in the form of orthosilicic acid. In contrast, the concentration of H_4SiO_4 in pharmaceuticals, containing monomethylsilanetriol (MMST), did not exceed 50 μg g^{-1}. Only dietary supplements, in the form of a tablet contained a concentrated amount of Si (650 μg g^{-1}) in which the bioavailable form of silicon was comparable with liquid dietary supplements with OSA. Furthermore, the concentration of the available form in the preparation depends, to a large extent, on the method of its production. An optimized production method can increase its content even twice, which confirms the results.

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Przyswajalne formy krzemu w suplementach diety

Streszczenie. Krzem (Si) jest pierwiastkiem niezbędnym do prawidłowego funkcjonowania organizmu. Wpływa na żywotność komórek, różnicowanie osteoblastów, elastyczność naczyń krwionośnych, syntezę kolagenu typu I, a także kondycję skóry, włosów i paznokci. Jest również uznawany za czynnik przeciwmiażdżycowy. Zawartość krzemu w organizmie wynosi od 6 do 7 g, a jedyną jego przyswajalną formą jest kwas ortokrzemowy. Średnie dziennie zapotrzebowanie organizmu na ten pierwiastek mieści się w przedziale od 20 do 40 mg, którego dieta w pełni nie zapewnia. Ponadto zawartość krzemu w organizmie spada wraz z wiekiem, dlatego też zachodzi potrzeba suplementacji.

Dostępnych handlowo jest wiele suplementów diety w płynie, żelu oraz sprayu, które różnią się stężeniem oraz zawartym związkiem krzemu. Celem badań było oznaczenie zawartości kwasu ortokrzemowego w płynnych suplementach diety. Do badań wyselekcjonowano 13 suplementów diety, w których oznaczono metodą spektrofotometryczną stężenie przyswajalnego krzemu. Metoda ta była oparta na reakcji w środowisku kwaśnym zdysocjowanego krzemu z molibdenianem amonu.

Spośród wybranych produktów największe stężenie przyswajalnej formy krzemu otrzymano dla farmaceutyków składających się z kwasu ortokrzemowego stabilizowanego choliną, które mieści się w przedziale 50-2000 ppm. Natomiast jego stężenie w preparatach zawierających monometylosilanetriol (MMST) nie przekroczyło 50 ppm.

Słowa kluczowe: nauki chemiczne, kwas ortokrzemowy, spektroskopia Uv-Vis

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