Assessment of estimated daily intake of 3-monochloropropane-1,2-diol from soy sauce in Korea

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Abstract Soy sauces collected from the Korean market were determined for 3-monochloropropane-1,2-diol (3-MCPD) and daily intake of 3-MCPD through the consumption of soy sauce was estimated. Thirty-one samples were chosen based on a market share in 2017. The amount of 3-MCPD varied from not detected to 54.97 µg/kg with a mean value of 11.62 µg/kg. Seven soy sauces, which corresponded to 23% of the analysed samples, exceeded 20 µg/kg that is a maximum limit established by the Ministry of Food and Drug Safety in Korea. Daily intake of 3-MCPD was estimated as 1.22 ng/kg body weight (bw) for average consumers and 4.47 ng/kg bw for 95th high consumers, respectively. The exposure for average consumers amounted to 0.03–0.11% of the provisional maximum tolerable daily intake (PMTDI, 4 µg/kg bw). This indicates that the exposure to 3-MCPD from soy sauce is of low concern in the Korean population.

Keywords 3-Monochloropropane-1,2-diol · Soy sauce · Daily intake · Risk assessment · Korea

Introduction

Acid-hydrolysed vegetable protein (acid-HVP) produced from the reaction of hydrochloric acid with protein under high temperature is used as a flavour enhancer in various foods such as soy sauce and soup (Caltà et al., 2004). During acid-HVP production, 3-monochloropropane-1,2-diol (3-MCPD) can be naturally formed from chlorine and lipid as a contaminant (Caltà et al., 2004). Due to its carcinogenicity and nephrotoxicity, 3-MCPD was classified as a possible human carcinogen (Group 2B) by the International Agency for Research on Cancer (IARC) (IARC, 2013). In the eighty-third report of the Joint FAO/WHO Expert Committee on Food Additives (JECFA), a provisional maximum tolerable daily intake (PMTDI) of 3-MCPD was established as 4 µg/kg body weight (bw) (JECFA, 2017). The occurrence of 3-MCPD has been primarily reported in soy sauce as the acid-HVP is added to improve aroma and taste of soy sauce (Wong et al., 2006). European Commission has set a maximum limit of 3-MCPD as 20 µg/kg in soy sauce (European Commission, 2017) and U.S. Food and Drug Administration as 1.0 mg/kg in Asian-style sauce (FDA, 2019). Australia New Zealand Food Authority (ANZFA) reported a maximum level of 3-MCPD as 0.2 mg/kg in soy sauce (ANZFA, 2001).

The main exposure to 3-MCPD is through the diet. In the monitoring of 5712 food samples consumed in Korea, 3-MCPD was detected in 5.3% of the total samples, in particular with the highest detection rate of 25% in soy sauce (MFDS, 2019). Soy sauce is the most commonly used seasoning in Korean cuisine, indicating that general population can be exposed to 3-MCPD. Daily intake of soy sauce for average consumers and 95th high consumers were 6.32 g and 23.06 g in 2017 (KHIDI, 2019). Three

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types of soy sauce, which includes fermented, acid hydrolysed, and mixed products, are consumed in Korea. The fermented soy sauce is produced by a traditional brewed method with enzymatic hydrolysis of protein, lipid, and carbohydrate for several months or longer. To shorten the traditional fermentation process, chemical hydrolysis was employed to yield an acid hydrolysed soy sauce. Since high amount of 3-MCPD in the chemically hydrolyzed soy sauce and its possible health risk were issued, the acid hydrolysed product has been almost disappeared in the Korean market. Nowadays, the acid hydrolysed soy sauce was mixed with the traditional brewed soy sauce, which was called as a mixed soy sauce, and sold with a lower cost on the market.

According to the sales of soy sauce at the Korean market in 2017, the mixed soy sauce was top-ranked with a market share of 48.5%, followed by the fermented sauce of 36.4% (KAF and FTC, 2018). Korean regulation agency set a maximum level of 3-MCPD of 300 µg/kg for soy sauce and set a maximum limit of 20 µg/kg for soy sauce in MFDS, (2020). Exposure estimation of 3-MCPD intake from the consumption of soy sauce and risk characterization for a potential health effect in the Korean population needs to be investigated. Therefore, the objectives of this study were (i) to determine 3-MCPD content in soy sauce samples with high market share in the Korean market, (ii) to estimate the exposure to 3-MCPD through soy sauce for average and high consumers, and (iii) to assess a health risk in Koreans.

Materials and methods

Materials

Hydromatrix and sodium chloride were purchased from Agilent technology (Lake Forest, CA, USA) and Daejung Chemicals & Metals (Siheung, Korea), respectively. Anhydrous sodium sulfate was obtained from Tokyo Chemical Industry Company (Tokyo, Japan). Diethyl ether, ethyl acetate, isooctane (2,2,4-trimethylpentane), and *n*-hexane were purchased from Samchun Chemicals (Pyungtack, Korea). 3-Chloro-1,2-propanediol (3-MCPD, ≥ 98.0%), 3-chloro-1,2-propane-1,1,2,3,3-d₅-diol (3-MCPD-d₅, ≥ 98.0%), and *N*-heptafluorobutyrylimidazole (HFBI) were purchased from Sigma-Aldrich (St. Louis, MO, USA).

Samples

The ratio of three types in soy sauce was chosen based on a market share in 2017 (KOCA, 2017; KAF and FTC, 2018) and thirty-one samples with high production amount in

each type of soy sauce were collected from the Korean market in 2018. The samples consisted of mixed (*n* = 20), fermented (*n* = 10), and acid hydrolysed (*n* = 1) products. The selected samples were top-ranked products of major soy sauce companies in the Korean market and accounted of more than 90% of the annual sale in 2018 (KOCA, 2017; KAF and FTC, 2018). For the acid hydrolysed product, only one sample was commercially available in the market.

Preparation of standard solution

3-MCPD and 3-MCPD-d₅ (each 25 mg) were separately dissolved in 25 mL of ethyl acetate (1 mg/mL), followed by 100-fold dilution (10 µg/mL). It was used as a working solution of 3-MCPD. One mL of 3-MCPD-d₅ stock solution (1 mg/mL) was diluted in 100 mL of ethyl acetate and used as an internal standard (10 µg/mL).

Method validation

The linearity was tested at six concentrations of 3-MCPD in a range of 2.5–80 ng/mL. To evaluate a limit of detection (LOD), limit of quantification (LOQ), and repeatability, fermented soy sauce with small amount of 3-MCPD was spiked with 3-MCPD (10 µg/mL) to three concentrations (10, 50, and 100 µg/kg). The analysis was performed three times within one day for intraday assay as well as three continuous days for interday assay. The LOD and LOQ were determined as a signal to noise ratio of 3.3 and 10, respectively. The recovery was calculated by comparing the detected value with the spiked level. The precision was calculated as the percentage of the standard deviation divided by the average value of recovery.

Sample preparation

3-MCPD was determined by the method of the Association of Official Analytical Chemists (AOAC) method 2000.01 (AOAC, 2020b) with a slight modification. Eight gram of soy sauce was weighed into a 250 mL beaker and then 80 µL of 3-MCPD-d₅ solution (10 µg/mL in ethyl acetate) was added into the sample as an internal standard. Sodium chloride solution (5 M) was added to the beaker until total weight reached to 20 g. The mixture was sonicated in the ultrasonic bath (Power Sonic 410, Hwashin, Gwangju, Korea) with frequency of 40 kHz for 10 min. The resulting mixture was manually mixed with 8 g of hydromatrix (4.4 cm I.D., 2.8 cm height) and then packed into a glass column (4.4 cm I.D., 32.5 cm length). Twenty gram of anhydrous sodium sulfate was packed on the top with a layer of 1 cm. The column was washed using 90 mL of hexane-diethyl ether (9:1, v/v) and then 3-MCPD was eluted with 250 mL of diethyl ether. After removing

residual water using 15 g of anhydrous sodium sulfate, the eluate was evaporated at 40 °C and then transferred into a volumetric flask of 10 mL and brought to the volume using diethyl ether. All samples were analysed in triplicate.

Derivatization

The prepared sample (1 mL) was dried under a gentle stream of nitrogen and then dissolved in 1 mL of isooctane. The mixture was heated for 20 min at 70 °C after addition of 50 µL of HFBI. After cooled below 40 °C, 1 mL of distilled water was added, vortexed, and stood until it was separated into two phases. The upper phase was transferred to another vial, which was followed by the addition of anhydrous sodium sulfate.

GC/MSD condition

3-MCPD was detected using a 7820A gas chromatography/5933E quadrupole mass spectrometer (Agilent Technologies, Santa Clara, CA, USA). DB-5MS column (30 m length, 0.25 mm I.D., 0.25 µm film thickness; Agilent J&W, Folsom, CA, USA) was used for separation. Flow rate of helium (99.9999%) used as a carrier gas was 1 mL/min and each sample (1 µL) was injected in the splitless mode at 70 eV. The oven temperature was held for 1 min at 50 °C, 2 °C/min to 74 °C, 0.5 °C/min to 76 °C, 55 °C/min to 270 °C, and held for 5 min. The interface and ion source temperatures were 270 °C and 240 °C, respectively. The mass spectrometer was firstly worked in the scan mode for qualification of 3-MCPD. The fragment ions of m/z 253, 275, 289, and 453 for 3-MCPD and m/z 257, 278, 294, and 456 for internal standard 3-MCPD- d_5 were monitored in the selected ion monitoring mode. The ratio of m/z 253 (3-MCPD) to m/z 257 (3-MCPD- d_5) were used for quantification of 3-MCPD in soy sauce. For confirmation of 3-MCPD, relative abundance ratios of m/z 253, 275, 289 to m/z 453 ion in the standard were compared with those of the sample. At least 2 of the 4 ion ratios in sample must be within 80–120% of standard ion ratios (AOAC, 2020b).

Daily intake estimation

The food consumption data and average body weight for gender and age groups were obtained from the National Food & Nutrition Statistics 2017 (KHIDI, 2019), which was extracted from the 2017 Korea National Health and Nutrition Examination Survey conducted by the Ministry of Health and Welfare/Korea Centers for Disease Control and Prevention. The data collected by a 24 h dietary recall and a food frequency questionnaire covers 7167 respondents, which was categorized into the following subgroups: total, male, female, eight age groups (1–2, 3–5, 6–11,

12–18, 19–29, 30–49, 50–64, and 65 ≤). The daily intake of 3-MCPD was calculated with mean concentration of 3-MCPD in soy sauce and daily intake for average consumers or 95th percentile high consumers. Then, the estimated daily intake of 3-MCPD was divided by average body weight of each subgroups.

Risk assessment

The JECFA reported renal tubular hyperplasia as the most sensitive end-point of 3-MCPD from two long-term carcinogenicity studies. Based on the lowest BMDL₁₀ of 0.87 mg/kg bw per day for renal tubular hyperplasia and a 200-fold uncertainty factor, the PMTDI was established as 4 µg/kg bw per day (JECFA, 2017). To assure whether the estimated daily intake of 3-MCPD poses a risk to public health in Korea, the exposure was expressed as a percentage of the PMTDI for 3-MCPD.

Statistical analysis

All statistical analyses were performed using SPSS IBM version 21.0 (Statistical Package for Social Science, SPSS Inc., Chicago, IL, USA). Average and standard deviation were calculated from three measurements. Associations among the percentage of acid hydrolysed soy sauce in soy sauce samples were determined using Pearson's correlation analysis.

Results and discussion

Method validation

3-MCPD is generally derivatized prior to gas chromatographic analysis due to its low volatility and high polarity (Hamlet et al., 2002). Phenylboric acid (PBA), heptafluorobutyric acid (HFBA), and HFBI has been commonly used as a derivatizing reagent of 3-MCPD (Genualdi and Nyman 2017; Kim et al., 2006a; Christova-Bagdassarian et al., 2013; Xu et al., 2013; Wong et al., 2006). 3-MCPD derivatized with HFBI had more fragments than other derivatives in mass spectrometry, which made it easier to confirm 3-MCPD from foods that contains various components (Lee and Khor, 2015). Moreover, 3-MCPD derivatives using HFBI had three times of peak area compared with HFBA derivatives (Xu et al., 2006). Meanwhile, excess PBA remaining after derivatization caused a damage to the chromatography system (Lee and Khor, 2015). The Association of Official Analytical Chemists (AOAC) recommended HFBI for the derivatization of 3-MCPD (AOAC, 2002b). From these reasons, HFBI was chosen for the derivatization of 3-MCPD in this study.

To confirm that the analytical method is suitable, linearity, LOD, LOQ, and repeatability were tested at three concentrations (10, 50, and 100 µg/kg) of 3-MCPD and the results are shown in Table 1. A good linearity was observed with a correlation coefficient of 0.9991 in the range of 2.5–80 ng/mL of 3-MCPD. The LOD and LOQ values were 2.42 µg/kg and 7.33 µg/kg, respectively. These values were acceptable based on the analysis criteria of 3-MCPD as 5 µg/kg or less for LOD and 10 µg/kg or less for LOQ (European Commission, 2007). Moreover, the LOD value was lower than those of earlier studies (Kim et al., 2006a; Wong et al., 2006; Xu et al., 2006, 2013). The recovery was in the range of 91.43–100.90% for intraday and 87.22–102.41% for interday. The repeatability was 1.35–3.79% for intraday and 1.91–6.72% for interday, respectively. These values were in the acceptable range of the European Commission (European Commission, 2007), which suggested the recovery of 75–110% in the analysis of 3-MCPD. The AOAC reported that the guideline for 3-MCPD are 75–120% for recovery and less than 8% for repeatability (AOAC, 2002a). In this study, the LOD, LOQ, recovery, and repeatability meet the European Commission criteria as well as the AOAC guideline.

Identification of 3-MCPD

The peak of 3-MCPD was confirmed using a retention time and the ratios of fragment ions. In total ion chromatogram of mixed soy sauce (Fig. 1A), 3-MCPD and internal standard 3-MCPD-d₅ were eluted at 14.35 min and 14.57 min. Mass spectrum and fragmentation of derivatized 3-MCPD are shown in Fig. 1B and C. The major fragment ions of derivatized 3-MCPD were *m/z* 453 (–CH₂Cl), 289 (–C₃F₇CO₂), 275 (–C₃F₇CO₂CH₂), and 253 (–C₃F₇CO₂–HCl) ions. The fragment ion with an *m/z* value of 169 was known to be derived from derivatizing reagent HFBI (Hamlet

et al., 2002). In the selected monitoring, the ratio of responses at *m/z* 253, 275, and 289 relative to the response at *m/z* 453 was compared for the standards and samples. The AOAC (2002b) suggested that fragment abundance ratio of samples should be within ± 20% of the mean of the ion abundance ratios of the standard to confirm peak identity. In this study, ion abundance ratios of fragments in all samples were in the range of 80–120% of standard. Four fragments including *m/z* 257, 278, 294, and 456 were observed for the internal standard 3-MCPD-d₅ with the highest intensity of *m/z* 257. Therefore, peak area ratio at *m/z* 253 (3-MCPD) to *m/z* 257 (3-MCPD-d₅) was used for the quantification of 3-MCPD.

3-MCPD concentration

The concentrations of 3-MCPD in 31 soy sauce samples are presented in Table 2. Of the analysed soy sauces, 3-MCPD was found in twenty-seven samples, amounting for 87% of the total. Four samples that 3-MCPD was not detected were fermented soy sauces. In addition, the fermented samples had the lowest mean concentration of 3-MCPD compared with other type samples. Similarly, Christova-Bagdassarian et al. (2013) demonstrated that fermented soy sauce showed a significant lower amount of 3-MCPD compared with acid hydrolysed and mixed soy sauces. The highest value of 54.97 µg/kg was found in the mixed product (Table 2). It is much lower than the values reported previously. Wong et al. (2006) found that the highest concentration (110.8 mg/kg) of 3-MCPD was observed in imported soy sauce. Nyman et al. (2003) demonstrated that the maximum value of 3-MCPD was 876 mg/kg in 36 soy sauces sold in USA. Christova-Bagdassarian et al. (2013) reported the highest level of 3-MCPD in 21 soy sauces was 186.6 µg/kg and hydrolysed soy protein had higher values of 3-MCPD than fermented

Table 1 Validation results of 3-MCPD analytical method in soy sauce

Spiked (µg/kg)	Intraday			Interday		
	Observed (µg/kg)	Recovery (%)	RSD ^a (%)	Observed (µg/kg)	Recovery (%)	RSD ^a (%)
10	9.40	94.00	3.79	9.53	95.30	3.60
	9.53	95.30		9.94	99.40	
	10.09	100.90		10.24	102.41	
50	47.59	95.17	1.35	43.61	87.22	6.72
	48.29	96.59		48.29	96.59	
	47.01	94.03		49.66	99.32	
100	96.04	96.04	2.61	92.59	92.59	1.91
	95.20	95.20		95.22	95.22	
	91.43	91.43		96.04	96.04	

^aRSD relative standard deviation

Fig. 1 Total ion chromatogram of mixed soy sauce (A), mass spectrum of derivatized 3-MCPD (B), and analytical procedure of 3-MCPD (C)

soy sauces. In this study, the mean concentration of thirty-one samples was 11.62 µg/kg (Table 2). It is approximately one-seventh of the value of Kim et al. (2006a) who reported that mean level of 3-MCPD in 72 Korean soy sauces was 80 µg/kg. The formation of 3-MCPD during acid-HVP production can be reduced by alkali neutralization after acid hydrolysis, substitute sulfuric acid for hydrochloric acid, and careful control of acid hydrolysis (FAO, 2008). These reduction methods employed for soy sauce production may lead to the decrease of 3-MCPD level in soy sauce.

The maximum limit of 3-MCPD for soy sauce in Korea was 300 µg/kg until 2019 (Kim et al., 2006a). Recently, Korean Ministry of Food and Drug Safety enforced the maximum limit of 3-MCPD as 20 µg/kg in hydrolysed and mixed soy sauce (MFDS, 2020). It is equal to the maximum limit of the European Commission and Malaysia for soy sauce (European Commission, 2006; Malaysia Food Act 1983 and Regulation 1985, 1983). Meanwhile, it is lower than the regulation level of Canada (1.00 mg/kg) and

Australia & New Zealand (0.20 mg/kg) for 3-MCPD in soy sauce (Health Canada, 2018; ANZFA, 2001). Among 31 samples analysed herein, seven mixed soy sauce samples (23% of the total) exceeded the maximum limit of 20 µg/kg for 3-MCPD. Fu et al. (2007) demonstrated that half of 629 Chinese soy sauces manufactured in 2003–2004 had higher level than 20 µg/kg (Table 3). In comparison, among 164 Chinese soy sauce samples reported in 2013, eleven samples exceeded 20 µg/kg (Xu et al., 2013). Genualdi and Nyman (2017) also found a substantial reduction of 3-MCPD level in 60 Asian soy sauces analysed in 2015 in comparison with those in 2003. These indicate that 3-MCPD concentration in soy sauce has been significantly decreased. However, taken into consideration that 23% of soy sauce samples examined in this study had higher level than the maximum limit of 3-MCPD in Korean soy sauce (MFDS, 2020), a continuous monitoring for 3-MCPD is required.

3-MCPD can be formed as a contaminant during the acid-HVP production, which is a major ingredient of acid

Table 2 3-MCPD levels and proportion of acid hydrolyzed soy sauce in soy sauce samples

Soy sauce	3-MCPD ($\mu\text{g/kg}$)	Mean ^a ($\mu\text{g/kg}$)	Acid hydrolyzed ^b (%)
Fermented-1	4.58	2.70	–
Fermented-2	4.90		–
Fermented-3	3.85		–
Fermented-4	2.95		–
Fermented-5	N.D. ^c		–
Fermented-6	7.01		–
Fermented-7	N.D.		–
Fermented-8	N.D.		–
Fermented-9	N.D.		–
Fermented-10	3.69		–
Mixed-1	20.37	16.45	80.00
Mixed-2	8.50		95.00
Mixed-3	18.26		83.00
Mixed-4	24.62		70.00
Mixed-5	3.96		80.00
Mixed-6	11.82		95.00
Mixed-7	12.62		95.00
Mixed-8	54.97		50.00
Mixed-9	16.75		65.00
Mixed-10	26.81		95.00
Mixed-11	20.13		80.00
Mixed-12	4.44		70.00
Mixed-13	4.03		93.00
Mixed-14	10.57		50.00
Mixed-15	3.09		90.00
Mixed-16	44.58		80.00
Mixed-17	8.75		95.00
Mixed-18	20.90		80.00
Mixed-19	3.88		80.00
Mixed-20	9.91		97.50
Acid hydrolyzed-1	4.18	4.18	100.00
Total	N.D.- 54.97	11.62	

^aMean value of 3-MCPD in each type of soy sauce^bProportion of acid hydrolyzed soy sauce listed in the label^cN.D. not detected

hydrolysed soy sauce. It is assumed that a proportion of acid hydrolysed soy sauce can be correlated with 3-MCPD level in soy sauce. The amount of acid hydrolysed soy sauce added in the samples was obtained from the label of each sample bottle. The percentage of acid hydrolysed product ranged from 50 to 97.5% in 20 mixed soy sauces. No correlation between 3-MCPD concentration and the percentage of acid hydrolysed soy sauce was found in the mixed soy sauce. It is consistent with the results of other studies, demonstrating that 3-MCPD levels in the mixed soy sauce did not correlated with the amount of acid hydrolysed soy sauce (Kim et al., 2006a, b). It seems that

the amount of hydrolysed soy sauce is not critical for the concentration of 3-MCPD in soy sauce.

Estimated intake

Table 4 shows average body weight, soy sauce consumption data, and exposure to 3-MCPD from the consumption of soy sauce. Daily mean and 95th percentile intake in the Korean population were 6.32 g and 23.06 g, respectively. It is lower than daily intakes of other Asian countries: Japan (30.00 g) and China (10.70 g) (Kobayashi, 2013; Chinese Ministry of Health, 2004). On the other hand, it is

Table 3 Summary of 3-MCPD levels in soy sauce previously reported

Country	Collection year	Number of sample	Positive (%)	Samples exceeding 20 µg/kg ^a (%)	3-MCPD concentration (µg/kg)		References
					Mean	Range	
Bulgaria		21	100.0	33.3		3.7–186.6	Christova-Bagdassarian et al. (2013)
Brazil	2009–2011	45			220.6–221.4 ^b		Arisseto et al. (2013)
	2010–2011	61	11.5	9.8		N.D.–4405	Vicente et al. (2015)
China	2003–2004	629		52.5			Fu et al. (2007)
		164	17.7	6.7		N.D.–5706	Xu et al. (2013)
USA		36	88.9			N.D.–876000	Nyman et al. (2003)
	2015	60	13.3	13.3		N.D.–530	Genualdi and Nyman (2017)
Korea	2005	72	36.1		80	N.D.–3131	Kim et al. (2006a)
		27	29.6			100–300	Kim et al. (2008)

^aMaximum limit of 3-MCPD in soy sauce (European Commission, 2006)

^bLower bound and upper bound average of 3-MCPD concentrations

Table 4 Estimated intakes of 3-MCPD from consumption of soy sauce in the Korean population

Group	Body weight ^a (kg)	Soy sauce consumption ^a (g/day)		3-MCPD intake ^b (ng/kg bw/day)		% PMTDI ^c	
		Mean	95th	Mean	95th	Mean	95th
Total	60.73	6.32	23.06	1.22	4.47	0.03	0.11
<i>Gender</i>							
Male	66.76	7.12	26.73	1.26	4.71	0.03	0.12
Female	54.68	5.50	19.70	1.18	4.24	0.03	0.11
<i>Age</i>							
1–2	12.20	2.29	7.14	2.21	6.89	0.06	0.17
3–5	17.69	3.94	11.87	2.62	7.90	0.07	0.20
6–11	33.18	5.22	18.38	1.85	6.52	0.05	0.16
12–18	58.59	6.07	19.25	1.22	3.87	0.03	0.10
19–29	67.34	7.51	28.78	1.31	5.03	0.03	0.13
30–49	67.24	7.51	28.78	1.31	5.04	0.03	0.13
50–64	59.37	6.31	22.33	1.25	4.43	0.03	0.11
≥ 65	60.73	5.30	20.98	1.03	4.07	0.03	0.10

^aCited from the National Food & Nutrition Statistics 2017 (KHIDI, 2019)

^bCalculated using mean concentration of 3-MCPD, per capita consumption of soy sauce, and average body weight of subgroups

^cPercentage of 3-MCPD intake to PMTDI (4 µg/kg bw per day) established by the JECFA

slightly higher than Malaysian intake, which was 6.26 g for male and 6.03 g for female (Wong et al., 2020).

For the estimation of the exposure to contaminant, the World Health Organization (WHO) recommended that the half of LOD was used for all results less than LOD when the number of samples with the values below LOQ were less than 60% (WHO, 2002). In this study, 51.6% of samples analysed was less than LOQ (7.33 µg/kg).

Consequently, half of LOD values (2.42 µg/kg) was used in four samples with 3-MCPD below LOD for the estimation of the exposure to 3-MCPD. Using the mean concentration (11.77 µg/kg) of 3-MCPD, soy sauce consumption data, and body weight (Table 4), mean and 95th high exposure to 3-MCPD were estimated to be 1.03–2.62 ng/kg bw/day and 3.87–7.90 ng/kg bw/day, respectively. Male was found to be more exposed to

3-MCPD than female. Among eight age groups, younger groups had relatively higher exposure to 3-MCPD compared with adult groups. The daily intake of high consumers was about three times higher than that of average consumers.

Risk assessment

The IARC classified 3-MCPD as a possible carcinogen to humans (IARC, 2013) and the JECFA established a PMTDI to be 4 µg/kg bw per day (JECFA, 2017). The proportion of estimated 3-MCPD intake to the PMTDI is presented in Table 4. The exposures corresponded to 0.03–0.07% of the PMTDI for average consumers and 0.10–0.20% for 95th percentile high consumers, respectively. This is similar to the result of Malaysian people, which was 0.05% of PMTDI for male and 0.06% of PMTDI for female (Wong et al., 2020). This shows that the exposure to 3-MCPD from soy sauce is of low concern in Koreans. In a worst-case scenario using the highest concentration (54.97 µg/kg) of 3-MCPD, the exposure rose up to 0.12–0.31% of PMTDI for average consumers and 0.45–0.92% of PMTDI for 95th high consumers. This indicates that further studies to cover other foods that contain acid-HVP as a food ingredient should be continued to assess a health risk from dietary pattern of Koreans.

In conclusion, 23% of the examined soy sauce samples exceeded the maximum level of 20 µg/kg for 3-MCPD. It should be noted that more efficient methods to reduce 3-MCPD concentration need to be employed in soy sauce production, although the mean concentration of 3-MCPD was lower than other studies reported previously. From the viewpoint of 0.03–0.07% of PMTDI for average consumers, there is of low concern in the Korean population. These results can be used in a risk management to determine priorities for possible intervention of food contaminants in Korea.

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Compliance with ethical standards

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

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