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RESEARCH ARTICLE

Occurrence and risk characterization of non-nutritive sweeteners in selected food products from Korea

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Abstract Non-nutritive sweeteners (NNS) are food additives that impart a sweet taste to food product with lower calories. Acesulfame potassium, aspartame, sodium saccharin, sucralose, steviol glycosides and enzymatically modified stevia are permitted in Korea. The study established the method of each NNS and applied it to each food items consumed in Korea. For risk assessments, the estimated daily intake (EDI) value for each NNS was calculated. EDI values of NNS were compared directly with each ADI (acceptable daily intake). The total estimated daily intake ranges by age compared with the % ADI were 0.12–0.53, 0.93–1.68, 0.05–0.20, 0.06–0.42 and 0.17–0.98% for acesulfame potassium, sodium saccharin, aspartame, sucralose and sum of stevioside and rebaudioside A, which were based on the overall averages. It can be concluded that the daily dietary intake of each of the five NNS is at a safe level when considered as a proportion of the ADI.

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Introduction

Obesity is a worldwide epidemic. Increased interest in body weight and health among consumers has led to the commercialization of alternative sweeteners that can control blood sugar, lower the risk of tooth decay, and lower calories (Chattopadhyay et al., 2014; Karp et al., 2016). The Food and Drug and Administration (FDA) have approved six artificial non-nutritive sweeteners (NNS) for use as food additives in the USA, which include acesulfame potassium, aspartame, advantame, neotame, saccharin, and sucralose (FDA, 2018). Moreover, steviol glycosides, including stevioside and rebaudioside A, which are natural constituents of the leaves of *Stevia rebaudiana* Bertoni, a plant native to parts of South America and commonly known as Stevia, are considered generally-recognized-as-safe (GRAS) for use as NNS under specified conditions (FDA, 2018). Sweeteners as food additives, such as acesulfame potassium, aspartame, saccharin, sucralose, steviol glycosides, and enzymatically modified stevia are permitted in Korea (MFDS, 2019). Acesulfame potassium has not shown any human health problems associated with its consumption, and it is permitted as a food additive in cookies, canned food, chewing gum, sauce, candy, and beverages in Korea (European Commission, 2000b). Aspartame is allowed in bread, cookies, cereal, and health functional foods in Korea, and extensive testing has proven it is safe as consumed in normal diets, with no possibility of allergic reaction or carcinogenesis (European Commission, 2002). Sodium saccharin is used

in salted fish, pickles, kimchi, and beverages in Korea. It is banned from many other countries because lifetime exposure to high doses of saccharin causes bladder cancer in male rats, and yet overall scientific evidence does not link saccharin and human bladder cancer (European Commission, 1997). Sucralose has been approved for use by authorities in more than 80 countries, including Korea, where it is used in cookies, chewing gum, jam, beverages, and sugar substitutes (European Commission, 2000a; Kroger et al. 2006). In Korea, enzymatically modified stevia should contain more than 80% of stevia glycosides on a dry matter basis. Stevioside and rebaudioside A are the most well-known steviol glycosides (Gardana et al. 2003). The use of sugar, glucose, syrup, and honey is restricted as food additives, and animal and human studies have shown no carcinogenic, genotoxic, or reproductive toxicity when these ingredients are consumed as food additives in the normal diet (EFSA, 2011). For the risk assessment of NNS, the Joint FAO/WHO Expert Committee on Food Additives (JECFA) established acceptable daily intake (ADI) values. The ADI values proposed by the JECFA and adopted in the current study, are 5 mg/kg bw/day for sodium saccharin, 40 mg/kg bw/day for aspartame, 15 mg/kg bw/day for acesulfame potassium, 15 mg/kg bw/day for sucralose, and 4 mg/kg bw/day for steviol glycoside (JECFA,2006a; JECFA, 2006b; JECFA, 2006c; JECFA ,2016; JECFA, 2017). Due to the varying diets and cultures between countries, each nation administers its own food laws and standards (Codex Alimentarius, 2018; Commission Regulation, 2011). Based on consumption data from the Korea National Health and Nutrition Examination Survey (KNHANES), Suh et al., (2014) reported that the national average intake of aspartame was 58.37 μg/kg bw/day, an amount equivalent to 0.15% of the ADI (40 mg/kg bw/day) established by the JECFA. Teenagers (aged 13–19 years) had the highest intake (136.04 μg/kg bw/day, 0.34% of the ADI) by age group followed by 1–2 year olds, at 133.16 μg/kg bw/day (0.33% of the ADI). In both groups, the primary source of aspartame was carbonated beverages, and in the 1–2 year olds, fermented milk was also a major contributor. The national average intake of acesulfame potassium was 14.23 μg/kg bw/day, equivalent to 0.09% of the ADI (15 mg/kg bw/day) established by the JECFA. Therefore, the objectives of this study were to validate specificity, linearity, precision, accuracy, limit of detection (LOD), limit of quantitation (LOQ) and to apply the method to each food items consumed in Korea, and to examine the estimated daily intake of each NNS with reference to the daily food consumption data per person collected from the Korea National Health and Nutrition Survey for the total population, gender, and age. So, this research assessed safety of each NNS comparing and reviewing the EDI (estimated daily intake) with ADI suggested by JECFA.

Materials and methods

Collection samples

The distribution of food usage was surveyed based on the 2018 KNHANES data (KNHANES, 2018). The most highly and frequently consumed processed foods were identified and reflected in the sample collection rate. Sampling was determined by examining the 2016–2018 food item manufacturing report and import declaration, reflecting results of market research, for the type and distribution of food additives, and the samples were collected depending on the contribution ratio of each food item manufacture amounts and sales. For the exposure assessment, the selected food products were collected using each NNS as much as possible. In particular, most of the kimchi containing artificial sweeteners was from China. Food products incorporated with the target NNS were purchased from large discount stores, grocery stores, convenience stores, and online stores in Seoul (Korea) and other regions, and the data listed on the food labels were recorded. The total food products (n = 1017) purchased included samples for the analysis of acesulfame potassium (n = 250), sodium saccharin (n = 151), aspartame (n = 179), sucralose (n = 240), and stevioside and rebaudioside A (n = 197) in 2019.

Reagents

Standards of acesulfame potassium (A132500, 98%), aspartame (A790015, 98%), sucralose (S692500, 98%), and rebaudioside A (R139500, 98%) were purchased from Toronto Research Chemicals, Inc. (Toronto, Canada). Sodium saccharin standard (PHR1348, 99.98%) was bought from Sigma–Aldrich Co. (St. Louis, MO, USA), and stevioside standard (KPL2047, $\geq$ 90%) was obtained from Wako Chemical Co. (Osaka, Japan). Formic acid, triethylamine, zinc sulfate heptahydrate, and diethyl ether were obtained from Sigma–Aldrich Co. (St. Louis, MO, USA), and potassium ferrocyanide trihydrate was purchased from Showa Chemical, Inc. (Tokyo, Japan). Water and methanol, used in HPLC analysis, were obtained from JT Baker (Phillipsburg, NJ, USA), and acetone was bought from Fisher Scientific Co. (Pittsburgh, PA, USA). Sep-Pak® Vac 6 cc (1 g) C18 cartridges and Vac 6 cc (500 mg) C18 cartridges were procured from Waters (Milford, MA, USA).

Sample pretreatment

Acesulfame potassium, sodium saccharin, aspartame, and sucralose

Acesulfame potassium, sodium saccharin, aspartame and sucralose were analyzed as described previously in Korea Food Additives Code (Lim et al., 2013; MFDS, 2019; Yang and Chen, 2009). A buffer solution (pH 4.5) was prepared by adding 0.8 mL formic acid to 1 L water, and the pH adjusted to 4.5 with triethylamine. 5 g of each sample was precisely weighed, then diluted with 50 mL of the buffer solution (pH 4.5). The mixture was extracted by sonication for 15 min and centrifuged at 4000 rpm for 10 min. 10 mL of the supernatant was injected into a activated C18 cartridge (Sep-Pak, Vac 6 cc, 1 g), which has washed sequentially with 3 mL methanol and 10 mL of the buffer (pH 4.5). It was then washed with the buffer solution (pH 4.5). After the buffer was removed, the cartridge was rewashed with 1 mL methanol. Subsequently, 2 mL of methanol was diluted in 1 mL of twice, and the purified solution eluted through a Sartorius Minisart® syringe filter (Göttingen, Germany) to prepare a test solution.

Stevioside and rebaudioside A

Stevioside and rebaudioside A were analyzed by referring to Korea Food Additives Code (Ha et al., 2013; MFDS 2019). Pretreatment steps for removal of fat and protein were implemented based on each food type. For solid foods, about 5–10 g of finely homogenised sample was combined with 10–20 mL water by sonication for 20 min. Water was added to the solution to complete the volume to 50 mL and shaken, and the mixture centrifuged at 4000 rpm for 10 min. The supernatant was taken in 10–20 mL portions and poured into an activated C18 cartridge (Sep-Pak, Vac 3 cc, 500 mg). Next, 10 mL of 10% methyl alcohol solution was added to the cartridge, which was then washed, and the target compound was eluted with 4 mL of 90% methyl alcohol solution. The solution was concentrated to 1 mL with nitrogen and filtered through a 0.45-μm microfilter to obtain the test solution. For samples with high-fat content, water was added to the sample, followed by ultrasonic extraction and centrifugation. The supernatant was transferred to a separatory funnel and 50 mL of diethyl ether was added and shaken. This solution was placed and was taken only the layer of water. This operation was repeated twice to eliminate all fat before proceeding to the step. For samples with high protein content, water was added to the sample, followed by 2 mL of Carrez 1 reagent (150 g of potassium ferrocyanide trihydrate in 1 L distilled water. And 2 mL of Carrez 2 reagent (300 g zinc sulphate heptahydrate in 1 L distilled water) was added and shaken for 2 min. The solution was adjusted to 50 mL with distilled water, and the next step proceeded. HPLC analysis conditions for the NNS are shown in Supplementary Table 1.

Estimated daily intake (EDI) of sweeteners and evaluation of safety

As proposed by the MFDS, the national average estimated daily intake of each NNS was obtained by multiplying the average concentration (C_{ave}) of each NNS in each food category by the daily consumption data (F_{ave}), extracted from KNHANES (KNHANES, 2018) dividing it by the average body weight (bw) of KNHANES in 2018 (Eq. 1). The national daily intake data of NNS from food is given in Table 1.

$$\text{EDI} = C_{ave} \times F_{ave}/\text{bw} \quad (1)$$

In addition, the risk assessment of each NNS was calculated as a proportion of the respective ADI value established by the JECFA (Eq. 2). These results were then used to evaluate the safety of the EDI for each NNS.

$$\text{Risk } (\%\ \text{ADI}) = (\text{EDI}/\text{ADI}) \times 100 \quad (2)$$

Method validation

Acesulfame potassium, sodium saccharin, aspartame, and sucralose were evaluated by analyzing a series of five standard solution concentration of 2–100 mg/kg. The correlation coefficient (R^2) of each calibration curve was 0.9998–1.000, which was suitable with the Codex standard (Codex Alimentarius, 2003). Stevioside and rebaudioside A showed highly linear calibration curves (R^2 = 0.9999) for 0.5–50 mg/kg of the standard solution. The limit of detection (LOD) and the limit of quantitation (LOQ) were calculated by using the signal-to-noise ratio of 3 and 10, respectively. LOD and LOQ values of 0.1 and 0.3, 0.1 and 0.3, 1.2 and 4.1, and 1.1 and 3.6 mg/kg were calculated for acesulfame potassium, saccharin sodium, aspartame, and sucralose, respectively. For stevioside and rebaudioside A, the calculated LOD and LOQ values were 0.05 and 0.15, 0.09 and 0.29 mg/kg, respectively. Acesulfame potassium, saccharin sodium, aspartame, and sucralose were evaluated for precision and accuracy at beverages and candies adding concentrations (10, 50, 200 mg/kg) of NNS. As results of six replicative test, the average recovery range from beverages and candies was 96.2–112.9% (relative standard deviation [RSD] 0.2–1.3%) for acesulfame potassium, 94.4–103.5% (RSD 0.2–0.9%) for sodium saccharin, 82.0–107.3% (RSD 0.4 –16%) for aspartame, and 81.2–115.7% (RSD 0.4–1.7%) for sucralose. Stevioside and rebaudioside A analyses were repeated six times at

Table 1 Daily intakes of each food types by age group in Korea (g/day)

Food types	NNS intake—Total									NNS intake—Consumer only								
	All	Male	Female	1–2	3–6	7–12	13–19	20–64	65 <	All	Male	Female	1–2	3–6	7–12	13–19	20–64	65 <
Cookie	7.065	7.805	6.456	8.660	10.816	12.817	14.714	6.924	2.255	34.005	39.305	29.987	19.706	25.705	34.370	44.872	36.568	24.531
Pickles	4.752	4.158	5.240	0.013	2.387	3.155	6.551	5.614	3.544	100.757	92.706	106.806	1.011	62.414	85.028	90.866	96.214	182.499
Other beverages	5.590	5.744	5.463	6.095	2.145	6.974	4.394	6.552	3.633	101.944	104.923	99.502	95.693	31.401	72.284	60.947	111.363	175.395
Kimchi	63.373	79.317	50.270	5.295	16.860	36.244	52.322	75.345	60.832	86.480	102.696	71.784	17.317	28.176	49.962	79.220	97.884	83.100
Fruit, vegetable beverages	2.661	2.754	2.585	1.524	3.671	0.656	1.088	2.744	3.452	103.087	105.976	100.684	59.800	63.971	39.289	78.000	115.654	113.462
Gums	0.077	0.089	0.067	–	0.142	0.198	0.209	0.065	0.022	4.444	5.740	3.569	–	12.975	5.616	6.414	3.537	3.082
Carbonated beverages	7.266	9.190	5.684	1.312	6.656	13.853	22.638	7.102	1.876	283.004	297.113	266.208	206.000	203.008	266.664	314.006	279.353	413.971
Candies	0.481	0.460	0.498	0.398	0.874	1.387	0.792	0.188	0.776	12.802	13.265	12.472	5.673	11.848	20.769	17.926	9.684	12.484
Instant Fried Noodles	0.008	–	0.014	–	–	–	–	0.014	–	55.977	–	55.977	–	–	–	–	55.977	–
Soybean Sauce	0.015	0.011	0.018	–	–	0.049	0.011	0.018	0.001	6.277	5.965	6.447	–	–	8.728	2.443	7.350	1.070
Fermented milk product	2.853	3.265	2.514	8.553	6.365	1.901	6.742	2.139	2.600	107.606	117.297	98.884	95.914	89.600	93.160	207.076	105.146	97.967
Tea	0.005	0.001	0.007	–	–	–	–	0.004	0.011	8.000	2.000	14.000	–	–	–	–	15.000	5.667
Sauces	0.060	–	0.109	–	–	–	0.995	–	–	428.000	0.000	428.000	–	–	–	428.000	–	–
Fermented Soybean Sauce	0.002	0.005	0.000	–	–	0.032	–	–	–	17.300	17.300	–	–	–	17.300	–	–	–
(Fermented) Korean Red Ginseng beverages	0.001	–	0.002	–	–	–	–	–	0.004	6.000	0.000	6.000	–	–	–	–	–	6.000
Dried Fish Products	0.733	0.703	0.757	0.295	0.235	0.661	0.614	0.995	0.253	26.790	27.061	26.587	11.569	10.740	23.736	37.697	29.984	15.640

beverages and soy sauce adding different concentrations (5, 20, 50 mg/kg). The average accuracy range was 84.2–102.2% (RSD 0.4–4.9%) for stevioside, and 80.9–101.8% (RSD 0.3–3.8%) for rebaudioside A, respectively. These data were within the acceptable range of 80–120%, as recommended by the International Conference of Harmonization (ICH) Guideline Q2 (R1) (ICH, 2005). Thus, the method was suitable for its intended purpose. The result of method validation for five NNS are presented in Table 2.

Results and discussion

Monitoring results

The concentrations of NNS in various processed food products are shown in Table 3.

Table 2 Validation results of the analytical method

Food additive	Samples	Added standards (mg/kg)	Accuracy (%)	Precision (%RSD)	Linearity (r^2)	LOD (mg/kg)	LOQ (mg/kg)
Acesulfame potassium	Drink	10	105.5 ± 0.5	0.5	1.0000	0.1	0.3
		50	96.4 ± 0.2	0.2			
		200	96.2 ± 0.2	0.3			
	Candy	10	112.9 ± 1.4	1.3			
		50	98.7 ± 0.3	0.3			
		200	102.9 ± 0.2	0.2			
Sodium saccharin	Drink	10	99.8 ± 0.7	0.8	1.0000	0.1	0.3
		50	94.8 ± 0.2	0.2			
		200	95.1 ± 0.3	0.3			
	Candy	10	103.5 ± 1.0	0.9			
		50	94.4 ± 0.3	0.3			
		200	100.3 ± 0.2	0.2			
Aspartame	Drink	10	83.3 ± 0.9	1.0	0.9999	1.2	4.1
		50	107.3 ± 1.0	1.0			
		200	93.6 ± 0.6	0.6			
	Candy	10	82.0 ± 1.3	1.6			
		50	91.1 ± 0.9	1.0			
		200	84.4 ± 0.3	0.4			
Sucralose	Drink	10	94.3 ± 1.6	1.7	0.9998	1.1	3.6
		50	115.7 ± 1.2	1.0			
		200	96.3 ± 0.4	0.4			
	Candy	10	81.2 ± 0.8	1.0			
		50	93.8 ± 0.9	1.0			
		200	87.2 ± 0.6	0.7			
Stevioside	Drink	5	84.2 ± 1.3	1.5	0.9999	0.05	0.15
		20	88.7 ± 1.8	2.0			
		50	95.3 ± 0.5	0.6			
	Soy sauce	5	97.0 ± 4.7	4.9			
		20	102.2 ± 0.4	0.4			
		50	99.9 ± 1.1	1.1			
Rebaudioside A	Drink	5	80.9 ± 3.1	3.8	0.9999	0.09	0.29
		20	85.1 ± 1.0	1.1			
		50	92.2 ± 0.3	0.3			
	Soy sauce	5	97.1 ± 2.2	2.2			
		20	99.9 ± 3.2	3.2			
		50	101.8 ± 2.3	2.3			

Acesulfame potassium

Acesulfame potassium was detected at a rate of 44% (110/250 food items). Among the seven food types examined, kimchi showed the highest detection rate (100%), and the next highest detection rates occurred in chewing gums (73%) and candies (69%). Chewing gums (271.4 mg/kg), candies (138.6 mg/kg), cookies (33.2 mg/kg), and carbonated beverages (23.9 mg/kg) had the top four highest average amounts of acesulfame potassium.

Saccharin sodium

Of the 151 food items quantitatively analyzed for saccharin sodium, 41 were positive (27%). Among the four food types examined, all 15 samples of pickled foods contained this NNS, resulting in the highest detection rate (100%). Kimchi also showed a high detection rate of 90%. Pickled foods (357.6 mg/kg), other beverages (68.7 mg/kg), and kimchi (19.9 mg/kg) had the top three highest average concentrations of saccharin sodium.

Aspartame

Aspartame was positively identified in 77 out of the 179 food items (43%) analyzed for this NNS. Among the five food types examined, kimchi showed the highest detection rate (100%), followed by pickles (53%), candies (46%), and cookies (43%). Candies (505.0 mg/kg), chewing gum (96.2 mg/kg), and pickled food (88.3 mg/kg) had the top three highest average concentrations of aspartame,

Sucralose

Sucralose was detected at a rate of 60% (145/240 food items). Among the six food types examined, the fruit/vegetable beverages showed the highest detection rate (100%). Carbonated drinks (89%), chewing gums (73%), and other beverages (68%) had the next three highest detection rates. The highest average amount of sucralose was found in chewing gum (152.6 mg/kg), followed by candies (102.2 mg/kg) and carbonated beverages (59.6 mg/kg).

Stevioside and rebaudioside A

Stevioside and rebaudioside A were detected at a higher rate (96%, 190/197 food items) than any of the other four NNS, and in the most diverse food types. Among the 14 food types examined, all samples of instant fried noodle, mixed soy sauce, fermented milk, tea, fermented soy sauce, fermented Korean red ginseng beverages, and dried seafood were positive for sum of stevioside and rebaudioside A, and high rates also occurred in sauces (94%) and candies (91%). Fermented Korean red ginseng beverages (70.2 mg/kg) carbonated beverages (51.3 mg/kg), and fruit/vegetable beverages (34.8 mg/kg) had the top three highest average concentrations of these two NNS.

Estimated daily intake (EDI) of sweeteners and evaluation of safety

Figure 1 and Table 4 show the EDI and risk assessment results of acesulfame potassium, sodium saccharin, aspartame, sucralose, and sum of stevioside and rebaudioside A among age groups and between genders for national average or only consumer average, calculated by using the overall average. Figure 2 is presented in the proportional distribution of each NNS. The estimated average intakes of acesulfame potassium (0.021 mg/kg bw/day), sodium saccharin (0.057 mg/kg bw/day), aspartame (0.024 mg/kg bw/day), which was the lowest among the analyzed NNS, sucralose (0.017 mg/kg bw/day), and sum of stevioside and rebaudioside A (0.013 mg/kg bw/day) represented 0.14%, 1.13%, 0.06%, 0.12%, and 0.32% of the respective ADI, indicating that their levels of consumption by the average Korean consumer are safe. There were no differences in the NNS intakes as a proportion of the respective ADI values between the genders. The only exception was saccharin sodium intake, which was slightly higher in females (1.22%) than males (1.07%) because of the difference between the male and female intake of pickles at ≥ 1 g/day. Age-group intake levels for acesulfame potassium, sodium saccharin, aspartame, sucralose, and sum of stevioside and rebaudioside A had ranges of 0.12–0.53%, 0.93–1.68%, 0.05–0.20%, 0.06–0.42%, and 0.17–0.98%, respectively. These intake levels in all age groups were evaluated as safe. Children aged 1–12 years showed a higher intake of acesulfame potassium than those aged 13 years and older when comparing the levels according to age with the ADI because of the lower body weight of 1–12 year olds.

The major contributing foods for acesulfame potassium consumption were fruit/vegetable beverages (0.00745 mg/kg bw/day), kimchi (0.00397 mg/kg bw/day), and cookies (0.00386 mg/kg bw/day), which together accounted for

Table 3 Occurrence of non-nutritive sweeteners in food types from Korea

Food additive	Food types	Tested no	Detected no	Detected no./ Tested no. (%)	Concentration (mg/kg)		
					Range	Overall average Conc.[a]	Positive average Conc.[b]
Acesulfame Potassium	Other beverages	50	17	34%	N.D.–92.2	13.6	40.1
	Fruit, vegetable beverages	18	12	67%	N.D.–68.0	17.0	25.5
	Cookie	76	8	11%	N.D.–452.9	33.2	315.8
	Kimchi	10	10	100%	1.6–7.2	3.8	3.8
	Gums	30	22	73%	N.D.–854.9	271.4	370.1
	Candies	48	33	69%	N.D.–593.5	138.6	201.5
	Carbonated beverages	18	8	44%	N.D.–167.0	23.9	53.8
	Total	250	110	44%			
Sodium saccharin	Cookies	76	6	8%	N.D.–327.6	13.8	175.4
	Pickles	15	15	100%	11.3–554.5	357.6	357.6
	Other beverages	50	11	22%	N.D.–545.0	68.7	312.1
	Kimchi	10	9	90%	N.D.–29.6	19.9	22.1
	Total	151	41	27%			
Aspartame	Cookies	76	33	43%	N.D.–415.8	61.6	141.9
	Kimchi	10	5	50%	4.2–10.3	3.9	7.7
	Pickles	15	8	53%	N.D.–677.1	88.3	165.5
	Gums	30	9	30%	N.D.–862.8	96.2	320.7
	Candies	48	22	46%	N.D.–2377.8	505.0	1101.9
	Total	179	77	43%			
Sucralose	Other beverages	50	34	68%	N.D.–142.5	34.7	51.0
	Fruit, vegetable beverages	18	18	100%	4.9.–170.2	37.9	37.9
	Cookies	76	24	32%	N.D.–578.0	36.7	116.1
	Gums	30	22	73%	N.D.–759.7	152.6	208.1
	Candies	48	31	65%	N.D.–518.5	102.2	158.3
	Carbonated beverages	18	16	89%	N.D.–249.8	59.6	67.1
	Total	240	145	60%			

Table 3 continued

Food additive	Food types	Tested no	Detected no	Detected no./ Tested no. (%)	Concentration (mg/kg)		
					Range	Overall average Conc.[a]	Positive average Conc.[b]
Sum of stevioside and rebaudioside A	Other beverages	29	29	100%	2.1–75.7	32.1	32.1
	Fruit, vegetable beverages	19	19	100%	1.9–113.6	34.8	34.8
	Cookies	26	21	81%	0.2–32.1	10.6	13.1
	Instant Fried Noodles	12	12	100%	20.3–63.0	30.1	30.1
	Soybean Sauce	11	11	100%	0.6–9.3	5.5	5.5
	Fermented milk product	10	10	100%	0.6–2.2	1.1	1.1
	Tea	10	10	100%	0.8–11.2	8.1	8.1
	Sauces	16	15	94%	N.D.–132.0	18.5	19.7
	Fermented Soybean Sauce	12	12	100%	1.6–31.2	9.6	9.6
	Fermented Korean Red Ginseng beverages	10	10	100%	6.4–137.3	70.2	70.2
	Pickles	10	10	100%	0.6–28.5	10.1	10.1
	Dried-Seafood	11	11	100%	0.1–8.0	9.6	9.6
	Candies	11	10	91%	N.D.–27.0	7.5	8.2
	Carbonated beverages	10	10	100%	1.8–98.0	51.3	51.3
	Total	197	190	96%			

[a]Average calculated from all samples. N.D. was considered as '0'

[b]Average calculated from values of detected sample

more than 70% of the total intake of this NNS. Pickles (0.0280 mg/kg bw/day) and kimchi (0.0208 mg/kg bw/day) represented the main sources of saccharin sodium, accounting for more than 80% of the intake of this NNS. Cookies (0.0072 mg/kg bw/day), pickles (0.0069 mg/kg bw/day), and kimchi (0.0055 mg/kg bw/day) substantially contributed to the intake of aspartame. Carbonated beverages (0.00713 mg/kg bw/day) and cookies (0.00427 mg/kg bw/day) accounted for more than 60% of total intake of sucralose. Carbonated beverages (0.00614 mg/kg bw/day) and other beverages (0.00295 mg/kg bw/day) accounted for over 70% of total intake of stevioside and rebaudioside A.

Additionally, the estimated average intakes of the only consumer groups were taking acesulfame potassium (0.496 mg/kg bw/day), sodium saccharin (0.745 mg/kg bw/day), aspartame (0.302 mg/kg bw/day), sucralose (0.173 mg/kg bw/day) and sum of stevioside and rebaudioside A (0.552 mg/kg bw/day). The percentage in relation to ADI were 3.31, 14.89, 0.75, 1.15, 13.80% for acesulfame potassium sodium saccharin, aspartame, sucralose, and sum of stevioside and rebaudioside A, which were all within safe levels.

Kim et al. (2017) estimated the average daily intake of four types of NNS (sodium saccharin, aspartame, acesulfame potassium and sucralose), the general estimated daily intake and high intake (95th percentile groups) of the sodium saccharine levels were 0.18 mg/kg bw/day and 0.64 mg/kg bw/day, respectively. The general intake of aspartame, acesulfame potassium, and sucralose were 0.33, 0.26, and 0.32 mg/kg bw/day, respectively. Aspartame, acesulfame potassium, and sucralose were found to be 1.49, 1.00, and 1.09 mg/kg bw/day, respectively, at the high intake. Wang et al. (2021) assessed the daily intake of 1885 food additives (measured as saccharin and acesulfame potassium) by five age groups (6–10, 11–17, 18–49, 50–64, and $\geq$ 65 years) in Nanjing, China. The estimated average intakes of saccharine and acesulfame potassium 0.81–2.24% and 0.69–4.08% of the respective ADI. The estimated exposure of sweeteners in Nanjing was well

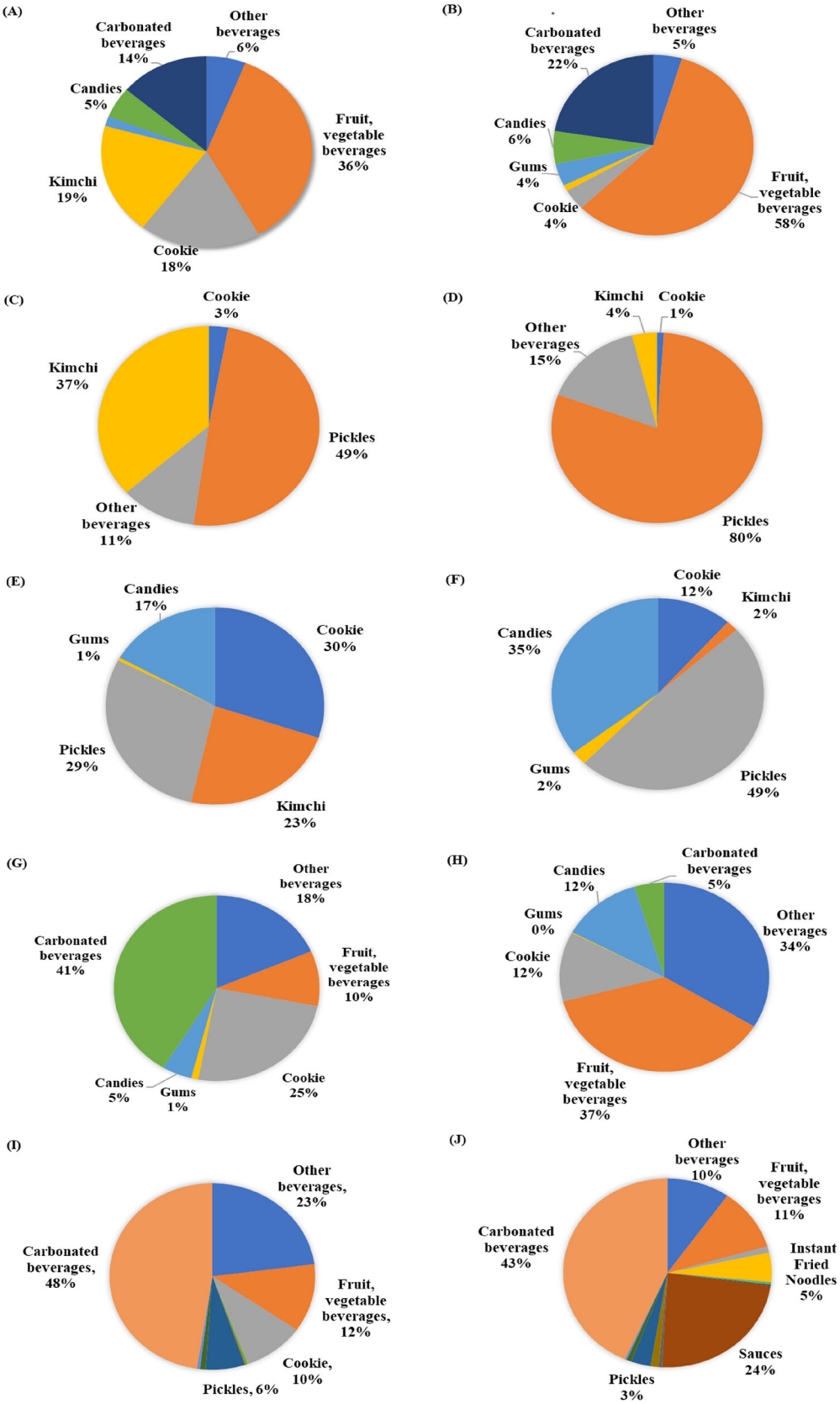

Fig. 1 The percentage compared to ADI of NNS for average, gender, and age of national population. ((**A**) based on average food intake-total of NNS; (**B**) based on average food intake-consumer of NNS)

Table 4 Estimated daily intake and % of ADI of acesulfame potassium, sodium saccharin, aspartame, sucralose, sum of stevioside and rebaudioside A (mg/kg bw/day)

Food additive	EDI value	NNS intake—total									NNS intake—consumer only								
		All	male	female	1–2	3–6	7–12	13–19	20–64	65 <	All	male	female	1–2	3–6	7–12	13–19	20–64	65 <
Acesulfame Potassium	Total	0.021	0.021	0.021	0.060	0.079	0.041	0.028	0.019	0.019	0.496	0.474	0.527	1.467	1.259	0.596	0.471	0.472	0.594
	% of ADI	0.14%	0.14%	0.14%	0.40%	0.53%	0.27%	0.19%	0.13%	0.12%	3.31%	3.16%	3.51%	9.78%	8.40%	3.97%	3.14%	3.14%	3.96%
Sodium saccharin	Total	0.057	0.053	0.061	0.053	0.084	0.076	0.066	0.060	0.046	0.745	0.643	0.857	0.619	1.435	1.110	0.664	0.661	1.336
	% of ADI	1.13%	1.07%	1.22%	1.06%	1.68%	1.51%	1.33%	1.20%	0.93%	14.89%	12.87%	17.14%	12.38%	28.71%	22.21%	13.27%	13.23%	26.71%
Aspartame	Total	0.024	0.023	0.025	0.063	0.080	0.060	0.037	0.021	0.020	0.302	0.041	0.048	0.139	0.171	0.124	0.075	0.038	0.035
	% of ADI	0.06%	0.06%	0.06%	0.16%	0.20%	0.15%	0.09%	0.05%	0.05%	0.75%	0.10%	0.12%	0.35%	0.43%	0.31%	0.19%	0.09%	0.09%
Sucralose	Total	0.017	0.018	0.017	0.058	0.063	0.052	0.037	0.015	0.009	0.173	0.166	0.184	0.572	0.347	0.252	0.173	0.164	0.214
	% of ADI	0.12%	0.12%	0.11%	0.39%	0.42%	0.35%	0.25%	0.10%	0.06%	1.15%	1.11%	1.22%	3.81%	2.31%	1.68%	1.15%	1.10%	1.42%
Sum of stevioside and rebaudioside A	Total	0.013	0.013	0.013	0.035	0.039	0.034	0.027	0.012	0.007	0.552	0.365	0.592	1.328	0.839	0.581	0.526	0.381	0.568
	% of ADI	0.32%	0.33%	0.32%	0.87%	0.98%	0.86%	0.68%	0.30%	0.17%	13.80%	9.12%	14.80%	33.19%	20.97%	14.53%	13.15%	9.51%	14.21%

below the ADIs, as relative intakes at the 95th percentile were 29.7% for saccharin, and 35.9% for acesulfame potassium of the respective ADIs. None of the food additives exceeded the % of ADI.

Similarly to the results of the current study, an aspartame reevaluation conducted by the EFSA Panel on Food Additives and Nutrient Sources added to Food calculated age intakes of 1.6–16.3 mg/kg bw/day for infants aged 12–35 months, 1.8–12.6 mg/kg bw/day for 3–9 years, 0.8–4.0 mg/kg bw/day for 10–17 years, 0.7–8.5 mg/kg bw/day for 15–64 years, and 0.4–4.4 mg/kg bw/day for $\geq$ 65 years (EFSA, 2013). Comparing with previous studies, the intake studied from Korea, China and EU showed that sweetener intake was below the respective ADIs. The data provide that the results do not indicate to be a significant shift in NNS intake.

In conclusion, an examination of the food types and distribution of five NNS in food products was based on a review of the most highly and frequently consumption of KNHANES, the item manufacturing report and the import declaration form. Based on the overall average results of the quantitative analysis of the NNS through the monitoring experiment, the EDI of each NNS was examined with reference to the daily food consumption data per person collected from KNHANES for the total population and only consumer group. The detection rates of NNS-positive food items were 44% (110/250) for acesulfame potassium, 27% (41/151) for saccharin sodium, 43% (77/179) for aspartame, 60% (145/240) for sucralose, and 96% (190/197) for sum of stevioside and rebaudioside A. The calculated daily intake of each food revealed that the highest exposure to acesulfame potassium, sodium saccharin, and aspartame was by fruit drink, pickles, and cookies, respectively. Additionally, carbonated beverages were the primary source of the consumption of sucralose, and sum of stevioside and rebaudioside A. The total estimated daily intake ranges by age as a proportion of the respective ADI were 0.12–0.53% for acesulfame potassium, 0.93–1.68% for sodium saccharin, 0.05–0.20% for aspartame, 0.06–0.42%, for sucralose, and 0.17–0.98% for sum of stevioside and rebaudioside A. It can be concluded that the daily dietary intake of each of the five NNS is at a safe level when considered as a proportion of the ADI.

The global artificial sweeteners market was USD 7.8 Billion in 2020. The market will be expected to increase at a healthy compound annual growth rate (CAGR) of 3.52% during 2020–2026 (Renub Research 2021). The research is able to use different data sources on the periodic safety assessment of these growing food additives market. NNS risk assessments should be conducted on a regular basis with quantitative analysis on the dietary intake and monitoring of food additives in processed foods.

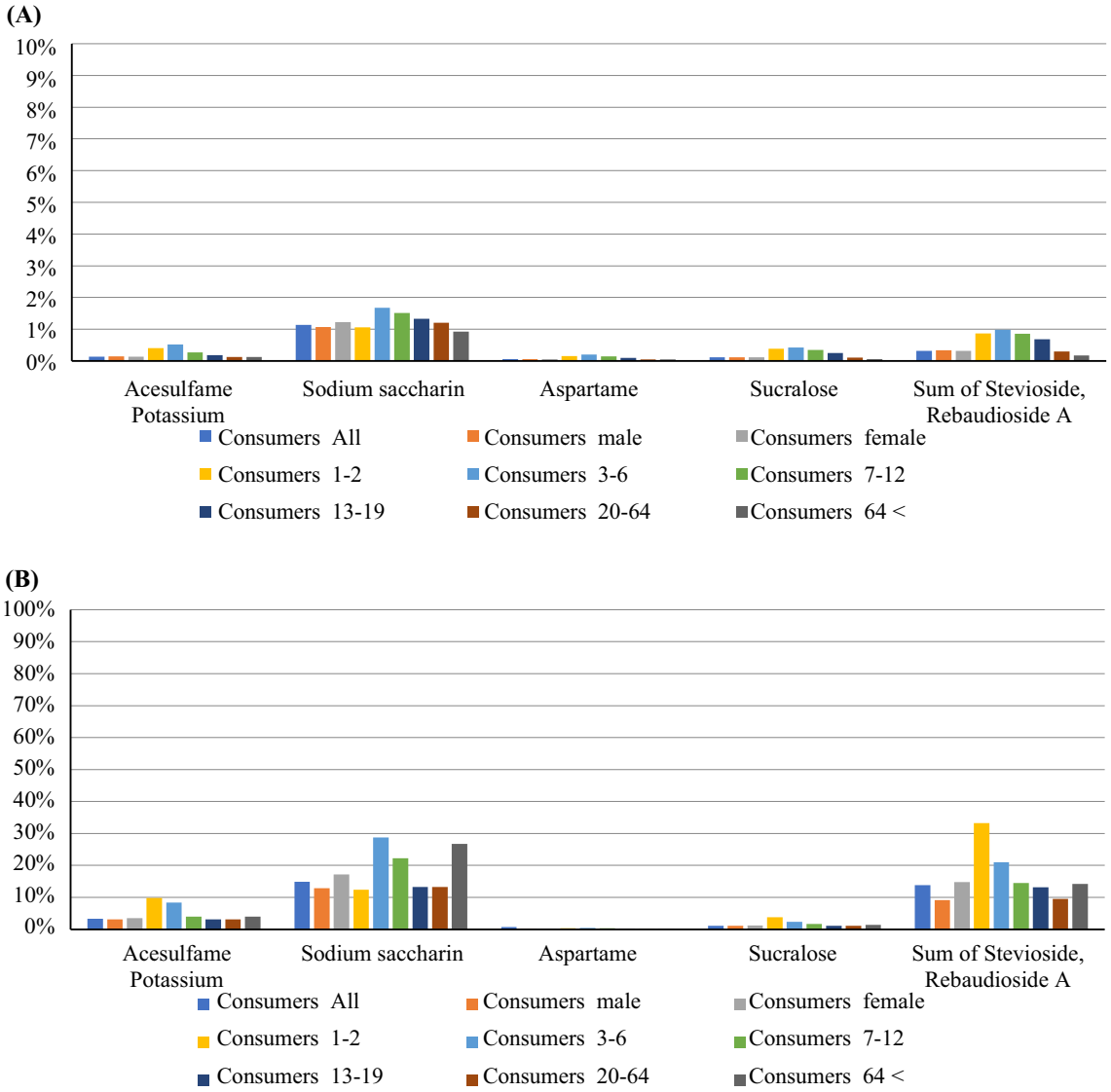

Fig. 2 Proportional distribution of each NNS. ((**A**): Average food intake-total rate of acesulfame potassium; (**B**) Average food intake-consumer rate of acesulfame potassium; (**C**) Average food intake-total rate of sodium saccharin; (**D**) Average food intake-consumer rate of sodium saccharin; (**E**): Average food intake-total rate of aspartame; (**F**) Average food intake-consumer rate of aspartame; (**G**) Average food intake-total rate of sucralose; (**H**) Average food intake-consumer rate of sucralose; (**I**) Average food intake-total rate of sum of stevioside and rebaudioside A; (**J**) Average food intake-consumer rate of sum of stevioside and rebaudioside A)

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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