Silicon content in Beers From Korean Market and Estimation of its Alimentary Uptake

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Abstract

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Silicon content of Korean domestic beer was approximately 13.2 mg/l, which was 142% higher than 9.24 mg/l in imported beer. The contents of Ca and Mg were in the range of 31–33 mg/l and 39-41 mg/l, respectively, which were similar in Korean domestic and imported beers. Through beer ingestion, the men's average Si intake was approximately 24.3 mg/day, which was 195% higher than the women's average Si intake (12.4 mg/day). In addition, it was found that 20–29 aged men and women took approximately 33.7 and 25.1 mg/day of Si, respectively, which are higher Si intakes through beer ingestion as compared to other age ranges. As to people in other age-ranges, the women's Si intake through beer ingestion was half that of men's. Domestic beer-1 and beer-2 had 8.50 and 6.45 Si µg/won of Si content per unit price, respectively. Taken together with these results, it was estimated that the more expensive the price of beer, the lower the Si content per unit price. Therefore, it is supposed that the cheap Korean domestic beer is an effective supplier of Si, the beer being considered the major resource for Si intake by humans in Korea.

Keywords: alcoholic baverages; minerals; intake; physico-chemical characteristics

Beers contain several compounds, such as alcohols, amines, carbonyls, esters, minerals, organic acids, sulphur compounds, and phenols, which come from beer-brewing materials (malted cereals, hops, water, and yeast). Many researchers reported that silicon (Si) exists as orthosilicic acid (OSA) which is a soluble complex in beers. Soluble and edible OSA might play an important role in the development of bones and connective tissues (Sripanyakorn *et al.* 2004). It has been reported that beer is the major resource of Si intake for people (Sripanyakorn *et al.* 2004). U.S. citizens take approximately 20–50 mg of Si a day (Pennington 1991; Sripanyakorn *et al.* 2004), and a high Si intake was observed in young adults and men. Only 5% of silicon is taken from the food formulae to the human body, otherwise approximately 40–80% of silicon is taken from beers brewed with whole barley (Bellia *et al.* 1996; Jugdaohsingh *et al.* 2002; Sripanyakorn *et al.* 2004; Casey & Bamforth 2010). At 26th Annual Meeting of American Society for Bone and Mineral Research (ASBMR), Tucker, a professor in Tufts University Boston, reported that beers and wines improve the bone density of human (Tucker *et al.* 2004).

Silicon has been implicated as an important essential nutrient in the bone formation in both animal and cellular models (Carlisle 1972; Schwarz & Milne 1972; Rico *et al.* 2000; Reffitt *et al.* 2003; Jugdaohsingh *et al.* 2004). OSA is the form predominantly absorbed by humans and is found in numerous tissues including bones, tendons, aorta, liver, and kidney. Nevertheless, the Recommended

Dietary Allowance (RDA) has been established for silicon intake. The deficiency of silicon induces deformities in skull and peripheral bones, and results in poorly formed joints, reduced contents of cartilage and collagen, and the disruption of the mineral balance in the femur and vertebrae (Martin 2007). The physiological concentration of OSA in stimulates collagen type 1 synthesis and osteoblastic differentiation in human osteoblast-like cells *in vitro* (Reffitt *et al.* 2003). Choline-stabilisation increases the bioavailability of OSA as a nutritional supplement. OSA has been known to prevent the loss of hair tensile strength (Wickett *et al.* 2007) and to have positive effects on the skin surface and skin mechanical properties (Calomme *et al.* 2006). In addition, OSA increases collagen concentration in calves (Calomme & Vanden Berghe 1997) and has a potential beneficial effect on the bone collagen formation in osteopenic females (Spector *et al.* 2008). In addition, according to the recent research regarding the biofunctions of Si, the correlation of aluminium and Alzheimer's disease has included the use of silicon in beverages (Exley *et al.* 2006; González-Muñoz *et al.* 2008a,b), due to its abilities both to reduce aluminium uptake in the digestive system and cause renal excretion of aluminium.

In Korea, the total consumption of alcoholic beverages has increased significantly (approximately quintuple) since 1965, and especially beers showed magnificent increases in consumption over 20 times (Ryu 2011). According to the report regarding the delivery amounts of alcohol beverages in 2010, the beer was the most popular alcoholic beverage with the possessory rate of 57.4% in Korea (Alcohol & Liquor Industry Association 2011). In addition, it was reported that the Koreans took approximately 3.6 l of beers per capita per month in the recent three years (Ryu 2011).

The aim of this study is to analyse and compare the silicon and other mineral contents, which are important for bone health, in Korean domestic and imported beers, and to estimate the silicon intake of the Koreans through beer consumptions.

MATERIAL AND METHODS

Material. Eleven domestic beers (DBs) and four imported beers (IBs) were purchased from the markets in Samcheok, Korea, in November 2010. Lager Beer kit (Coopers Co., Adelaide, Australia), containing 1.7 kg of malt/hop extract and 5 g of *Saccharomyces cerevisiae,* was used for brewing beer in the laboratory. Sucrose and water (Minemine®) were obtained from Cheil-jedang and Dongwon F&B Co., Ltd (both Gyeonggi-do, Korea), respectively.

Fermentation of beer. For brewing beer in the laboratory, malt/hop extract (1.7 l), sucrose 1 kg), and water (20 l) were added into a plastic fermentation jar (25 l), and then *Saccharomyces cerevisiae* (5 g) was added as the fermentation starter. Beer brewing was accomplished through primary fermentation for 2 weeks at 22°C. After the removal of the yeast from the bottom of the fermenter, the beer was transferred to a new bottle containing 0.1% sucrose, and the temperature was set at 18°C. After 2 weeks, the beer samples were stored at –20°C, and subsequently analysed after thawing.

Samples preparation. All liquid samples were centrifuged at 3000 rpm for 15 min using the centrifuge 5810R (Eppendorf, Hamburg, Germeny) and then the gasses in the supernatants were removed by the Ultrasonic Cleaner (JAC 2010; Jinwoo, Seoul, Korea), in 60 minutes. Then liquid samples were used for the measurement of physicochemical characteristics and mineral contents.

Physico-chemical analysis of samples. Total sugar content in the samples was determined by the portable refactometer (model N-1α; ATAGO Co. Ltd., Tokyo, Japan) using 50 μl sample, and the pH was measured with a pH meter (model 725p; Istek Co., Seoul, Korea). For the determination of total titratable acidity (TTA), the samples (10 ml) were filtered with 0.45 mm syringe filter and then titrated with 0.1N NaOH after the addition of 1–2 drops of phenolphthalein. TTA was calculated by the following equation using the consumed amount (ml) of 0.1N NaOH at the end-point (pink colour).

Total titratable acidity% (TTA%) = [(ml of 0.1N NaOH) × (N NaOH) × 0.075 (DL-tartaric acid coefficient) × 100]/ml sample

Determination of ethanol in samples. For the determination of ethanol contents in the samples, the samples were centrifuged for 15 min at 3000 rpm, filtered with 0.45 mm syringe filter, and analysed with an Alcolyzer (Anton Paar GmbH, Graz, Austria). The confidence range of detection was between 0–20% (v/v), and the accuracy and repeatability were 0.1 and 0.01%, respectively.

Analysis of the mineral contents. Inductively Coupled Plasma-Atomic Emission Spectrometer

(ICP-AES, Vista-Pro; Varian, Mulgrave, Australia) was set to reflected power 1.2 kW, argon (Ar) flow-gas, plasma flow 15 l/min, 1.5 l/min of auxiliary gas flow rate, and 0.7 l/min of nebuliser gas flow rate. Metal elements in the injected sample were analysed in high temperature plasma, which was created from high-frequency waves of ICP induction coil by Ar gas flowing into a quartz tube. The wavelengths for the detection of metal ions were set for chromium (Cr) at 262 nm, for calcium (Ca) at 396 nm, for phosphorus (P) at 213 nm, for magnesium (Mg) at 279 nm, for silicon (Si) at 251 nm, and for selenium (Se) at 196 nm. Homogenised yeast and sugar samples (0.2 g) were mixed with 7 ml of H_2O_2 and 2 ml of HNO_3, and were acid-hydrolysed using the Microwave Digestion System (Ethos Touch Control; Milestone Inc., Bergamo, Italy). The samples temperature was increased to 85°C for 3 min, 145°C for 9 min, and then kept at 180°C for 4 minutes. The hydrolysed samples were diluted 20 times with distilled water and were analysed with ICP-AES.

Statistical analysis. All results were expressed as the means ± SD after triplicate analysis. The means were analysed using one-way analysis of variance (ANOVA) and 99% confidence levels using Microsoft® Excel Statpro®, as described by Albright *et al.* (1999).

RESULTS AND DISCUSSION

Alcohol intakes by Koreans through consumption of alcoholic beverages

Since recently, the consumption of beer in South Korea has been increasing steadily. Except for men of 50–64 years of age, it has been found that beer is the most popular alcoholic beverage, regardless of the gender and age. In Korea, amount of, the alcohol intake, according to the age and gender, showed that beer represented a high proportion in the total alcoholic beverage intake, being 50.8% and 77.7% for men and women, respectively (Table 1). This result indicated that the ingestion of beer makes a large portion in the Korean alcohol consumption, and generally the younger people aged over 20, drink much more beer. With men aged 30–49 and 50–64, it was estimated that the intake amounts of Soju and beer were similar. Soju is a clear liquor distilled from Takju, and usually contains approximately 20% ethanol. Takju is a Korean traditional rice wine made by fermenting a mixture of boiled rice and starters for short periods of time (about 4–7 days) and aging (about 1–3 days). The final ethanol concentration of Takju ranges between 6~7%.

Physico-chemical characteristics and mineral contents of commercial and laboratory brewed beers

Physico-chemical characteristics of several Korean domestic beers (DBs) and imported beers (IBs) are shown in Table 2. Eleven Korean domestic beers had the average ethanol content 4.6%, sugar content 4.76 Brix (%), pH 4.07, and TTA 0.18%, while four imported beers had the average ethanol content 5.6%, sugar content 6.15 Brix (%), pH 4.2, and TTA 0.2%. Korean domestic and imported beers have similar physico-chemical characteristics.

Beer contains many kinds of micronutrient minerals, and was reported to play a role as a source of minerals for human nutrients. The contents of several minerals in beers including silicon (Si) were analysed using ICP-AES (Table 3). The Si content of Korean domestic beer was approximately 13.2 mg/l, which was 142% higher than 9.24 mg/l of imported beer. The contents of Ca and Mg were in the range of 31–33 mg/l and 39–41 mg/l, respectively, being similar in Korean domestic and imported beers. Otherwise, P, Se, and Cr were contained over twice the concentration in the

Table 1. Alcohol intake of Koreans

	Women (g/person/day)			Men (g/person/day)		
	20–29	30–49	50–64	20–29	30–49	50–64
Soju	11.2	7.9	8.6	67.9	73.8	66.8
Takju	0.0	1.4	8.0	9.4	6.6	20.6
Beer	87.0	28.7	13.5	117.1	82.8	52.7

Data are from Hong *et al.* (2007)

Table 2. Physico-chemical characteristics of commercial and laboratory-brewed beers in Korea

Beer		pH	Brix (%)	Acid-value (TTA, %)	Ethanol (%)
Domestic beer	DB-1	4.14 ± 0.01	4.20	0.15 ± 0.02	4.14
	DB-2	4.04 ± 0.01	6.00	0.35 ± 0.02	5.04
	DB-3	4.19 ± 0.00	5.40	0.18 ± 0.01	3.67
	DB-4	4.10 ± 0.00	5.20	0.16 ± 0.00	4.86
	DB-5	4.18 ± 0.00	2.80	0.17 ± 0.00	4.21
	DB-6	4.22 ± 0.00	4.00	0.16 ± 0.03	4.48
	DB-7	4.02 ± 0.00	6.00	0.20 ± 0.02	4.75
	DB-8	4.15 ± 0.01	5.20	0.18 ± 0.01	4.71
	DB-9	4.03 ± 0.02	4.20	0.14 ± 0.01	4.63
	DB-10	3.86 ± 0.01	5.40	0.17 ± 0.00	4.81
	DB-11	3.90 ± 0.01	4.00	0.15 ± 0.01	3.35
Average		4.07	4.76	0.18	4.60
Imported beer	IB-1	4.41 ± 0.01	8.00	0.22 ± 0.02	7.26
	IB-2	4.23 ± 0.01	5.60	0.18 ± 0.00	5.08
	IB-3	4.20 ± 0.00	5.80	0.19 ± 0.03	5.67
	IB-4	4.11 ± 0.01	6.60	0.25 ± 0.00	5.39
Average		4.20	6.15	0.20	5.60
Lab-brewed beer		3.80 ± 0.04	4.90 ± 0.27	0.24 ± 0.00	4.23 ± 0.01

imported beers. Especially the content of phosphorous in the imported beers was approximately 235 mg/l (average value), which was 193% higher than P contents in Korean domestic beers.

The own brewed beer was found to contain approximately 4.23% of ethanol, 4.90 Brix (%) of sugar 0.24% of TTA, and ITS pH was 3.80. Mineral contents in the brewed beer, determined by ICP-AES, showed 7.2 mg/l of Si, 19.1 mg/l of Ca, 127.9 of P, and 33.8 mg/l of Mg.

Korean domestic beer contained 25.24 mg/l of Si, the highest content, whereas the average Si content of Korean domestic beer is 13.26 mg/l (Table 3). Although the Si content of beer has not been well established so far, it was reported that beer contains approximately 18–19.2 mg/l of Si (Pennington 1991; Bellia *et al.* 1994; Sripanyakorn *et al.* 2004). Generally, the drinking water and other beverages have very low contents of Si. In the Western diet in which beer occupies a large portion, beer is considered to be a major contributor to Si intake in the body. In general, the whole grains, especially oats, barley, rice bran, and wheat bran, have high levels of Si, and hence it is expected that the grain products such as bread, rice, and breakfast cereals (Schwarz & Minle 1972; Pennington 1991), may contain high levels of Si. However, these grain products use the edible caryopsis of the cereals, whereas Si is found almost solely in the husk (Sripanyakorn *et al.* 2004). That is the reason for the low Si levels in grain food products.

In the human body, the dietary silicon (silicate) undergoes hydrolysis resulting in OSA forming that is readily absorbed in the gastrointestinal tract (Reffitt *et al.* 1999). Physiological concentrations of OSA stimulate collagen type I synthesis and osteoblastic differentiation in human osteoblast-like cells *in vitro* (Reffitt *et al.* 2003). It has been reported that Si plays a role as an important micromineral for the growth and development of bone and cartilage in animals (Carlisle 1986). The ingestion of beer or OSA increased the serum and urinary Si levels considerably, while the decreased serum Si concentration in totally parenterally fed infants was associated with a decreased bone mineral content (Spector *et al.* 2008). The supplementation with oral Si reduced the bone loss and induced bone formation in ovariectomised animals (Rico *et al.* 2000) and also increased femoral bone mineral density in osteoporotic women (Eisinger & Clairet 1993). In addition, the dietary Si intake is correlated with the bone mineral density in men and premenopausal women. Dietary silicon intake is positively associated with BMD in postmenopausal women

Table 3. Mineral compositions of commercial and laboratory-brewed beers in Korea

Beer		Mineral (mg/l)					
		Cr	Ca	P	Mg	Si	Se
Domestic beer	DB-1	0.003 ± 0.0008	44.13 ± 0.32	134.54 ± 1.17	50.22 ± 0.52	25.24 ± 0.39	0.24 ± 0.02
	DB-2	0.004 ± 0.0006	33.02 ± 0.14	148.78 ± 0.74	48.71 ± 0.16	19.16 ± 0.08	0.73 ± 0.02
	DB-3	0.003 ± 0.0003	35.04 ± 0.15	122.92 ± 0.33	53.40 ± 0.15	13.84 ± 0.06	1.01 ± 0.08
	DB-4	0.002 ± 0.0003	17.69 ± 0.03	113.46 ± 0.34	34.71 ± 0.16	13.38 ± 0.08	1.19 ± 0.17
	DB-5	0.003 ± 0.0004	28.40 ± 0.20	96.51 ± 0.31	36.04 ± 0.13	12.25 ± 0.04	1.06 ± 0.13
	DB-6	0.003 ± 0.0004	50.57 ± 0.31	128.70 ± 0.81	41.47 ± 0.41	11.72 ± 0.13	0.41 ± 0.08
	DB-7	0.002 ± 0.0003	45.24 ± 0.15	153.70 ± 0.50	36.69 ± 0.08	11.68 ± 0.06	0.98 ± 0.09
	DB-8	0.003 ± 0.0007	20.90 ± 0.04	162.95 ± 0.56	40.76 ± 0.18	10.46 ± 0.06	1.07 ± 0.03
	DB-9	nd ± 0.0001	27.73 ± 0.08	79.82 ± 0.37	31.28 ± 0.14	10.33 ± 0.05	0.98 ± 0.12
	DB-10	0.002 ± 0.0003	33.03 ± 0.17	113.01 ± 0.41	38.29 ± 0.11	10.05 ± 0.08	1.16 ± 0.12
	DB-11	0.003 ± 0.0002	31.40 ± 0.15	92.61 ± 0.25	33.82 ± 0.12	7.73 ± 0.06	0.80 ± 0.12
Average		0.003 ± 0.0001	33.38 ± 10.09	122.45 ± 26.54	40.49 ± 7.29	13.26 ± 4.92	0.88 ± 0.31
Imported beer	IB-1	0.006 ± 0.0006	27.30 ± 0.15	263.33 ± 1.02	39.33 ± 0.11	10.84 ± 0.03	1.63 ± 0.20
	IB-2	0.004 ± 0.0007	21.82 ± 0.13	205.17 ± 0.97	34.19 ± 0.10	10.05 ± 0.11	1.26 ± 0.10
	IB-3	0.004 ± 0.0006	38.51 ± 0.22	214.89 ± 0.92	36.78 ± 0.12	8.08 ± 0.023	1.38 ± 0.13
	IB-4	0.005 ± 0.0003	39.28 ± 0.08	257.51 ± 0.98	48.49 ± 0.21	8.02 ± 0.06	1.16 ± 0.09
Average		0.005 ± 0.000	31.73 ± 8.58	235.22 ± 29.46	39.70 ± 6.23	9.25 ± 1.42	1.36 ± 0.20
Lab-brewed beer		nd	19.1	127.9	33.8	7.2	1.2

nd – not detected

taking hormone replacement therapy (HRT), suggesting a possible interaction between the estrogen status and effects of silicon on bone (Spector *et al.* 2008). Thus the biological functions of Si are attributed to the metabolic bone-forming quality of soluble silicate (Jugdaohsingh *et al.* 2004; Sripanyakorn *et al.* 2004).

Mass balance during brewing beer in a laboratory

The flow of major minerals, which are Ca, P, Mg, and Si, was investigated during the brewing procedure of beer (Figure 1). As shown in the mass flow (Figure 1), the majority (60.6%) of the beer entering silicon emerged from malt and hops.

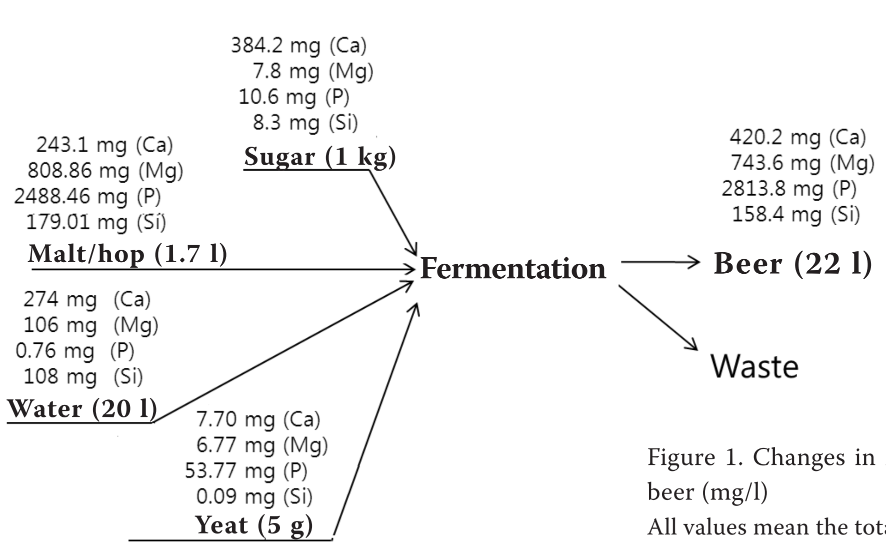

Figure 1. Changes in mineral contents of trial brewing beer (mg/l)
All values mean the total amounts of mineral

The own brewed beer (22 l) had approximately 7.2 mg/l of Si, which was 53.6% of the total Si content in the brewing materials. The losses of the Si content arose from the existence of the precipitate containing non-used substances after the beer fermentation and the growth of yeasts during beer brewing, which were removed for final beer product.

Evaluation of Si intakes through beers in Korea

Based on the amounts of alcohol intake (Table 1) and the average ethanol and Si contents in beers (Table 2), the amounts of Si intake through beers were calculated depending on the gender and age (Figure 2). The men's average Si intake was approximately 24.3 mg/day, which was 195% higher than the women's average Si intake (12.4 mg/day). In USA, Si intake was reported to be approximately 20–50 mg/ person per day (Pennington 1991; Uthus & Seaborn 1996; Jugdaohsingh *et al.* 2002). According to these results, the amounts of Korean and USA Si intake were similar, and it is supposed that the Korean diet pattern has been changed to the Western life style in most cases. Beer is considered to be the major source for Si intake by humans in Korea. Both men and women aged 20–29 were found to have a significantly high Si intake as compared to other age ranges. As the age increases, the Si intake by beer consumption is reduced in Korea. It is consistent with a report that in USA the highest Si intakes are showed in males and younger adults (Pennington 1991; Uthus & Seaborn 1996; Jugdaohsingh *et al.* 2002). This trend of Si intake was shown to be similar in both countries, and the reason is anticipated to be related to the consumption pattern of beer in the daily diet. In the age range of 20–29, men and women took approximately 33.7 and 25.1 mg/day of Si per capita, respectively, through beer intake. In other age groups, the women's Si intake was less than half that of the men's. For Silicon no official Recommended Dietary Allowance (RDA) currently exists. There are many controversial opinions on the nutritional function of Si. However, it is supposed that most diets that incorporate natural fruits, herbs, and vegetables supply the body with adequate amounts of silicon. The results (Figure 2) show that the Koreans, except for women at the age of 30–49 and of 50–64, take the respectable amount of silicon through beer intake only. This

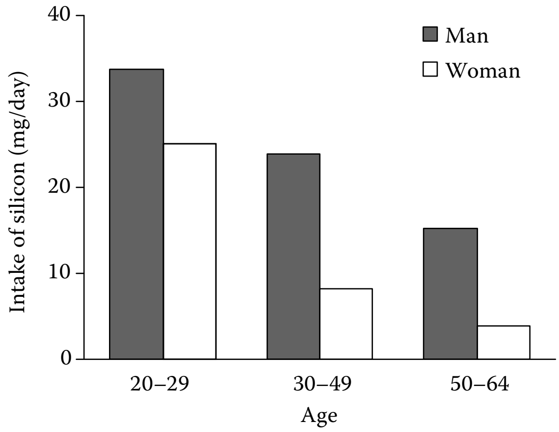

Figure 2. Silicon intake of Korean through consumption of beers

Table 4. Silicon content per unit price of beer

Beer		Si (mg/l)	Price* (won/0.1 l)	Alcohol per price (g/won)	Silicon per price (μg/won)
Domestic beer	DB-1	25.24 ± 0.39	297	0.34	8.50
	DB-2	19.16 ± 0.08	297	0.34	6.45
	DB-3	13.84 ± 0.06	276	0.36	5.01
	DB-4	13.38 ± 0.08	238	0.42	5.62
	DB-5	12.25 ± 0.04	332	0.30	3.69
	DB-6	11.72 ± 0.13	352	0.28	3.33
	DB-7	11.68 ± 0.06	652	0.15	1.79
	DB-8	10.46 ± 0.06	349	0.29	3.00
	DB-9	10.33 ± 0.05	238	0.42	4.34
	DB-10	10.05 ± 0.08	238	0.42	4.22
	DB-11	7.73 ± 0.06	352	0.28	2.20
Average		13.258	329	0.30	4.03

*Consumer Price (2010.12. at Samcheok, Korea) trend occurs in Korea as well as in the United States, Japan, and Germany, where beer is taken in much larger amounts than in Korea.

In addition, the Si content in Korean domestic beers per unit price is shown in Table 4. DB-1 and DB-2 had the highest Si contents per unit price of beer, which were 8.50 and 6.45 Si µg/won (the unit of the Korean currency), respectively. It was found that the more expensive is the price of beer, the lower is Si amount per unit price. Therefore, it is supposed that the relatively cheap domestic beer is an effective supplier for Si intake.

CONCLUSION

Taken together with physico-chemical characteristics and mineral contents, including Si content, in domestic and imported beers, the Si intake through beer ingestion is supposed to occupy a large part of total Si intake by the Koreans. Additionally, the comparatively cheap Korean domestic beers may be useful for the intake of Si, as well as of Ca, Mg, and P.

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