Silicon contents of home meal replacements sold in Korea

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Summary
To increase the understanding of the relationship between dietary silicon intake and various human health outcomes, this study assessed the silicon contents of 201 home meal replacement (HMR) products (124 ready-to-cook and 77 ready-to-eat products). Ready-to-cook foods included rice, porridge, noodles, broth, stew, soup, bread, dumplings, meat dishes and sauces, while ready-to-eat foods included lunch boxes, kimbap, burgers and sandwiches. The collected samples were analysed for silicon content using inductively coupled plasma-optical emission spectrometry. The average silicon content per serving was significantly higher in ready-to-eat foods at 7.68 mg compared to 3.03 mg in ready-to-cook foods, and the content per 100 g was also significantly different at 4.12 mg and 1.53 mg, respectively. When comparing the silicon content per serving of ready-to-cook foods by type, there were no significant differences. However, significant differences were determined in silicon content per serving of ready-to-eat foods by type, with sandwiches having the lowest average of 1.09 mg and kimbap having the highest average of 9.73 mg. The product types with the lowest price and highest silicon content were noodles and kimbap. The silicon content of HMR constructed in this study can be widely used to expand food composition database and assess the intake of silicon.

Keywords
silicon; home meal replacement; ready-to-eat; ready-to-cook; food composition database

Silicon plays an important role in the human health of bone and connective tissue metabolism [1–3]. Additionally, some studies suggested that silicon may provide benefits for cognitive function [4] and improve photodamaged skin, hair and nails [5]. According to an epidemiological study, silicon intakes greater than 30 mg per day were significantly associated with increased bone mineral density (*BMD*) when compared to intakes of less than 18 mg per day in pre-menopausal women and men [6]. In a cross-sectional, population-based study, dietary silicon had a significantly positive correlation with *BMD* in men and pre-menopausal women [6]. Additionally, in a cohort study, energy-adjusted silicon intake was significantly associated with femoral neck *BMD* in estrogen-replete women [7]. Despite the growing interest in physiological functions of silicon, limited research has been conducted on the relationship between silicon intake and various health outcomes. A major reason for this is the lack of a database of silicon content in commonly available foods.

The silicon content of food varies widely depending on the food type, food processing and the use of silicon-containing food additives [8]. Although the data on silicon content in commonly consumed food are incomplete, silicon content tends to be higher in plant-based foods, particularly cereal-based products, compared to animal foods [8]. According to research on the silicon content of foods in the United Kingdom, the highest contents of silicon were found in cereals and cereal products, especially in less refined cereals and oat-based products. Fruits and vegetables were also highly variable sources of silicon together with beer, a macerated whole-grain cereal product, which contained the highest level of silicon among beverages [9]. In our previous study to establish a silicon database of foods that are commonly consumed by Koreans, the daily average silicon intake among young Korean adult males was 37.5 mg and silicon intake from vegetables was found to have a positive correlation with serum total alkaline phosphatase, a bone formation marker [10].

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A silicon content database, based on the analysis of relevant foods, will allow further investigation of the role of silicon in human health.

On the other hand, social changes in Korea, such as an increase in single-person households, an increase in women's participation in the workforce or aging population, have led to diversification of processed foods [11]. The market for home meal replacements (HMR) has been growing steadily, with a 22% increase in 2020 compared to 2018, and is growing at a rate of 10% per year [12]. In addition to these social changes, the COVID-19 pandemic affected consumers' meal patterns and the purchase of HMR has increased both online and offline since the outbreak. According to Costa et al. [13], HMR are defined as main courses or pre-assembled main course components of a meal in single- or multiple-portion containers, designed to fully and speedily replace, at home, the main course of a homemade main meal. The Korean Ministry of Food and Drug Safety (MFDS) classifies HMR as ready-to-eat foods, fresh convenience foods and ready-to-cook foods, which are manufactured, processed and packaged for consumers to consume as is or with a simple cooking process [14]. Ready-to-eat foods are foods such as lunch boxes, kimbap, and burgers that can be consumed as is without further heating or cooking, while fresh convenience foods are foods such as salads or sprouts that can be consumed as is. Ready-to-cook foods are foods such as broths, stews, and soups that are manufactured for consumption after a simple heating and cooking process. In addition, a ready-to-prepare set consists of uncooked, cut raw foods and processed foods such as quantities of ingredients and seasonings needed for cooking and is manufactured for consumers to easily prepare and consume at home according to the provided recipe [15].

The use of HMR is increasing, but despite the various physiological functions of silicon, there are no data on the silicon content of contemporary processed foods such as HMR that can be used to assess the intake. In this study, we hypothesized that various types of HMR products have different silicon content and aimed to analyse the silicon content of commonly consumed HMR food products in Korea to provide data and develop a fundamental database for assessing silicon intake.

MATERIALS AND METHODS

Selection of products

The types of HMR foods included in this study were ready-to-eat and ready-to-cook foods, including frozen convenience foods. Fresh convenience foods and ready-to-prepare sets, which contain raw foods and allow for individual modification of ingredients when consumed or prepared, were excluded. We selected HMR products with high production, sales and consumption rates through online and offline market research and used a list of frequently consumed foods from the National Health and Nutrition Examination Survey in 2020 [16]. Considering that HMR products are continuously developed and introduced to the market, market research was conducted periodically from August 2020 to September 2022. A total of 201 products were selected, of which 124 were ready-to-cook and 77 were ready-to-eat products. The ready-to-cook products included rice (28), porridge (12), noodles (29), broth (7), stew (9), soup (5), bread (8), dumplings (10), meat dishes (7) and sauces (9), while the ready-to-eat foods included lunchboxes (11), kimbap (53), burgers (5) and sandwiches (8).

Nutritional information collection

The nutritional values of HMR products were investigated using food labels and nutrition fact labels. Information on products was collected, such as the product name, brand name, price, total weight, serving size and nutritional information. The nutritional information included energy, carbohydrates, sugar, protein, fat, trans fat, saturated fat, cholesterol and sodium content.

Analysis of silicon content

The selected HMR products were purchased and prepared as samples by homogenization in a blender HB6538KR (Philips, New York City, New York, USA). Approximately 1 g of the sample was taken and wet-digested with a microwave digestion system Multiwave 3000 (Anton Paar, Graz, Austria) after adding 7 ml of HNO_3 and 2 ml of H_2O_2. The digested solution was diluted with tertiary distilled water and analysed for silicon content using inductively coupled plasma-optical emission spectrometry (ICP-OES) by the instrument Optima 8300DV (PerkinElmer, Waltham, Massachusetts, USA). The analysis conditions were as follows: radio frequency 40 MHz, wavelength range 163–782 nm, the measured resolution was within 0.006 nm at 200 nm, plasma viewing was dual view and the detector type was a segmented array charge-coupled device (SCD) type 2. The analysed wavelength of silicon was 251.611 nm. The analysis was repeated three times per sample to keep the relative standard deviation within 3%. The recovery of detection from the wet digestion of the product to the analysis of silicon content was maintained within ± 5% by analysing the certified reference material (CRM) No. 2007-00959-001 (Korea Research Institute of Standards and Science, Yuseong, Daejeon, South Korea) with the same method. All reagents used in the analysis were from Chemitop (Jincheon, South Korea) and Samchun Pure Chemical (Pyeongtaek, South Korea).

Statistical analysis

All the data obtained in this study were calculated as mean and standard deviation. The differences in variables within ready-to-cook and ready-to-eat products were evaluated by an unpaired *t*-test. In addition, differences in variables between the types of HMR products were evaluated by post hoc analysis using Duncan's multiple range test with significance found by one-way ANOVA. Statistical analyses were conducted using SAS (Version 9.4, SAS Institute, Cary, North Carolina, USA). The level of statistical significance was set at $p < 0.05$.

RESULTS AND DISCUSSION

In this study, we analysed and assessed the silicon content of 201 HMR products to provide

Tab. 1. Price, weight and nutritional information of home meal replacements.

	Ready-to-cook (*n* = 124)			Ready-to-eat (*n* = 77)			*p*-value
	Mean ± *SD*	Median	*IQR*	Mean ± *SD*	Median	*IQR*	
Price							
Per package [USD]	3.83 ± 1.66	3.80	2.30–5.30	1.77 ± 0.78	1.80	1.10–2.00	< 0.001
Per 100 g [USD]	1.17 ± 0.49	1.08	0.83–1.45	0.84 ± 0.19	0.81	0.72–0.90	< 0.001
Weight							
Per package [g]	364.74 ± 180.34	375.00	213.00–452.50	212.62 ± 90.27	209.00	147.00–238.00	< 0.001
Per serving [g]	217.41 ± 80.00	210.90	160.00–280.00	212.62 ± 90.27	209.00	147.00–238.00	0.694
Values per serving size							
Energy [kJ]	1 304.83 ± 586.36	1318.00	826.35–1705.00	1 622.09 ± 741.91	1485.30	1004.20–1841.00	0.002
Carbohydrates [g]	45.44 ± 29.98	36.65	21.50–68.00	53.92 ± 21.72	51.00	37.00–60.00	0.021
Sugar [g]	7.30 ± 6.76	5.20	3.00–9.50	6.09 ± 4.78	6.00	2.00–8.00	0.139
Protein [g]	10.71 ± 6.37	10.00	7.00–14.00	13.10 ± 8.25	11.00	6.00–15.00	0.031
Fat [g]	9.73 ± 8.80	8.00	3.05–13.30	13.20 ± 8.99	11.00	6.00–19.00	0.008
Trans fat [g]	0.06 ± 0.15	0.00	0.00–0.00	0.05 ± 0.12	0.00	0.00–0.00	0.595
Saturated fat [g]	2.90 ± 3.19	1.85	0.80–4.15	2.96 ± 2.39	2.20	1.10–4.50	0.884
Cholesterol [mg]	27.10 ± 40.07	10.00	0.00–40.00	46.84 ± 54.11	32.00	12.00–55.00	0.007
Na [mg]	969.81 ± 543.74	865.00	566.65–1238.80	840.40 ± 415.36	809.00	520.00–1060.00	0.059
Values per 100 g							
Energy [kJ]	692.18 ± 366.51	633.20	461.30–854.20	769.87 ± 167.82	719.90	653.30–818.00	0.043
Carbohydrates [g]	23.64 ± 16.44	21.85	10.00–32.25	25.88 ± 4.06	25.70	23.50–28.10	0.150
Sugar [g]	4.22 ± 4.65	2.75	1.25–5.40	2.84 ± 2.01	2.60	1.30–3.60	0.004
Protein [g]	5.42 ± 4.65	4.70	3.50–6.85	5.95 ± 1.94	5.50	4.60–7.20	0.132
Fat [g]	5.43 ± 5.02	3.50	1.55–8.40	6.25 ± 3.84	5.00	3.80–7.50	0.194
Trans fat [g]	0.03 ± 0.09	0.00	0.00–0.00	0.04 ± 0.09	0.00	0.00–0.00	0.930
Saturated fat [g]	1.76 ± 2.12	0.80	0.35–2.90	1.33 ± 1.01	1.10	0.70–1.80	0.054
Cholesterol [mg]	13.13 ± 17.65	5.60	0.00–18.00	20.78 ± 25.90	15.20	8.40–24.70	0.024
Na [mg]	518.36 ± 419.37	413.15	322.50–567.85	393.56 ± 104.95	380.80	342.10–449.30	0.002
Si content							
Per serving size [mg]	3.03 ± 3.72	1.61	0.70–3.87	7.68 ± 8.01	2.89	1.21–12.77	< 0.001
Per 100 g [mg]	1.53 ± 1.78	0.70	0.40–2.05	4.12 ± 4.10	1.40	0.50–8.65	< 0.001

p-Value was tested by unpaired *t*-test between ready-to-cook and ready-to-eat products.
n – number of samples. *SD* – standard deviation, *IQR* – interquartile range.

Tab. 2. Price, weight and nutritional information of ready-to-cook products.

	Rice (n = 28)	Porridge (n = 12)	Noodles (n = 29)	Broth (n = 7)	Stew (n = 9)
Package price [USD]	3.43 ± 1.31 ^{cd}	2.81 ± 1.03 ^{d}	4.82 ± 1.16 ^{ab}	3.46 ± 1.14 ^{cd}	3.61 ± 0.91 ^{bcd}
Package weight [g]	282.21 ± 121.73 ^{cd}	355.83 ± 114.99 ^{bc}	543.77 ± 188.34 ^{a}	447.14 ± 77.83 ^{ab}	342.44 ± 139.75 ^{bc}
Serving weight [g]	224.61 ± 43.73 ^{b}	270.83 ± 60.78 ^{ab}	254.38 ± 75.74 ^{ab}	299.43 ± 29.09 ^{a}	246.89 ± 71.43 ^{ab}
Values per serving size					
Energy [kJ]	1 489.80 ± 269.38 ^{b}	866.43 ± 318.95 ^{cd}	1 840.30 ± 413.48 ^{a}	463.60 ± 126.05 ^{e}	885.09 ± 336.03 ^{cd}
Carbohydrates [g]	61.93 ± 14.98 ^{b}	37.81 ± 16.85 ^{c}	79.17 ± 26.75 ^{a}	7.81 ± 8.48 ^{f}	14.57 ± 5.68 ^{ef}
Sugar [g]	4.39 ± 2.87 ^{bc}	6.88 ± 10.41 ^{abc}	12.51 ± 8.67 ^{a}	1.27 ± 0.96 ^{c}	5.67 ± 2.48 ^{bc}
Protein [g]	9.25 ± 3.01 ^{cde}	6.00 ± 2.11 ^{ef}	12.30 ± 4.14 ^{bc}	10.51 ± 4.37 ^{bcde}	14.71 ± 4.24 ^{b}
Fat [g]	7.81 ± 5.27 ^{cd}	3.38 ± 2.73 ^{d}	9.06 ± 6.45 ^{bcd}	4.13 ± 3.14 ^{d}	10.64 ± 8.56 ^{bcd}
Trans fat [g]	0.03 ± 0.11 ^{bc}	0.00 ± 0.00 ^{c}	0.04 ± 0.15 ^{bc}	0.07 ± 0.13 ^{bc}	0.04 ± 0.13 ^{bc}
Saturated fat [g]	1.58 ± 1.30 ^{d}	0.77 ± 0.62 ^{d}	2.32 ± 3.35 ^{cd}	1.29 ± 1.80 ^{d}	2.80 ± 2.33 ^{bcd}
Cholesterol [mg]	27.48 ± 36.63 ^{bcd}	11.95 ± 16.24 ^{cd}	7.72 ± 19.92 ^{d}	60.00 ± 85.03 ^{b}	45.30 ± 41.04 ^{bc}
Na [mg]	757.14 ± 327.83 ^{cdef}	629.17 ± 143.34 ^{def}	1 599.23 ± 606.28 ^{a}	968.77 ± 350.77 ^{bcd}	1257.72 ± 166.90 ^{ab}
Values per 100 g					
Energy [kJ]	672.46 ± 112.89 ^{cde}	409.94 ± 449.04 ^{ef}	761.69 ± 221.09 ^{cd}	156.54 ± 45.09 ^{f}	393.98 ± 226.24 ^{ef}
Carbohydrates [g]	28.09 ± 7.19 ^{bc}	17.68 ± 18.85 ^{cd}	32.56 ± 14.25 ^{b}	2.64 ± 3.07 ^{e}	6.09 ± 2.09 ^{de}
Sugar [g]	1.89 ± 1.18 ^{cd}	2.64 ± 3.65 ^{cd}	5.11 ± 3.70 ^{bc}	0.43 ± 0.33 ^{d}	2.49 ± 1.27 ^{cd}
Protein [g]	4.19 ± 1.49 ^{def}	2.54 ± 1.74 ^{f}	5.20 ± 2.53 ^{cde}	3.60 ± 1.77 ^{ef}	6.27 ± 1.97 ^{bcd}
Fat [g]	3.47 ± 2.44 ^{cd}	1.72 ± 2.40 ^{cd}	3.72 ± 2.74 ^{cd}	1.37 ± 0.96 ^{d}	5.01 ± 5.25 ^{c}
Trans fat [g]	0.01 ± 0.05 ^{c}	0.00 ± 0.00 ^{c}	0.01 ± 0.06 ^{c}	0.03 ± 0.05 ^{bc}	0.01 ± 0.03 ^{c}
Saturated fat [g]	0.72 ± 0.67 ^{e}	0.43 ± 0.70 ^{e}	0.90 ± 1.15 ^{e}	0.41 ± 0.54 ^{e}	1.24 ± 1.14 ^{de}
Cholesterol [mg]	12.21 ± 16.45 ^{bcd}	4.16 ± 5.59 ^{cd}	2.80 ± 6.88 ^{d}	20.21 ± 28.31 ^{b}	19.93 ± 17.96 ^{b}
Na [mg]	337.77 ± 151.36 ^{c}	295.28 ± 309.69 ^{c}	652.17 ± 280.59 ^{bc}	319.64 ± 107.61 ^{c}	557.72 ± 208.49 ^{bc}
Si content					
Per serving size [mg]	3.16 ± 4.23	1.37 ± 0.46	4.25 ± 4.81	2.43 ± 2.34	5.93 ± 4.74
Per 100 g [mg]	1.54 ± 2.27	0.60 ± 0.41	1.66 ± 1.56	0.81 ± 0.79	2.64 ± 2.10

Data represent mean ± standard deviation. Different superscripts within a row (all 10 product types) indicate significant difference calculated by Duncan's multiple range test at $\alpha = 0.05$ (a > b > c > d > e > f).
n – number of samples.

data on their nutritional properties and information. Tab. 1 shows the price, weight and nutritional information of ready-to-cook and ready-to-eat HMR products. The average price and weight per package were 3.83 USD and 364.74 g for the ready-to-cook products, respectively, which were significantly higher than 1.77 USD and 212.62 g for the ready-to-eat products ($p < 0.0001$), respectively. However, serving size was not significantly different between the two types of HMR products. Energy and nutrient content per product serving size was significantly higher for ready-to-eat than for ready-to-cook products. The silicon content per serving size was significantly lower ($p < 0.0001$) for ready-to-cook products than for ready-to-eat products. Comparing the silicon content of ready-to-cook and ready-to-eat products, ready-to-eat products had a greater silicon content than ready-to-cook products. This result can be interpreted as indicating that ready-to-eat products are single meals, such as lunchboxes, kimbap, burgers or sandwiches, while ready-to-cook products are dish products that compose a meal. Daily silicon intake is believed to be in the range of 20–50 mg. McNaughton et al. [8] reported a silicon intake of 18.6 mg per day among 209 healthy postmenopausal British women aged 60 years and older. In addition, Kim et al. [17] reported that the daily silicon intake of 80 healthy Korean adults aged 20–69 was 22.8 mg for men and 19.3 mg for women, and among 185 healthy Polish adults aged 20–70, it was reported to be 24.0 mg for women and 27.7 mg for men [18]. The silicon content of 7.68 mg per serving of the ready-to-eat products in our study

Tab. 2. *continued*

	Soup (n = 5)	Bread (n = 8)	Dumplings (n = 10)	Meat dish (n = 7)	Sauce (n = 9)	p-value
Package price [USD]	2.70 ± 2.20 [d]	4.46 ± 1.45 [bc]	5.86 ± 1.38 [a]	4.27 ± 1.94 [bc]	1.37 ± 0.53 [e]	< 0.001
Package weight [g]	270.00 ± 260.38 [cd]	306.88 ± 116.16 [bcd]	381.00 ± 101.06 [bc]	279.86 ± 156.78 [cd]	166.67 ± 40.31 [d]	< 0.001
Serving weight [g]	86.00 ± 90.44 [e]	108.63 ± 31.75 [de]	151.00 ± 3.16 [d]	210.86 ± 78.18 [bc]	160.00 ± 57.66 [cd]	< 0.001
Values per serving size						
Energy [kJ]	548.10 ± 274.29 [de]	1 201.46 ± 403.22 [bc]	1 266.60 ± 135.08 [b]	1 896.31 ± 924.58 [a]	757.19 ± 240.54 [de]	< 0.001
Carbohydrates [g]	13.60 ± 2.07 [ef]	35.33 ± 11.50 [cd]	29.19 ± 4.66 [cde]	21.51 ± 10.12 [cdef]	19.11 ± 6.53 [cdef]	< 0.001
Sugar [g]	4.80 ± 1.48 [bc]	8.20 ± 4.11 [ab]	4.63 ± 2.43 [bc]	9.24 ± 5.95 [ab]	8.56 ± 4.93 [ab]	< 0.001
Protein [g]	2.00 ± 0.71 [f]	7.71 ± 3.89 [cde]	11.65 ± 1.94 [bcd]	25.69 ± 12.68 [a]	7.33 ± 4.69 [de]	< 0.001
Fat [g]	7.66 ± 7.76 [cd]	12.91 ± 6.19 [bc]	15.17 ± 3.35 [b]	29.43 ± 18.59 [a]	6.76 ± 4.74 [cd]	< 0.001
Trans fat [g]	0.16 ± 0.22 [ab]	0.14 ± 0.22 [abc]	0.11 ± 0.19 [bc]	0.26 ± 0.25 [a]	0.00 ± 0.00 [c]	0.009
Saturated fat [g]	4.52 ± 4.68 [bc]	4.78 ± 3.84 [bc]	5.11 ± 1.52 [b]	9.21 ± 2.95 [a]	3.20 ± 2.71 [bcd]	< 0.001
Cholesterol [mg]	15.00 ± 18.71 [cd]	14.04 ± 9.44 [cd]	27.65 ± 16.64 [bcd]	99.01 ± 51.58 [a]	26.56 ± 29.99 [bcd]	< 0.001
Na [mg]	438.00 ± 74.30 [f]	471.65 ± 142.20 [ef]	599.11 ± 105.33 [def]	1 064.76 ± 461.10 [bc]	846.67 ± 268.79 [cde]	< 0.001
Values per 100 g						
Energy [kJ]	1 229.52 ± 706.91 [a]	1 128.39 ± 306.10 [ab]	839.25 ± 92.85 [cd]	908.96 ± 294.81[bc]	602.44 ± 420.93 [de]	< 0.001
Carbohydrates [g]	45.70 ± 35.62 [a]	32.68 ± 5.64 [b]	19.34 ± 3.15 [cd]	10.54 ± 4.23 [de]	17.54 ± 18.34 [cd]	< 0.001
Sugar [g]	15.08 ± 11.51 [a]	7.71 ± 3.40 [b]	3.07 ± 1.63 [cd]	4.81 ± 3.15 [bc]	7.00 ± 5.87 [b]	< 0.001
Protein [g]	5.54 ± 4.34 [bcde]	7.01 ± 1.91 [bc]	7.73 ± 1.33 [b]	11.89 ± 2.13 [a]	5.36 ± 3.51 [cde]	< 0.001
Fat [g]	9.78 ± 3.07 [b]	12.50 ± 6.02 [ab]	10.05 ± 2.23 [b]	14.13 ± 7.00 [a]	5.02 ± 3.48 [c]	< 0.001
Trans fat [g]	0.08 ± 0.11 [abc]	0.11 ± 0.21 [ab]	0.07 ± 0.13 [bc]	0.16 ± 0.16 [a]	0.00 ± 0.00 [c]	0.001
Saturated fat [g]	5.66 ± 2.01 [a]	4.54 ± 3.71 [ab]	3.39 ± 1.04 [bc]	4.64 ± 1.69 [ab]	2.41 ± 1.96 [cd]	< 0.001
Cholesterol [mg]	12.60 ± 11.98 [bcd]	13.03 ± 8.88 [bcd]	18.39 ± 11.15 [bc]	47.86 ± 22.77 [a]	16.36 ± 19.04 [bcd]	< 0.001
Na [mg]	1 503.68 ± 1193.27 [a]	445.73 ± 118.53 [bc]	395.84 ± 61.16 [bc]	506.64 ± 109.50 [bc]	724.01 ± 679.06 [b]	< 0.001
Si content						
Per serving size [mg]	1.58 ± 2.36	2.72 ± 2.79	1.60 ± 1.16	2.52 ± 2.35	1.51 ± 1.66	0.079
Per 100 g [mg]	2.12 ± 1.89	2.19 ± 2.08	1.05 ± 0.75	1.09 ± 0.66	1.64 ± 2.57	0.278

was similar to the silicon intake of 7–17 mg for a meal, which is one-third of the daily common intake.

Tab. 2 shows data on price, weight and nutritional information of ready-to-cook products. Product prices and weights were highest for dumplings and noodles, respectively, while lowest for sauces among product types ($p < 0.0001$). Regarding energy, carbohydrates, sugars and sodium content, noodles had the highest content per serving, while soups had the highest content per 100 g. Meat dish products had the highest protein and fat contents. Regarding silicon content, stews had the highest content and porridge the lowest, with no significant differences between product types.

Ready-to-cook products are produced and sold as individual dishes that compose a meal, while ready-to-eat products can be used as a single meal. A typical Korean meal consists of rice as a staple dish, a soup or stew and a variety of side dishes. This allows consumers to conveniently prepare meals by selecting a part from a variety of ready-to-cook products. In this study, ready-to-cook products were categorized according to the types of dishes that compose a meal and their silicon contents were compared. The silicon content per serving size ranged from 0.70–3.87 mg for 124 ready-to-cook products. The silicon content by ready-to-cook product type was highest for stews and lowest for porridge with no significant difference between product types.

Major food sources of dietary silicon in Western countries are cereals and their products, such as breakfast cereals, bread, beer and some fruits and vegetables [19]. Rice products, which are staple dishes in Asian meals, had a silicon content of 3.16 mg per serving in this study. This value was similar to 1.89 mg per 100 g in instant cooked rice and 2.19 mg per 100 g in rice reported by Choi and Kim [10]. A rice-based meal with stew (5.93 mg per serving) and a meat dish (2.52 mg per serving) can provide a total of 11.61 mg of silicon. Especially, Korean HMR stews, such as soybean-paste stew or kimchi stew, may be higher in silicon because they contain a variety of ingredients, mostly vegetables, as opposed to Western stews, which contain mostly meat. Therefore, the silicon content of this simple meal is similar to 7–17 mg of a typical silicon intake per meal, which is higher than that in a single ready-to-eat product. However, since silicon content varies widely among ready-to-cook products and is not mandatorily included on nutrition fact labels, it is difficult to choose foods with high silicon contents, so future research and strategies to overcome this shortcoming are needed.

Tab. 3 shows the price, weight and nutritional information of ready-to-eat products. The average price, weight and energy and nutrient content per product were significantly higher for lunchboxes. However, burgers had the highest energy and nutrient contents per 100 g of product. The silicon content was significantly higher in kimbap than in other products. The distribution of HMR types according to silicon content and price is shown in Tab. 4. The percentages of products with a high silicon content and low price were significantly highest in noodles among ready-to-cook products and kimbap among ready-to-eat products.

HMR are produced to meet consumer demands for convenience, taste and nutrition.

Tab. 3. Price, weight and nutritional information of ready-to-eat products.

	Lunchbox (n = 11)	Kimbap (n = 53)	Burger (n = 5)	Sandwich (n = 8)	p-value
Package price [USD]	3.32 ± 0.24 a	1.43 ± 0.48 c	1.94 ± 0.36 b	1.79 ± 0.17 bc	< 0.001
Package weight (= serving weight) [g]	390.91 ± 47.73 a	182.51 ± 57.0 b	194.40 ± 54.33 b	178.38 ± 31.45 b	< 0.001
Values per serving size					
Energy [kJ]	3 026.93 ± 416.74 a	1 256.15 ± 368.30 d	2 176.50 ± 694.48 b	1 768.25 ± 292.35 c	< 0.001
Carbohydrate [g]	97.18 ± 11.69 a	46.17 ± 12.55 b	53.00 ± 14.42 b	46.38 ± 13.20 b	< 0.001
Sugar [g]	11.18 ± 5.34 a	3.89 ± 2.58 b	12.60 ± 3.05 a	9.63 ± 5.53 a	< 0.001
Protein [g]	28.91 ± 5.97 a	9.36 ± 4.17 c	18.40 ± 6.80 b	12.88 ± 3.60 c	< 0.001
Fat [g]	23.91 ± 7.20 a	8.63 ± 5.00 b	26.20 ± 11.84 a	20.63 ± 3.85 a	< 0.001
Trans fat [g]	0.03 ± 0.06	0.06 ± 0.14	0.08 ± 0.18	0.04 ± 0.07	0.823
Saturated fat [g]	6.24 ± 1.95 a	1.84 ± 1.41 c	5.74 ± 3.24 a	4.16 ± 1.56 b	< 0.001
Cholesterol [mg]	126.64 ± 68.25 a	24.22 ± 19.96 c	72.00 ± 52.12 b	71.25 ± 74.90 b	< 0.001
Na [mg]	1 510.82 ± 387.45 a	707.43 ± 288.28 c	1 069.40 ± 260.39 b	656.38 ± 293.65 c	< 0.001
Values per 100 g					
Energy [kJ]	775.88 ± 76.40 c	700.08 ± 95.29 c	1 116.64 ± 160.19 a	1 007.25 ± 167.66 b	< 0.001
Carbohydrates [g]	24.94 ± 1.98	25.92 ± 4.24	27.44 ± 2.53	25.91 ± 5.72	0.727
Sugar [g]	2.89 ± 1.48 b	2.09 ± 1.20 b	6.62 ± 1.19 a	5.35 ± 2.73 a	< 0.001
Protein [g]	7.40 ± 1.47 b	5.12 ± 1.42 c	9.38 ± 1.12 a	7.29 ± 1.73 b	< 0.001
Fat [g]	6.11 ± 1.67 b	4.75 ± 2.31 b	13.36 ± 4.73 a	11.96 ± 3.63 a	< 0.001
Trans fat [g]	0.00 ± 0.00	0.04 ± 0.10	0.06 ± 0.13	0.03 ± 0.07	0.525
Saturated fat [g]	1.59 ± 0.51 b	0.95 ± 0.60 b	3.02 ± 1.88 a	2.40 ± 1.17 a	< 0.001
Cholesterol [mg]	31.95 ± 17.27 ab	12.91 ± 10.68 b	39.42 ± 31.07 a	45.90 ± 61.85 a	< 0.001
Na [mg]	391.97 ± 118.34 b	381.96 ± 83.19 b	561.64 ± 112.24 a	367.54 ± 137.81 b	0.002
Si content					
Per serving size [mg]	3.39 ± 3.66 ab	9.73 ± 8.67 a	5.88 ± 3.23 ab	1.09 ± 0.83 b	0.0047
Per 100 g [mg]	0.93 ± 1.14 b	5.40 ± 4.26 a	3.28 ± 2.13 ab	0.59 ± 0.43 b	0.0002

Data represent mean ± standard deviation. Different superscripts within a row indicate significant difference calculated by Duncan's multiple range test at $\alpha = 0.05$ (a > b > c > d).
n – number of samples.

Tab. 4. Distribution of home meal replacements according to silicon content and price.

Si content per 100 g		≥ Median				< Median				χ^2-value	*p*-value
Price per 100 g		< Median		≥ Median		< Median		≥ Median			
Number of samples		*n*	[%]	*n*	[%]	*n*	[%]	*n*	[%]		
Ready-to-cook	Rice (*n* = 28)	2	7.1	8	28.6	8	28.6	10	35.7	72.732	< 0.001
	Porridge (*n* = 12)	2	16.7	2	16.7	8	66.6	0	0.0		
	Noodles (*n* = 29)	13	44.8	6	20.7	8	27.6	2	6.9		
	Broth (*n* = 7)	3	42.9	0	0.0	4	57.1	0	0.0		
	Stew (*n* = 9)	2	22.2	4	44.5	3	33.3	0	0.0		
	Soup (*n* = 5)	1	20.0	3	60.0	1	20.0	0	0.0		
	Bread (*n* = 8)	0	0.0	6	75.0	0	0.0	2	25.0		
	Dumplings (*n* = 10)	0	0.0	6	60.0	0	0.0	4	40.0		
	Meat dish (*n* = 7)	0	0.0	6	85.7	0	0.0	1	14.3		
	Sauce (*n* = 9)	2	22.2	2	22.2	5	55.6	0	0.0		
Ready-to-eat	Lunchbox (*n* = 11)	0	0.0	2	18.2	3	27.3	6	54.5	45.202	< 0.001 *
	Kimbap (*n* = 53)	21	39.6	11	20.8	14	26.4	7	13.2		
	Burger (*n* = 5)	0	0.0	5	100.0	0	0.0	0	0.0		
	Sandwich (*n* = 8)	0	0.0	1	12.5	0	0.0	7	87.5		

n – number of samples, * – analysed by Fisher's exact test.

As these factors are met, the high price of HMR products is a burden to consumers. When comparing the silicon content by price of HMR products in this study, the types with the highest silicon content at lower prices were noodles among ready-to-cook HMR and kimbap among ready-to-eat HMR products. McNaughton et al. [8] reported that the food group with the highest contribution to silicon intake was grains, such as breakfast cereals, breads, rice or pasta, among 209 women aged 60 years and older. Our previous study showed the same results among 400 healthy Korean adult males aged 19–25 [10]. Kim et al. [17] also reported a high silicon intake from vegetables and grains among 80 healthy Korean adults aged 20–69. Kimbap is a rice dish seasoned with salt and sesame oil, filled with various fillings, rolled in seaweed and then cut into bite-sized pieces. Kimbap is often used as a whole meal in Korea because it contains rice as a staple food and a variety of ingredients, such as seaweed, vegetables, eggs or meats, which are rich in minerals and vitamins [20]. Present study also found similar results, identifying kimbap as an inexpensive and nutritious ready-to-eat product with a high silicon content.

The silicon content of HMR products per estimated energy requirement (*EER*, 10 878 kJ) for Korean men aged 19–29 years is shown in Fig. 1. Among ready-to-cook products, the silicon content per this energy was the highest in stew, followed by broth, bread, noodles and soup. Among ready-to-eat products, the silicon content was the highest in kimbap, followed by burgers, lunchboxes and sandwiches. Modern society is concerned about micronutrient deficiency at excessive energy intake, as dietary issues appear alongside high-energy and low-nutrient meals. An index of nutritional quality [21], which calculates whether a particular nutrient meets the reference value when the reference energy value is met, is used to assess the nutrient density degree of foods or diets. In this study, because the reference value of silicon is not set in Korea [22], the silicon content per *EER* value for adult men, was assessed in HMR products. The results showed that the silicon content was the highest in stew among ready-to-cook products and in kimbap among ready-to-eat products (Fig. 1).

Analysing the silicon content of 53 selected instant foods, Prescha et al. [23] reported that silicon contents per serving in soups (0.10–30.20 mg), main courses (0.63–37.91 mg) and coffee drinks (0.21–13.37 mg) ranged widely and some products, such as tomato soups, Napoli spaghetti or spaghetti Bolognese, contained more than 25 mg of silicon in one ready-to-eat serving. In our study, the silicon content of HMR products also varied widely, even within the same product type. Nevertheless, when comparing the silicon content per serving by HMR types, kimbap, stew, and noodles showed to have high silicon content. Silicon content was reported to be higher in plant foods than in meat or dairy products,

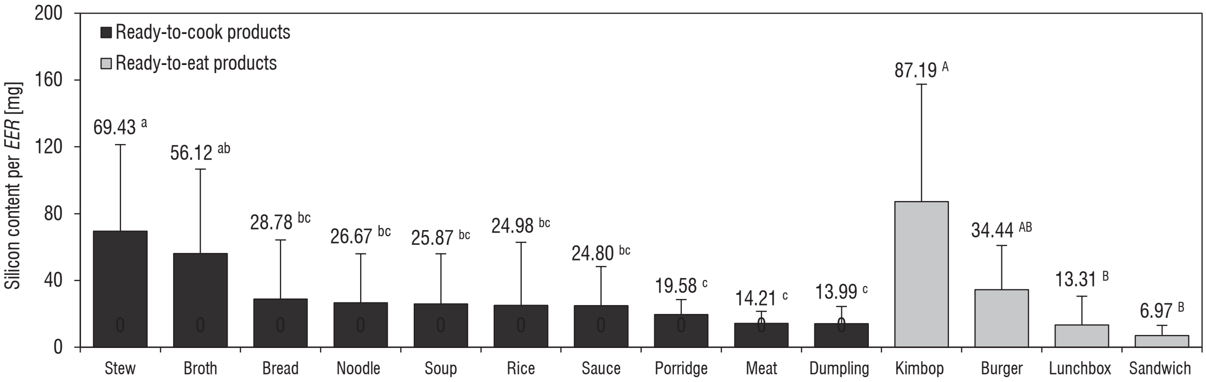

Fig. 1. Silicon content of home meal replacements per estimated energy requirement for Korean men aged 19–29 years.

Different superscripts above the bars indicate significant difference calculated by Duncan's multiple range test at $\alpha = 0.05$ (a > b > c and A > B). *EER* – estimated energy requirement (10 878 kJ).

while being abundant in grains, vegetables and beverages [9, 19]. Wheat products have higher levels of silicon than rice products, as reported for spaghetti products by Prescha et al. [23]. Stew, a brothy food containing a variety of foods, mainly vegetables that are silicon sources [9, 19], has higher levels of silicon. In addition, as mentioned earlier, kimbap is made from a variety of ingredients, including silicon sources, which might cause that its silicon content per 10 878 kJ was the highest among ready-to-eat products.

Our study has some limitations and strengths. The notable weakness in this study is the difficulty in generalizing the results due to regional limitations and the comparatively small number of HMR products analysed. However, our findings on the silicon content of various types of HMR products could be useful for making adequate nutritional choices regarding silicon. As the supply and demand for HMR products are expanding substantially, it is necessary to continuously analyse a variety and wider range of HMR products and to compare them according to characteristics, such as main ingredients, to build a database of silicon content.

CONCLUSIONS

This study showed that the silicon contents per serving size of HMR products were 0.70–3.87 mg for 124 ready-to-cook products and 1.21–12.77 mg for 77 ready-to-eat products. The types of foods with lower product prices and higher silicon contents were noodles among ready-to-cook products and kimbap among ready-to-eat products. The silicon content per 10 878 kJ, the *EER* value for adult men in Korea, was the highest in stew among ready-to-cook products and in kimbap among ready-to-eat products. The database of the silicon content in HMR products constructed through our results can be used to expand food composition database and assess the intake of silicon. The findings can also be used to choose HMR products that ensure adequate silicon intake.

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