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Daily intake assessment of saccharin, stevioside, D-sorbitol and aspartame from various processed foods in Korea

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Abstract
This study was carried out to estimate the daily intakes (EDIs) of artificial sweeteners such as saccharin, stevioside, D-sorbitol and aspartame in order to evaluate the safety of the artificial sweeteners in Korea. A total of 274 food samples were selected from the foods considered to be representative sources of artificial sweeteners in the Korean diet and analysed by using HPLC with evaporative light scattering and ultraviolet detectors. In case of aspartame, the reference values were used without instrumental analysis. The EDIs of saccharin, stevioside, D-sorbitol and aspartame for average consumers were 0.028, 0.008, 4.9 and 0.14 mg kg^{-1} body weight day^{-1}, respectively, and as a proportion of the acceptable daily intake (ADI) were not higher than 1% of ADI of the Joint FAO/WHO Expert Committee on Food Additives (JECFA). For 90th percentile consumers, the EDIs of saccharin, stevioside, D-sorbitol and aspartame were 2.0, 0.20, 141 and 4.6 mg kg^{-1} body weight day^{-1}, respectively, and as a proportion of the ADI, the EDIs of saccharin and aspartame were 40.7% and 11.4% of the ADI set by the JECFA, respectively. Because JECFA did not assign ADIs for stevioside and D-sorbitol, the values for these sweeteners were not compared. According to these results, the EDIs of artificial sweeteners such as saccharin and aspartame in Korea are significantly lower than ADI set by the JECFA.

Keywords: *Estimated daily intake (EDI), monitoring, artificial sweeteners, saccharin, stevioside, D-sorbitol, aspartame*

Introduction

The replacement of sugars with non-nutritive sweeteners in foods and beverages presents a variety of challenges to the food technologist. The main purposes of the replacement might be low calories, economics, stability, intense sweetness and the prevention of dental problems (Bakal 1987). For these reasons, there has been a growing desire in most countries to use artificial sweeteners other than sucrose. However, statistics on the use of sweeteners is diverse amongst different countries because of differences in the approval status of food additives by technical regulation depending on countries. Saccharin, stevioside, D-sorbitol and aspartame are the most popular artificial sweeteners in Korea.

Saccharin, stevioside and aspartame are approximately 200 times sweeter than sucrose and have been used for a number of years as sweeteners in many countries (Homler 1984; Newsome 1986; Crosby and Furia 2000). D-sorbitol has about half the sweetness of sucrose and is absorbed more slowly in the digestive tract than sucrose. Because of this effect, sorbitol is used mainly as a sweetening agent for dietetic foods (Salminen and Hallikainen 1990).

Some adverse effects have been reported for saccharin, stevioside and aspartame. In some long-term rat studies, an induction of a higher incidence of bladder cancer was found among rats consuming saccharin (Salminen and Hallikainen 1990). Limited evidence suggests stevioside is non-toxic to humans. However, a recent study has shown that stevioside is degraded by rat intestinal microflora, and the resulting steviol (that can cause mutation) is almost completely absorbed (Crosby and Furia 2000). The results of one long-term

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rat study with aspartame were consistent with an increased incidence of intracranial neoplasm in the treated animals (Salminen and Hallikainen 1990). The toxicology of sorbitol has been reviewed recently by the WHO. The Joint FAO/WHO Expert Group on Food Additives has given sorbitol an average daily intake (ADI) of 'not specified', which means that no health hazards are foreseen. Since sorbitol is absorbed slowly, foods sweetened with it are thought suitable for diabetics provided the calories are taken into account. However, large amounts of sorbitol can cause flatulence, diarrhoea and abdominal distension. Gradual addition of sorbitol into the diet may increase the tolerance of the individual (Salminen and Hallikainen 1990).

Although saccharin, stevioside, D-sorbitol and aspartame are not strongly hazardous materials, it is necessary to assess the potential risk because Koreans consume these artificial sweeteners everyday. One approach for assessing human exposure to potentially harmful chemicals is by food-monitoring programmes such as the analysis of representative food items (Coancher and Mes 1993). Some European countries have evaluated the daily intake of artificial sweeteners such as sodium saccharin and aspartame through consumer surveys: the UK (Hinson and Nicol 1992), Germany (Bär and Biermann 1992), and the Netherlands (Hulshof and Bouman 1995), and the daily intake of saccharin has been evaluated in Japan (Japanese Food Additive Association 1989). However, data on artificial sweeteners in food items are scarce in Korea.

In this study, the concentrations of saccharin, stevioside and D-sorbitol in various processed foods were determined and the estimated daily intakes (EDIs) of saccharin, stevioside, D-sorbitol and aspartame were estimated by coupling the concentrations of these sweeteners in foods with individual dietary intake data obtained from the National Nutrition Survey in 1998. In the case of aspartame, since information can be obtained from recently monitored data (Lee et al. 1997), the reference values were used without instrumental analysis.

Materials and methods

Sampling plan and the determination of saccharin, stevioside and D-sorbitol in foods

Stevioside can be used as a sweetener, but with some with limitations. It should not be added in some food categories. D-sorbitol is permitted for use in any kind of food in Korea. Therefore, manufacturers and importers of stevioside and D-sorbitol were surveyed to determine the target food categories to prioritize monitoring. Domestic food manufacturers using stevioside and D-sorbitol were also surveyed.

As a result, foods that used saccharin, stevioside and D-sorbitol are shown in Table I. In this study, based upon the results of the above survey (Table I), food categories for estimating the daily intake of saccharin, stevioside and D-sorbitol were selected.

Thirteen food categories such as snack, *gang-naeng-ie* (a kind of pop corn), *kimchi* (vegetables such as Chinese cabbage, radish, cucumber and green onion, which are pickled in salt and fermented with mixture of red pepper and spices), pickled garlic, pickled scallion, pickled radish, pickled cucumber, *jeot-kal* (a food product made of whole or parts of fish, crustaceans, molluscs and echinoderms as raw materials that are fermented and salted), *surimi* (Japanese food product made of water-washed protein of fish), popsicle, yoghurt, soy sauce, and beverage were selected and it was determined which were considered to be representative sources of saccharin in the Korean diet. Nine food categories such as *gang-naeng-ie*, candy, honey, pickled radish, pickled cucumber, *jeot-kal*, carbonated beverage, *so-ju* (a traditional liquor made of starch and *koji*, which are fermented and distilled), soy sauce for the stevioside and 18 food categories such as snack, bread, candy, chewing gum, *kimchi*, dried fish, fish sausage, fried *surimi*, *jeot-kal*, *surimi*, popsicle, yoghurt, *so-ju*, beverage, bacon, sausage, ham,

Table I. Food usage of saccharin, stevioside and D-sorbitol in Korea.

Artificial sweeteners	Manufacturer	Main food usage
Saccharin	Kumyang Co. Shinwon JMC Co.	Pickled products Ground fishery product Cookies Dried file fish Seasonings Soy sauce Popsicles
Stevioside	Samyang Technil Taepyungyang Co. Kwangmil Co. Samyang Henex Co.	Cookies Sugar product Beverages Seasonings Soy sauce Honey *So-ju*
D-sorbitol	Backkwang Co. LG Chemical Co. Samyang Henex Co.	Ground fishery products Ground meat products Dried file fish Pickled foods *Jeot-kal* Cookies Beverages Milk products *So-ju*

Data are the result of manufacturers' survey in the present study.

ground meat product for the D-sorbitol were selected. They were considered to be representative sources of stevioside and D-sorbitol in the Korean diet.

The content of saccharin in foods has been monitored for several years in Korea (Kim et al. 1990, 1999; Park and Lee 1992). According to previous studies, the detection rates of saccharin in foods differ. There is a much greater probability of detecting saccharin from foods showing a higher detection rate based on previous studies than those showing a lower detection rate. Due to this fact, food samples for the EDI of saccharin were selected by a stratified random sampling method employing a detection rate obtained from previous studies as a stratum. The detection rates for the same food sample in the above three studies used the most recent data set. As these have rarely been found in the previous monitoring study on stevioside and D-sorbitol, the above sampling method could not be applied. It is a much greater chance to intake the stevioside and D-sorbitol from foods showing a higher total production amount than those showing a lower total production amount. Therefore, food samples for the EDI of stevioside and D-sorbitol were selected by a stratified random sampling method employing the total production amount of foods containing these sweeteners obtained from National Statistical Data on Foods and Food Additives in 1998 (KFDA 1999) as a stratum. The total production amount of foods containing stevioside and D-sorbitol deviated in each other. In order to collect the scattered total production mount data, data should be transformed by using third root (Quenoille 1950; Federer 1955). This sampling method is frequently used for stratified random sampling in all surveys. It is called proportional allocation because the sample size in each stratum is taken in proportion to the size of the stratum (Scheaffer et al. 1990).

The total sample numbers for the analysis of saccharin were determined according to equation (1); the total sample numbers for stevioside and D-sorbitol were determined according to equation (2):

$$n_{\mathrm{a}} = \frac{D_i}{\sum D_i} \times 100 \times \mathrm{TN} \qquad (1)$$

where n_{a} is the sample numbers of the specific 'a' food category, D_i is the previous detection rate (%) of sodium saccharin in the specific food categories, and TN is the total number of samples supposed to be analysed for the sodium saccharin:

$$n_{\mathrm{a}} = \frac{\sqrt[3]{P_{\mathrm{a}}}}{\sum \sqrt[3]{P_{\mathrm{n}}}} \times 100 \times \mathrm{TN} \qquad (2)$$

where n_{a} is the sample numbers of the specific 'a' food category, P_{a} is the amount of total production of 'a' food category containing 'a' artificial sweetener, P_{n} is the amount of total production of 'n' kinds of food categories containing 'a' artificial sweetener, and TN is the total number of samples supposed to be analysed for the specific 'a' artificial sweetener.

The samples in all food categories were purchased by a stratified random sampling basis of market share information. Half of the samples in each food category were from the companies in the upper 25% of market shares and 30% of samples were from the companies in the middle 50% of market share. The other 20% of samples were from the companies in the lower 25% of market share. These sampling designs were employed by Yoon et al. (2001, 2003), and more detailed information related to the sampling design are described in those papers.

HPLC analyses

Standards were purchased from Acros Organics (Geel, Belgium) for the analysis of saccharin and stevioside, and Sigma Chemical Co. (St Louis, MO, USA) for the analysis of D-sorbitol. Acetonitrile, toluene, methanol and distilled water of high-performance liquid chromatography (HPLC) grade were obtained from Wako Pure Chemicals (Osaka, Japan).

HPLC analysis for saccharin was performed according to the method of Chen and Fu (1995), with a slight modification on the solvent system. The mobile phase was 10 : 3 : 7 0.05% sodium phosphate buffer, acetonitrile and methanol.

HPLC analyses for stevioside were performed according to the method of Kitada et al. (1989), with a slight modification on sampling quantity. In case of liquid samples, 20 ml sample were treated in a Sep-Pak C_{18}, Millipore (Milford, MA, USA), which was pre-wetted with 5 ml methanol and water.

The extraction of D-sorbitol from the liquid phase foods was performed according to a pretreatment method of the Japanese Food Additive Association (1992), with a slight modification. The extracts were filtered with 0.45 μm membrane filter (Millipore) before HPLC analyses. The extraction of D-sorbitol from the solid-phase foods was performed according to the method of Dunmire and Otto (1979), with a slight modification. Samples containing more than 8% fat content were treated with diethyl ether instead of chloroform to remove fat in the sample and were filtered with a 0.45-μm membrane filter instead of centrifuging for 10 min at 2000 rpm. In the case of the chewing gum sample, extraction of D-sorbitol was followed by the method of Samarco (1977).

All treated samples were analysed by HPLC using the conditions shown in Table II. All samples and

Table II. HPLC conditions for analysis of saccharin, stevioside and D-sorbitol.

	Saccharin	Stevioside	D-sorbitol
HPLC system	Waters 510 pump	Waters 510 pump	Waters 600 pump
Injector			Model 7725
Column	Capcell-Pak	μBondapak NH_2	Sugar-Pak
Detector	Ultraviolet detector, 215 nm	486 ultraviolet detector, 210 nm	Altech, Evaporative Light Scattering Detector
Mobile phase	0.05% sodium phosphate buffer : acetonitrile : methanol = 10 : 3 : 7	Acetonitrile : water = 80 : 20	Water
Column temperature	–	–	90°C
Flow rate	0.8 ml min^{-1}	1.0 ml min^{-1}	0.5 ml min^{-1}
Drift temperature	–	–	122°C
Gas flow rate	–	–	2.6 SLPM[1]
Injection volume	20 μl	20 μl	20 μl

[1] Standard litres min^{-1}.

standards were run in duplicate, and the retention times were 26.4 min for saccharin, 6.6 min for stevioside and 15.0 min for D-sorbitol. Mean recoveries of saccharin, stevioside and D-sorbitol were 96.2, 99.0 and 97.6%, respectively. The detection limits for saccharin, stevioside and D-sorbitol were 10, 4 and 40 mg kg^{-1}, respectively.

Food consumption data

Food consumption data for assessment of the daily intake of saccharin, stevioside and D-sorbitol were obtained from the Korea National Health and Nutrition Survey 1998 (Ministry of Health and Welfare 1999). The Korea National Health and Nutrition Survey 1998 (KNHNS) was conducted based on the National Health Promotion Act of 1995 (Ministry of Health and Welfare, 1995, National Health Promotion Act, Seoul, MOHW) by a research institute experienced in nationwide surveys and the unique nationwide nutrition survey in Korea. Briefly, the survey visited 4828 households nationwide and was completed for 2 months from November to December in 1998. The sample households were selected by a stratified sampling method employing region and district as strata. Among those 4828 households visited, 4395 households agreed to participate, making up 11 525 subjects. Everyone aged 1 year and over in each sample household was included in the survey. This survey employed a 1-day 24-h recall method to monitor individual dietary intake. Those who could not be directly interviewed such as children and the elderly were interviewed with his/her guardian's help. To identify the types and quantity of food products used for cooking, the recipes for the foods were surveyed by interviewing housewives or guardians. Also, the intake amounts of food and processed food at eat-out as well as those in-house were surveyed through individual interview. The food intake of individuals was estimated using the recipes from each interviewed household and catering services for schools, work sites, etc.

The national survey methods and results by region and by age were described in detail elsewhere (Ministry of Health and Welfare 1999; Kim et al. 2003, 2004).

Assessment of the estimated daily intakes (EDIs) of saccharin, stevioside, D-sorbitol and aspartame

For average and high consumers (90th and 95th percentiles of consumers only) the EDIs of saccharin, stevioside, D-sorbitol and aspartame were calculated based on individual food intake data obtained from the National Health and Nutrition Survey in 1998 (MOHW 1999) and analytical data of 13 food categories for saccharin, nine food categories for stevioside and 18 food categories for D-sorbitol, and the reference value obtained from a previous study (Lee et al. 1997) for aspartame. The Korea National Health and Nutrition Survey results for average consumers of the selected food categories are shown in Table III. For average consumers, $\mathrm{EDI}_{(\mathrm{ave})i}$'s for each food category were obtained by multiplying the overall mean concentration (C_{ave}) of saccharin, stevioside, D-sorbitol and aspartame in each food category with the mean food consumption data $\{F_{(\mathrm{ave})i}\}$ of the total population per food category. Overall mean concentration was calculated from all samples' values and not detected was considered as '0'. For high consumers, $\mathrm{EDI}_{(90\mathrm{th})i}$'s and $\mathrm{EDI}_{(95\mathrm{th})i}$'s for each food category were obtained by multiplying the overall mean concentration (C_{ave}) of saccharin, stevioside, D-sorbitol and aspartame in each food category and the 90th percentile consumption data $\{F_{(90\mathrm{th})i}\}$ or 95th percentile consumption data $\{\mathrm{F}_{(95\mathrm{th})i}\}$ of consumers only. The calculation method of EDIs of saccharin, stevioside, D-sorbitol and aspartame was similar to previous reports (Yoon et al. 2001, 2003). EDIs were

Table III. Consumption data of food in which saccharin, stevioside, D-sorbitol and aspartame are used in Korea (1998 KNHNS) (g/person day^{-1}).

	Average consumption									High consumption	
		Age (years)									
Food categories	All subjects	1–2	3–6	7–12	13–19	20–29	30–49	50–64	>65	90th percentile	95th percentile
Snack	8.26	15.87	18.57	22.13	17.59	7.59	3.09	1.64	2.16	110.00	148.80
Gang-naeng-ie[a]	0.35	0.18	1.35	1.34	0.49	0.38	0.07	0.00	0.01	129.60	139.70
Bread	18.45	15.22	25.62	32.45	33.39	22.74	12.55	10.39	6.46	200.00	261.00
Chewing gum	0.04	0.27	0.19	0.04	0.05	0.01	0.01	0.00	0.00	14.00	15.00
Honey	0.56	0.09	0.03	0.54	0.75	0.36	0.93	0.34	0.11	84.00	200.20
Candy	0.54	1.41	1.68	1.33	0.89	0.17	0.20	0.25	0.55	30.00	47.00
Kimchi[b]	83.76	9.89	21.74	50.45	78.57	89.75	105.29	94.49	85.59	213.33	254.09
Pickled garlic	0.17	0.00	0.02	0.01	0.15	0.29	0.18	0.28	0.12	40.00	50.00
Pickled scallion	0.01	0.00	0.11	0.00	0.00	0.00	0.02	0.00	0.00	56.42	56.42
Pickled radish	3.37	0.79	3.07	3.07	5.21	6.11	3.38	1.35	0.32	75.00	100.28
Pickled cucumber (pickled in salt, pickled in vinegar)	0.26	0.01	0.03	0.38	0.54	0.27	0.29	0.08	0.17	108.39	170.7
Jeot-kal[c]	2.67	0.18	0.21	0.86	1.74	1.94	3.80	3.73	3.86	31.92	52.71
Mixed *surimi* (fish sausage, fried *surimi*, *surimi*)[d]	7.80	2.23	7.82	9.06	15.45	12.09	6.57	3.46	1.61	95.48	134.73
Popsicle	0.23	0.00	0.67	1.48	0.10	0.00	0.12	0.00	0.00	192.00	330.00
Yoghurt	10.49	47.55	33.35	13.67	9.06	8.71	7.09	4.21	5.30	202.50	270.30
Soy sauce (Korean and Chinese style)	6.60	1.82	3.70	5.84	6.39	6.74	7.97	6.82	5.30	19.22	28.06
Carbonated beverage	21.58	10.55	23.58	26.07	50.12	35.07	14.32	8.88	4.07	435.60	529.90
So-ju[e]	17.18	0.06	0.03	0.17	4.60	20.07	26.33	27.32	12.42	511.90	682.60
Dried file fish	0.35	0.08	0.28	0.57	1.03	0.73	0.14	0.01	0.01	36.92	48.47
Bacon	0.18	0.00	0.27	0.20	0.32	0.27	0.20	0.00	0.00	82.76	87.59
Sausage	1.22	0.96	2.23	1.73	3.38	1.47	0.69	0.31	0.07	74.00	112.80
Ham	2.96	0.89	5.88	5.54	6.45	3.60	1.88	0.96	0.09	80.67	104.30
Ground meat	0.12	0.00	0.16	0.27	0.39	0.00	0.13	0.00	0.00	100	100

[a] Food product of puffed corn.
[b] Vegetables such as Chinese cabbage, radish, cucumber and green onion, which are pickled in salt and fermented with mixture of red pepper and spices.
[c] Food product made of whole or parts of fish, crustaceans, molluscs and echinoderms as raw materials that are fermented and salted.
[d] Japanese food product made of water-washed protein of fish.
[e] Traditional liquor made of starch and *koji* that are fermented and distilled.
KNHNS, Korea National Health and Nutrition Survey.

adjusted with the standard body weights (bw_i) of *Recommended Dietary Allowances for Koreans* (The Korean Nutrition Society 2000) for the total population and age group.

To evaluate the dietary intakes of saccharin and aspartame, the EDIs were compared with ADI for saccharin, and aspartame 5 and 40 $mg\,kg^{-1}\,bw\,day^{-1}$, respectively, evaluated by the Joint FAO/WHO Expert Committee on Food Additives (JECFA) (FAO/IPCS 1999). Because the JECFA did not assign ADIs for stevioside and D-sorbitol; the values for these sweeteners were not compared.

Results and discussion

Monitoring results of saccharin, stevioside and D-sorbitol

The monitoring results of saccharin in various foods are shown in Table IV. A total of 62 food items of 13 food categories were sampled for the analysis of saccharin. Saccharin was detected in five food categories such as *gang-naeng-ie*, pickled scallion, pickled garlic, pickled radish and pickled cucumber. The detection rate of pickled garlic and pickled scallion were 100%. However, the saccharin content in pickled scallion was the highest in terms of positive means followed by pickled radish, pickled garlic, pickled cucumber, which were 586, 548, 517 and 264 ppm, respectively. The monitoring results of stevioside in foods are shown in Table V. A total of 62 food items of nine food categories were sampled for the analysis of stevioside. *So-ju*, a traditional liquor in Korea, showed the highest detection rate of stevioside: 78%. However, the stevioside content in *gang-naeng-ie* was the highest in terms of positive means followed by pickled radish and soy sauce, which were 82.8, 56.5 and 54.6 ppm, respectively. Monitoring results of D-sorbitol in various foods are shown in Table VI. A total of 150 food items in 18 food categories were sampled for the analysis of sorbitol. Chewing gum, dried file fish, fish sausage and *surimi* showed 100% detection rate. The sorbitol content in chewing gum was 109 ppm, which was the highest in terms of positive means followed by dried file fish, candy, *jeot-kal* and fish sausage, which are 61 788, 23 231, 20 254 and 12 979 ppm, respectively.

Estimated daily intakes (EDIs) of sodium saccharin, stevioside, D-sorbitol and aspartame

Tables VII and VIII show the daily intakes of saccharin, stevioside, D-sorbitol and aspartame for average and high consumers (90th and 95th percentiles of consumers only). For average consumers, the daily intake of saccharin ranged from 0.004 to 0.082 $mg\,kg^{-1}\,bw\,day^{-1}$ (Table VIII). There was no marked difference in the EDI of saccharin among age groups for average consumers, but the EDIs for young children (3–6 years) were slightly higher than those of other age groups (Table VIII). This is because the young children consumed more foods with saccharin such as pickled radish, *gang-naeng-ie*

Table IV. Concentrations of saccharin in various foods.

Food category	Number of samples	Number of detected samples	Saccharin concentration (ppm)		
			Range	Overall mean*	Positive mean**
Snack	8	0	n.d.	n.d.	n.d.
Gang-naeng-ie[a]	4	2	n.d.–380	130	260
Kimchi[b]	2	0	n.d.	n.d.	n.d.
Pickled garlic	3	3	224–708	517	517
Pickled scallion	2	2	409–764	586	586
Pickled radish	4	3	n.d.–736	411	548
Pickled cucumber (pickled in salt, pickled in vinegar)	8	3	n.d.–405	98.9	264
Jeot-kal[c]	3	0	n.d.	n.d.	n.d.
Surimi[d]	2	0	n.d.	n.d.	n.d.
Popsicle	6	0	n.d.	n.d.	n.d.
Yoghurt	6	0	n.d.	n.d.	n.d.
Soy sauce	9	0	n.d.	n.d.	n.d.
Beverage	5	0	n.d.	n.d.	n.d.

n.d., Not detected.
*Mean calculated from all samples values. n.d. was considered as '0'.
**Mean calculated from values of detected samples.
[a] Food product of pop corn.
[b] Vegetables such as Chinese cabbage, radish, cucumber and green onion, which are pickled in salt and fermented with mixture of red pepper and spices.
[c] Food product made of whole or parts of fish, crustaceans, molluscs and echinoderms as raw materials that are fermented and salted.
[d] Japanese food product made of water-washed protein of fish.

Table V. Concentrations of stevioside in various foods.

Food category	Number of samples	Number of detected samples	Stevioside concentration (ppm)		
			Range	Overall mean*	Positive mean**
Gang-naeng-ie[a]	4	1	n.d.–82.8	20.7	82.8
Candy	2	0	n.d.	n.d.	n.d.
Honey	2	0	n.d.	n.d.	n.d.
Pickled radish	4	1	n.d.–56.5	14.1	56.5
Pickled cucumber (pickled in salt, pickled in vinegar)	3	0	n.d.	n.d.	n.d.
Jeot-kal[b]	3	0	n.d.	n.d.	n.d.
Carbonated beverage	11	3	n.d.–15.8	3.0	10.9
So-ju[c]	23	18	n.d.–42.7	10.6	13.5
Soy sauce	10	4	n.d.–67.1	21.8	54.6

n.d., Not detected.
*Mean calculated from all samples values. n.d. was considered as '0'.
**Mean calculated from values of detected samples.
[a] Food product of pop corn.
[b] Food product made of whole or parts of fish, crustaceans, molluscs and echinoderms as raw materials that are fermented and salted.
[c] Traditional liquor made of starch and *koji* which are fermented, steamed and distilled.

Table VI. Concentrations of D-sorbitol in various foods.

Food category	Number of samples	Number of detected samples	Sorbitol concentration (ppm)		
			Range	Overall mean*	Positive mean**
Snack					
Gang-naeng-ie	2	2	612–3352	1982	1982
Other cookie	10	0	n.d.	n.d.	n.d.
Bread	4	2	n.d.–12 204	5589	11 178
Candy	4	3	n.d.–38 939	17 423	23 231
Chewing gum	4	4	498–223 522	108 760	108 760
Kimchi[a]	13	1	n.d.–443	34.1	443
Dried file fish	10	10	21 737–156 427	61 788	61 788
Mixed *surimi*					
Fish sausage	5	5	5159–26 126	12 979	12 979
Fried *surimi*	8	7	n.d.–14 900	4288	4900
Surimi[b]	4	4	43–8362	5184	5184
Jeot-kal[c]	7	5	n.d.–37 541	14 468	20 255
Popsicle	12	2	n.d.–1886	159	953
Yoghurt	7	5	n.d.–4356	1290	1806
So-ju[d]	9	3	n.d.–886	117	351
Beverage					
Carbonated beverage	8	8	119–1297	598	598
Other beverage	26	0	n.d.	n.d.	n.d.
Bacon	1	0	n.d.	n.d.	n.d.
Sausage	6	2	n.d.–16 401	2738	8214
Ham	7	2	n.d.–4860	1229	4300
Ground meat products	3	0	n.d.	n.d.	n.d.

n.d., Not detected.
*Mean calculated from all samples values. n.d. was considered as '0'.
**Mean calculated from values of detected samples.
[a] Vegetables such as Chinese cabbage, radish, cucumber and green onion, which are pickled in salt and fermented with mixture of red pepper and spices.
[b] Japanese food product made of water-washed protein of fish.
[c] Food product made of whole or parts of fish, crustaceans, molluscs and echinoderms as raw materials that are fermented and salted.
[d] Traditional liquor made of starch and *koji* which are fermented and distilled.

and pickled scallion than other age groups (Table VII).

The EDI of stevioside for average consumers ranged from 0.005 to 0.012 mg kg^{-1} bw day^{-1} and there was no remarkably difference in EDIs among age groups (Table VIII). The major contributing foods for stevioside consumption were *so-ju* and soy sauce (Table VII).

For the average consumer, the EDI of D-sorbitol ranged from 2.2 to 19.0 mg kg^{-1} bw day^{-1} and

Table VII. Consumption of saccharin, stevioside, D-sorbitol and aspartame from foods in which it is used (mg/person day^{-1}).

		Average consumption									High consumption	
Artificial sweeteners	Food category	All subjects	1–2	3–6	7–12	13–19	20–29	30–49	50–64	>65	90th percentile	95th percentile
Saccharin	*Gang-naeng-ie*[a]	0.046	0.023	0.18	0.17	0.064	0.050	0.009	0	0.001	16.8	18.2
	Pickled garlic	0.089	0	0.012	0.005	0.076	0.15	0.092	0.15	0.063	20.7	25.8
	Pickled scallion	0.009	0.002	0.062	0	0	0	0.014	0	0	33.1	33.1
	Pickled radish	1.4	0.32	1.3	1.3	2.1	2.5	1.4	0.56	0.13	30.8	41.2
	Pickled cucumber (pickled in salt, pickled in vinegar)	0.025	0.001	0.003	0.037	0.053	0.026	0.028	0.008	0.016	10.6	16.7
Stevioside	*Gang-naeng-ie*[a]	0.007	0.004	0.028	0.028	0.010	0.008	0.001	0.000	0.000	2.7	2.9
	Pickled radish	0.047	0.011	0.043	0.043	0.073	0.086	0.048	0.019	0.005	1.1	1.4
	Carbonated beverage	0.065	0.032	0.071	0.078	0.15	0.11	0.043	0.027	0.012	1.3	1.6
	So-ju[b]	0.18	0.001	0.000	0.002	0.049	0.21	0.28	0.29	0.13	5.4	7.2
	Soy sauce (Korean and Chinese style)	0.14	0.040	0.081	0.13	0.14	0.15	0.17	0.15	0.12	0.42	0.61
D-sorbitol	*Gang-naeng-ie*[a]	0.69	0.36	2.7	2.7	0.97	0.75	0.14	0.000	0.020	257	277
	Bread	103	85.1	143	181	187	127	70.1	58.1	36.1	1118	1459
	Candy	9.4	24.5	29.2	23.3	15.4	2.9	3.5	4.3	9.6	523	819
	Chewing gum	3.8	28.9	21.2	5.2	6.4	0.88	0.69	0.32	0.10	1523	1631
	Kimchi[c]	2.9	0.34	0.74	1.7	2.7	3.1	3.6	3.2	2.9	7.3	8.7
	Dried file fish	21.6	5.2	17.4	35.5	63.4	45.1	8.6	0.71	0.43	2281	2995
	Mixed *surimi* (fish sausage, fried *surimi*, *surimi*)[d]	55.0	15.7	55.2	63.9	109	85.3	46.4	24.4	11.4	674	951
	Jeot-kal[e]	38.6	2.6	3.1	12.4	25.1	28.0	55.0	53.9	55.8	462	763
	Popsicle	0.037	0.000	0.11	0.24	0.016	0.000	0.019	0.000	0.000	30.5	52.4
	Yoghurt	13.5	61.3	43.0	17.6	11.7	11.2	9.1	5.4	6.8	261	349
	So-ju[b]	2.0	0.006	0.003	0.020	0.54	2.3	3.1	3.2	1.5	59.9	79.9
	Carbonated beverage	12.9	6.3	14.1	15.6	30.0	21.0	8.6	5.3	2.4	261	317
	Sausage	3.3	2.6	6.1	4.7	9.2	4.0	1.9	0.84	0.18	203	309
	Ham	3.6	1.1	7.2	6.8	7.9	4.4	2.3	1.2	0.11	99.1	128
Aspartame	Candy	1.8	4.7	5.5	4.4	2.9	0.55	0.66	0.83	1.82	99.2	156
	Ice cream	0.91	1.2	1.6	2.0	2.6	0.52	0.58	0.058	0.068	45.4	62.3
	Yoghurt	0.64	2.9	2.0	0.84	0.56	0.53	0.43	0.26	0.32	12.4	16.6
	Carbonated beverage	3.6	1.8	3.9	4.4	8.4	5.9	2.4	1.5	0.68	72.7	88.4
	So-ju[b]	0.71	0.002	0.001	0.007	0.19	0.84	1.1	1.1	0.52	21.3	28.4

[a] Food product of puffed corn.
[b] Traditional liquor made of starch and *koji*, which are fermented and distilled.
[c] Vegetables such as Chinese cabbage, radish, cucumber and green onion, which are pickled in salt and fermented with mixture of red pepper and spices.
[d] Japanese food product made of water-washed protein of fish.
[e] Food product made of whole or parts of fish, crustaceans, molluscs and echinoderms as raw materials that are fermented and salted.

the EDIs of young children (1–6 years) were higher than those of other age groups (Table VIII). This is because young children consumed more high sorbitol-dense foods such as candy, chewing gum and yoghurt (Table VII). For 95th percentile consumers, the EDI of sorbitol was 184 mg kg^{-1} bw day^{-1} (Table VIII), but this was lower than the amount that can cause flatulence, diarrhoea and abdominal distension. The amount of sorbitol causing flatulence, diarrhoea and abdominal distension has been reported at 25–50 g day^{-1} (Ellis and Krantz 1943; Peters and Loch 1958).

The EDI of aspartame for average consumers ranged from 0.058 to 0.86 mg kg^{-1} bw day^{-1} and the EDIs of young children (1–6 years) were higher than those of other age groups. This is because young children prefer high aspartame-dense foods such as candy, yoghurt and ice cream.

Children and infants are known as a sensitive group due to their immaturity compared with adults (Renwick et al. 2000). Therefore, further research on children and infants who prefer foods containing artificial sweeteners, as in this present study, are needed to obtain better habitual intakes of artificial sweeteners for future risk assessment.

Table VIII. Estimated daily intakes of saccharin, stevioside, D-sorbitol and aspartame for average and high consumers (90th and 95th percentiles of consumers only) in Korea.

		Average consumption									High consumption	
Artificial sweeteners		All subjects	1–2	3–6	7–12	13–19	20–29	30–49	50–64	>65	90th percentile	95th percentile
Daily intake (mg/person day^{-1})	Saccharin	1.6	0.35	1.5	1.5	2.3	2.7	1.5	0.71	0.21	112	135
	Stevioside	0.45	0.087	0.22	0.28	0.42	0.56	0.55	0.48	0.26	10.9	13.7
	D-sorbitol	271	234	343	371	469	336	213	161	127	7758	10 138
	Aspartame	7.7	10.5	13.1	11.6	14.5	8.3	5.2	3.8	3.4	251	351
Daily intake (mg kg^{-1} body weight day^{-1})	Saccharin	0.028	0.028	0.082	0.045	0.042	0.045	0.025	0.011	0.004	2.0	2.5
	Stevioside	0.008	0.007	0.012	0.009	0.008	0.009	0.009	0.008	0.005	0.20	0.25
	D-sorbitol	4.9	19.0	18.7	11.3	8.3	5.5	3.5	2.6	2.2	141	184
	Aspartame	0.14	0.86	0.71	0.34	0.26	0.14	0.084	0.060	0.058	4.6	6.4
ADI (%)*	Saccharin	0.57	0.57	1.6	0.91	0.83	0.90	0.50	0.23	0.073	40.7	49.1
	Aspartame	0.35	2.1	1.8	0.89	0.65	0.34	0.21	0.15	0.15	11.4	16.0

* Set by the JECFA.

Comparison dietary intake of sweeteners with ADI

To evaluate the safety of daily intake per kg bw of artificial sweeteners, the results were compared with the ADI set by the JECFA (Table VIII). The ADIs referred in this study were decided from the JECFA and Scientific Committee for Food (SCF): 5 mg kg^{-1} bw day^{-1} for saccharin and 40 mg kg^{-1} bw day^{-1} for aspartame, respectively. The EDI of saccharin as a proportion of the ADI ranged from 0.073 to 1.7% in all age groups for average consumers. For 95th percentile consumers, the EDI of saccharin was 49% of the ADI. Overall, the EDI of saccharin was lower than the ADI for both average and high consumers (90th and 95th percentiles of consumers only) in Korea (Table VIII). For average consumers, the EDI of aspartame as a proportion of the ADI ranged from 0.15 to 2.1% in all age groups. For 95th percentile consumers, the EDI of aspartame was 16% of ADI. Therefore, the per cent ADI for aspartame was remarkably lower among both average and high consumers (90th and 95th percentiles of consumers only) in Korea (Table VIII). The ADI of stevioside is being evaluated by the JECFA and the final ADI has not yet been decided. Also, it is very difficult to evaluate the safety of the daily intake of stevioside because of the lack of an EDI for stevioside in other countries. However, the EDI of stevioside in Korea was 0.008 mg kg^{-1} bw day^{-1}. The source of intake of stevioside comes from *so-ju* and soy sauce, and its the amount is quite small. It also seems the daily intake of stevioside does not cause any health problems. Because D-sorbitol does not contain specific toxicity, the JECFA does not have an ADI for D-sorbitol. Even for 95th percentile consumers in Korea, the EDI of sorbitol was 184 mg kg^{-1} bw day^{-1}, which was lower than the amount that can cause diarrhoea. As a result, saccharin, stevioside, D-sorbitol and aspartame do not have any health impact on both average and high consumers (90th and 95th percentiles of consumers only).

Comparison with other countries

Some European countries have evaluated the daily intake of artificial sweeteners through consumer surveys. The daily intakes of saccharin for consumers only were 0.4 mg kg^{-1} bw day^{-1} in the Netherlands (Hulshof and Bouman 1995), 2.0 mg kg^{-1} bw day^{-1} in Denmark (unpublished data from the ISA reported by Renwick 1995), 0.28 mg kg bw day^{-1} in Germany (Bär and Biermann 1992), and 0.40 mg kg^{-1} bw day^{-1} in the UK (Hinson and Nicol 1992), respectively. Although there was a variation in the measuring methodology, the present study shows that the daily intake of saccharin for the average consumer in Korea is less than 10% of the daily intake of saccharin for consumers only of those countries in Europe. In the case of Japan, which uses a similar methodology with Korea, if 60 kg is considered as an average body weight, the daily intake of saccharin for the average consumer was 0.17 mg kg^{-1} bw day^{-1} (Japanese Food Additive Association 1989). This result shows that in comparison with the daily intake of Japan, Korea has a lower intake for saccharin than Japan. It is probably due to different levels of use for saccharin between Korea and Japan. The permitted level of saccharin in Korea ranged from 0.1 to 1.2 ppm in four food categories, but the level in Japan ranged from 0.2 to 2.0 ppm in 30 food categories (Korea Food Hygiene Institute 1997).

The daily intakes of aspartame for consumers only were 1.9 mg kg^{-1} bw day^{-1} in the Netherlands (Hulshof and Bouman 1995), 2.6 mg kg^{-1} bw day^{-1} in Denmark (unpublished data from ISA reported by Renwick 1995), 1.21 mg kg^{-1} bw day^{-1} in Germany (Bär and Biermann 1992), and

$0.40\,\mathrm{mg\,kg^{-1}\,bw\,day^{-1}}$ in the UK (Hinson and Nicol 1992), respectively. The present study also shows that Koreans consume only $0.14\,\mathrm{mg\,kg^{-1}\,bw\,day^{-1}}$ aspartame, which is less than 10% of the daily intake of aspartame for consumers only in European countries, and is a similar result with saccharin intake.

Conclusions

In Korea, the EDIs of saccharin and aspartame, even among high consumers, were remarkably below the ADI set by the JECFA. Even though daily intake levels of stevioside and D-sorbitol could not be compared with the JECFA's ADIs since there were no such values, the daily intakes of stevioside and D-sorbitol were extremely low in Korea. The reason might be that consumption of food with sweeteners and the use levels of sweeteners are relatively low. EDIs of sweeteners in young children (1–6 years) were higher than those of other age groups. It is because young children consumed more high sweetener-dense foods. Also, since gradual addition of artificial sweeteners into the diet might increase, further research for children needs to gain a future risk assessment of sweeteners for those subjects. According to the present study, the use of artificial sweeteners such as saccharin and aspartame could be expanded in terms of ADI in Korea.

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