Preplanned Studies

Exposure to Chloropropanols and Their Fatty Acid Esters and Glycidyl Fatty Acid Esters in the Sixth Total Diet Study — China, 2016–2019

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Summary

What is already known about this topic?

Chloropropanols, along with their fatty acid esters and glycidyl fatty acid esters (GEs), are prevalent contaminants in a variety of processed foods, posing potential health risks to humans.

What is added by this report?

In the Sixth China Total Diet Study (TDS), 3-monochloropropane-1,2-diol esters (3-MCPD esters) and GEs were identified as the predominant chloropropanols and their esters in composite food samples. Vegetables (47.0%) and cereals (15.4%) were the major contributors to exposure among the 12 food categories evaluated.

What are the implications for public health practice?

The Sixth China TDS highlighted concerns regarding potential health risks associated with dietary exposure to GEs. This study underscores the need for further attention in devising practical strategies to mitigate dietary exposure to GEs.

Chloropropanols and their derivatives, including fatty acid esters and glycidyl fatty acid esters (GEs), are prevalent contaminants arising from food processing. Notably, chloropropanols encompass both mono- and dichloro-substituted variants such as 2-monochloropropane-1,3-diol (2-MCPD) and 3-monochloropropane-1,2-diol (3-MCPD), as well as 1,3-dichloro-2-propanol (1,3-DCP) and 2,3-dichloro-1-propanol (2,3-DCP), each with corresponding fatty acid esters. These compounds are linked to reproductive toxicity, genotoxicity, and carcinogenicity. Evidence suggests that their fatty acid esters can be converted by lipases into free chloropropanols or glycidol, resulting in toxicity within the gastrointestinal tract (*1*). Given that dietary intake is the principal route by which these contaminants are ingested, they present a growing concern for food safety. Consequently, an assessment of dietary exposure to chloropropanols and their esters was performed as part of the Sixth China Total Diet Study (TDS) from 2016 to 2019, as detailed by Lyu et al (*2*). This assessment discovered that 3-MCPD esters and GEs are the most frequently detected contaminants in composite food samples. The escalating concern about the potential health hazards linked to GEs emphasizes the need for robust strategies to mitigate dietary exposure.

3-MCPD has been classified as a “possible human carcinogen” (Group 2B) by the International Agency for Research on Cancer (IARC) (*3*). Despite the recognized risk posed by 3-MCPD, there is limited data on the direct toxicity of other chloropropanols and their esters. Reflecting concerns over the long-term carcinogenic potential of 3-MCPD, the Joint FAO/WHO Expert Committee on Food Additives revised the provisional maximum tolerable daily intake (PMTDI) to 4 μg/kg body weight (BW) per day in 2017 (*1*). In 2018, the European Food Safety Authority (EFSA) established the tolerable daily intake for 3-MCPD and its esters (expressed as 3-MCPD equivalents) at 2 μg/kg BW per day, owing to the comparable toxicity of the chloropropanol esters and the free forms (*4*). This study conservatively applies the PMTDI of 4 μg/kg BW per day as a health-based guidance value (HBGV) for both 2-MCPD and its esters (expressed as 2-MCPD equivalents), assuming their toxicities are identical to those of 3-MCPD and its esters. Currently, food safety authorities have not set HBGVs for GEs. However, the EFSA advocates using a margin of exposure (MOE) approach for assessing the health risks from GE exposure, considering an MOE of 25,000 or higher as indicative of a low health concern (*5*).

The dietary exposure assessment to chloropropanols, their fatty acid esters, and GEs was performed focusing on a typical male adult from China (18–45 years old, 63 kg BW, engaged in light physical activity). This assessment spanned 24 provincial-level administrative divisions (PLADs) across 12 food categories within the scope of the Sixth China TDS. The study incorporated an analysis of seven chloropropanols and several esters, including 2-MCPD, 3-MCPD, 1,3-DCP, 2,3-DCP, 2-MCPD esters, 3-MCPD esters, and GEs. According to prior research, GEs were transformed into 3-bromopropanediol (3-MBPD) esters via bromination, and these, along with 2-MCPD esters and 3-MCPD esters, were hydrolyzed to their corresponding free forms for analysis. These forms were detected and quantified as glycidol equivalents, 2-MCPD, and 3-MCPD respectively (*6*). For detection purposes, derivatization was combined with quantification using internal standards through GC-MS/MS. The limit of detection (LOD) for chloropropanols, their esters, and GEs in dietary samples were established at 2.0, 4.0, and 4.0 μg/kg, respectively. When conducting descriptive statistical analyses of contamination levels and exposure, concentration values for specific food categories were set to 0.0 μg/kg if target contaminants were not detected across all samples within a category. Conversely, if levels were below the LOD, concentrations were calculated as half of the LOD value.

In this study, neither 1,3-DCP nor 2,3-DCP were detected in any of the 288 composite food samples analyzed. 2-MCPD was found only in five samples at concentrations near the LOD, leading to the exclusion of these chloropropanols from dietary intake assessment in this investigation. Table 1 presents summarized data on the contamination levels of detected chloropropanols, chloropropanol esters, and GEs across various food categories. The detection frequency (DF) of 3-MCPD esters (free 3-MCPD form) was notably higher at 87.2%, as was that of GEs (free glycidol form) at 74.3%, compared to 2-MCPD esters (free 2-MCPD form) at 41.3% and 3-MCPD at 30.6% in all samples evaluated. Among the 12 food categories, eggs exhibited the highest contamination levels for all target chloropropanol esters, with a geometric mean [95% confidence interval (95% *CI*)] of 79.7 (78.3, 81.1) μg/kg for 3-MCPD esters and 17.2 (15.5, 18.8) μg/kg for 2-MCPD esters. Vegetables followed, showing levels of 64.8 (63.9, 65.7) μg/kg for 3-MCPD esters and 15.7 (14.6, 16.7) μg/kg for 2-MCPD esters. The highest levels of GEs were found in meat with a geometric mean (95% *CI*) of 61.0 (60.3, 61.7) μg/kg, with vegetables next at 56.5 (55.5, 57.4) μg/kg (Figure 1). However, the peak concentrations for the esters were identified in an egg sample from Zhejiang Province — 4,390.0 μg/kg for 3-MCPD esters, 1,294.0 μg/kg for GEs, and 837.0 μg/kg for 2-MCPD esters. Compared to other food categories, vegetables displayed relatively higher geometric mean (95% *CI*) levels of 3-MCPD at 9.7 (8.4, 11.1) μg/kg, followed by potatoes at 3.5 (2.3, 4.7) μg/kg and meat at 2.3 (1.2, 3.3) μg/kg, with the highest concentration found in a vegetable sample from Guizhou Province (88.9 μg/kg).

Dietary exposure estimates to chloropropanols and their esters during the Sixth China TDS were derived from food consumption and contamination level data. The estimated dietary intakes of chloropropanols, chloropropanol esters, and GEs across the 24 PLADs are detailed in Supplementary Tables S1 and S2 (available at https://weekly.chinacdc.cn/). The average and high (95th percentile) dietary intakes were as follows: 3-MCPD esters (1.07, 2.20 μg/kg BW per day), GEs (0.79, 1.42 μg/kg BW per day), and 2-MCPD esters (0.26, 0.63 μg/kg BW per day) were all higher than those for 3-MCPD (0.14, 0.28 μg/kg BW per day). The highest dietary intake recorded for 3-MCPD esters was 3.51 μg/kg BW per day in Zhejiang Province, with Fujian Province following at 2.27 μg/kg BW per day. Despite eggs exhibiting the highest mean contamination level across the 24 PLADs, vegetables (43.5%) and cereals (15.1%) contributed more to the total intake of 3-MCPD esters than eggs (12.1%) due to their significantly larger consumption. The highest recorded intake of GEs was 2.04 μg/kg BW per day in Shaanxi Province, succeeded by Zhejiang Province (1.45 μg/kg BW per day). Similar to 3-MCPD esters exposure, GEs ingestion predominantly came from vegetables, though meat contributed more to GEs than it did to 3-MCPD or 2-MCPD esters. For 2-MCPD esters, the maximum intake was 0.90 μg/kg BW per day in Fujian Province, with the minimum at 0.06 μg/kg BW per day in Liaoning Province. Although the average intake of 3-MCPD was lower than 2-MCPD esters, the range of 3-MCPD intake (0.05 to 0.64 μg/kg BW per day) paralleled that of 2-MCPD esters. Notably, high intakes of 3-MCPD were observed in Guizhou Province and Hunan Province, at 0.64 and 0.28 μg/kg BW per day, respectively.

DISCUSSION

This study demonstrated that 3-MCPD esters and GEs, prevalent chloropropanols and their esters, are commonly found in various composite food categories, particularly in oil-based processed foods and fatty foods. High concentrations of 3-MCPD esters and

TABLE 1. Concentration levels (μg/kg) and DF (%) of 3-MCPD, 2-MCPD esters, 3-MCPD esters, and GEs in various composite food categories from the Sixth China TDS, 2016–2019.

Food category	Parameter	3-MCPD	2-MCPD esters	3-MCPD esters	GEs
Cereals	GM (95% *CI*)	1.2 (0.6–1.8)	2.2 (1.6–2.7)	8.3 (7.6–9.0)	3.5 (2.7–4.2)
	Median	1.0	2.0	9.0	4.0
	Range	ND to 4.8	ND to 8.0	ND to 24.0	ND to 16.0
	DF	12.5	8.3	95.8	54.2
Legumes	GM (95% *CI*)	2.1 (1.1–3.1)	5.2 (4.2–6.2)	24.6 (23.9–25.3)	20.8 (20.0–21.6)
	Median	1.0	4.5	22.0	19.5
	Range	ND to 14.6	ND to 29.0	9.0 to 75.0	5.00 to 106.0
	DF	45.8	62.5	100.0	100.0
Potatoes	GM (95% *CI*)	3.5 (2.3–4.7)	7.6 (6.2–9.0)	32.8 (31.7–34.0)	19.9 (18.6–21.1)
	Median	3.2	7.0	34.5	17.0
	Range	ND to 28.5	ND to 74.0	6.00 to 237.0	ND to 152.0
	DF	66.7	66.7	100.0	95.8
Meat	GM (95% *CI*)	2.3 (1.2–3.3)	11.2 (10.2–12.3)	59.3 (58.4–60.2)	61.0 (60.3–61.7)
	Median	1.8	11.5	51.0	62.0
	Range	ND to 15.9	ND to 56.0	16.0 to 317.0	22.0 to 196.0
	DF	50.0	87.5	100.0	100.0
Eggs	GM (95% *CI*)	1.8 (0.6–3.0)	17.2 (15.5–18.8)	79.7 (78.3–81.1)	43.4 (42.2–44.6)
	Median	1.0	19.5	68.0	39.0
	Range	ND to 60.7	ND to 837.0	11.0 to 4390.0	5.0 to 1294.0
	DF	29.2	87.5	100.0	100.0
Aquatic foods	GM (95% *CI*)	1.7 (0.8–2.7)	9.1 (7.9–10.3)	35.0 (33.9–36.1)	30.6 (29.8–31.4)
	Median	1.0	10.5	33.0	36.5
	Range	ND to 9.4	ND to 114.0	4.0 to 249.0	7.0 to 114.0
	DF	29.2	79.2	100.0	100.0
Diary products	GM (95% *CI*)	–	–	2.4 (1.9–3.0)	2.7 (2.1–3.3)
	Median	–	–	2.0	2.0
	Range	–	–	ND to 5.0	ND to 6.0
	DF	–	–	25.0	33.3
Vegetables	GM (95% *CI*)	9.7 (8.4–11.1)	15.7 (14.6–16.7)	64.8 (63.9–65.7)	56.5 (55.5–57.4)
	Median	9.9	17.5	61.5	63.5
	Range	ND to 88.9	ND to 102.0	13.0 to 230.0	14.0 to 267.0
	DF	87.5	95.8	100.0	100.0
Fruits	GM (95% *CI*)	–	–	3.9 (3.3–4.6)	–
	Median	–	–	4.0	–
	Range	–	–	ND to 9.0	–
	DF	–	–	75.0	–
Sugar	GM (95% *CI*)	–	2.1 (1.6–2.6)	12.9 (12.3–13.4)	6.7 (5.9–7.5)
	Median	–	2.0	12.5	5.5
	Range	–	ND to 4.0	9.00 to 27.0	ND to 44.0
	DF	–	8.3	100.0	91.7
Water and beverages	GM (95% *CI*)	–	–	3.5 (2.7–4.2)	2.8 (2.1–3.5)
	Median	–	–	3.0	2.0
	Range	–	–	ND to 10.0	ND to 10.0
	DF	–	–	50.0	29.2

Continued

Food category	Parameter	3-MCPD	2-MCPD esters	3-MCPD esters	GEs
Alcohol beverages	GM (95% *CI*)	1.7 (1.0-2.5)	−	9.4 (8.8–10.0)	5.3(4.6–6.1)
	Median	1.0	−	8.5	5.0
	Range	ND to 4.2	−	4.00 to 19.0	ND to 30.0
	DF	8.3	−	100.0	87.5

Note: "−" indicates that the target contaminant was not detected in this food category.
Abbreviation: 3-MCPD=3-monochloropropane-1,2-diol; 2-MCPD=2-monochloropropane-1,3-diol; GEs=glycidyl fatty acid esters; TDS=Total Diet Study; GM=geometric mean; *CI*=confidence interval; ND=non-detected; DF=detection frequency.

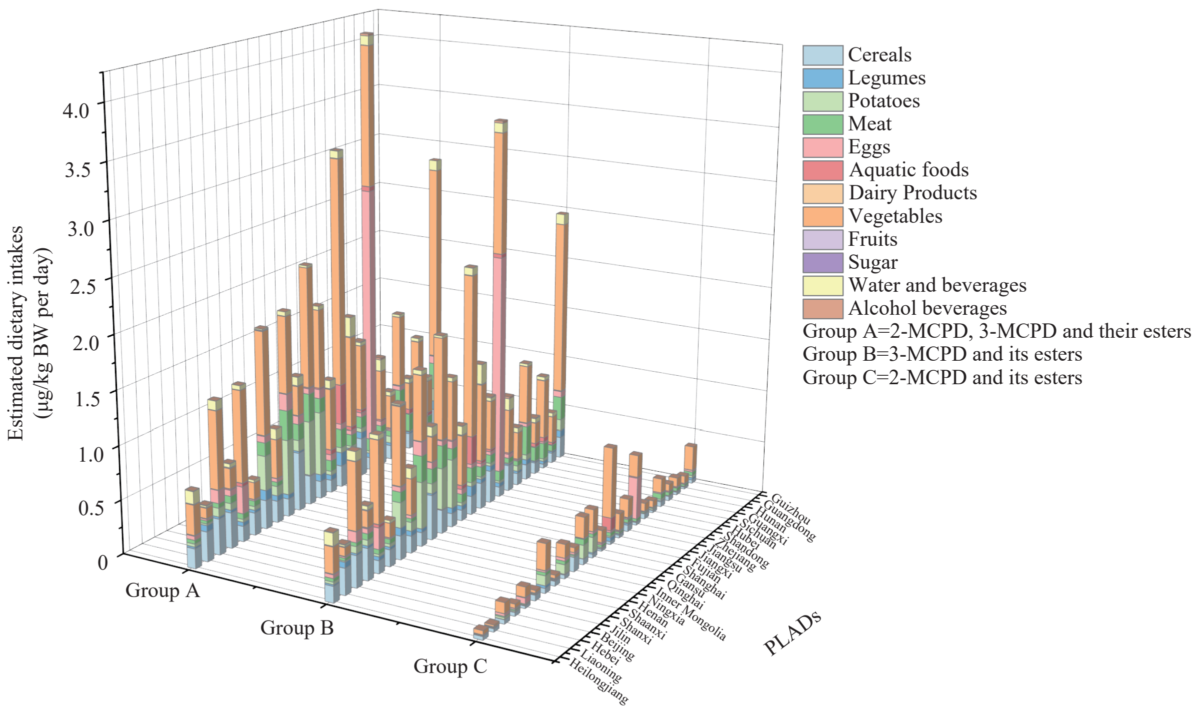

FIGURE 1. Estimated dietary intakes and contributions of various composite food categories of 3-MCPD, 2-MCPD esters, and 3-MCPD esters for adult males in 24 PLADs from the Sixth China TDS, 2016–2019.
Note: Group A=3-MCPD, 2-MCPD and their esters; Group B=3-MCPD and its esters; Group C=2-MCPD and its esters.
Abbreviation: PLADs=provincial-level administrative divisions; 3-MCPD=3-monochloropropane-1,2-diol; 2-MCPD=2-monochloropropane-1,3-diol; TDS=Total Diet Study.

GEs were detected in eggs, vegetables, meat, aquatic foods, and legumes, with DF values reaching 100%. Oil-based processed foods, including eggs and vegetables, are frequently prepared with edible oils and condiments at high temperatures. Previous research has identified high-temperature cooking as a critical factor in the formation of 3-MCPD esters and GEs, with a possible bidirectional transformation process occurring between these contaminants (*7*–*8*). Additionally, it has been noted that in environments containing oils, water, and sodium chloride, 3-MCPD esters can form under relatively low temperatures, facilitated by lipases (*9*).

Variations in dietary and cooking practices, as well as differences in consumption patterns, significantly influenced exposure levels to chloropropanols and their corresponding esters across the 24 PLADs studied. The majority of PLADs showed similar dietary contributions, with vegetables identified as the predominant source of chloropropanol and esters exposure. Cereals, meat, and potatoes were also major contributors to the intake of chloropropanol esters and GEs in most PLADs.

3-MCPD and its esters were aggregated for health risk assessment due to the equivalent toxicity of chloropropanol esters and their free forms. Figure 1 illustrates the estimated dietary intake and its contributions. The average dietary intake of 3-MCPD and its esters across the 24 PLADs was 1.21 μg/kg BW per day, constituting 30.3% of the PMTDI. This suggests that exposure to 3-MCPD and its esters is generally below the HBGV for most residents in China. Nonetheless, significant intake levels were noted in Zhejiang (3.58 μg/kg BW per day), Guizhou (2.46 μg/kg BW per day), and Fujian (2.34 μg/kg BW per day) Provinces, surpassing 55% of PMTDI. Additionally, a conservative health risk assessment calculated estimated intakes of 2-MCPD, 3-MCPD, and their esters, assuming similar toxicity. The mean dietary intake across the 24 PLADs was 1.48 μg/kg BW per day. Zhejiang Province exhibited the most considerable intake at 4.24 μg/kg BW per day, equating to 105.9% of PMTDI. Intakes in Fujian (3.24 μg/kg BW per day), Guizhou (2.80 μg/kg BW per day), and Qinghai (2.28 μg/kg BW per day) provinces approached the HBGV, highlighting potential health risks in these areas. The assessment of GEs utilized the MOE approach. The average MOE value was 12,963, falling below the EFSA's threshold. Only five out of the 24 PLADs had MOE values above 25,000, indicating minimal health concerns in these areas. However, significant health risks from GEs' consumption were identified in Shaanxi Province with an MOE value of 5,002, followed by Zhejiang at 7,044 and Gansu at 8,263.

This study has several limitations. Prior research raised concerns regarding infants and children's exposure to high concentrations of 3-MCPD and its esters, particularly from special diets like infant formula and infants' snacks. However, these foods were not involved in the present study. Additionally, in the present study, the dietary intakes were only estimated for adult males. Further studies on dietary exposure in susceptible populations like children and older populations are needed.

In conclusion, this study indicated that the health risks associated with dietary exposure to chloropropanols and their esters are low in China. However, GEs pose a potential health concern for many residents. Continuous monitoring of dietary exposure to both chloropropanols and their fatty acid esters, as well as GEs, is necessary, with a specific focus on regions where residents are exposed to high levels of these contaminants.

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SUPPLEMENTARY MATERIAL

SUPPLEMENTARY TABLE S1. Estimated dietary intakes (μg/kg BW per day) of 3-MCPD, 2-MCPD esters, 3-MCPD esters, and GEs in 24 PLADs from the Sixth China TDS, 2016–2019.

PLADs	3-MCPD	2-MCPD esters	3-MCPD esters	GEs
Heilongjiang	0.070	0.076	0.559	0.555
Liaoning	0.046	0.056	0.415	0.261
Hebei	0.208	0.184	1.017	1.171
Beijing	0.134	0.101	0.551	0.320
Jilin	0.264	0.184	0.996	0.723
Shanxi	0.066	0.087	0.364	0.274
Shaanxi	0.139	0.445	1.283	2.039
Henan	0.187	0.095	0.603	0.850
Ningxia	0.109	0.312	1.517	1.050
Inner Mongolia	0.052	0.217	1.010	0.611
Qinghai	0.085	0.435	1.761	0.807
Gansu	0.085	0.444	1.328	1.234
Shanghai	0.086	0.187	0.822	0.892
Fujian	0.069	0.898	2.272	0.951
Jiangxi	0.154	0.220	1.238	0.878
Jiangsu	0.084	0.301	0.946	0.746
Zhejiang	0.063	0.659	3.513	1.448
Shandong	0.165	0.136	0.763	0.945
Hubei	0.064	0.109	0.506	0.294
Sichuan	0.253	0.258	0.902	0.637
Guangxi	0.058	0.156	0.505	0.412
Hunan	0.282	0.156	0.644	0.437
Guangdong	0.079	0.123	0.429	0.357
Guizhou	0.640	0.343	1.820	0.993

Abbreviation: 3-MCPD=3-monochloropropane-1,2-diol; 2-MCPD=2-monochloropropane-1,3-diol; PLAD=provincial-level administrative division; GEs=glycidyl fatty acid esters; TDS=Total Diet Study.

SUPPLEMENTARY TABLE S2. Estimated dietary intakes (μg/kg BW per day) of 3-MCPD, 2-MCPD esters, 3-MCPD esters, and GEs by different composite food categories from the Sixth China TDS, 2016–2019.

Food categories	3-MCPD	2-MCPD esters	3-MCPD esters	GEs
Cereals	0.567	0.986	3.894	1.777
Legumes	0.095	0.204	0.793	0.764
Potatoes	0.174	0.578	2.109	1.440
Meat	0.134	0.493	2.408	2.249
Eggs	0.045	0.654	3.113	1.143
Aquatic foods	0.022	0.210	0.583	0.435
Diary products	0	0	0.029	0.034
Vegetables	2.391	3.055	11.201	9.715
Fruits	0	0	0.085	0
Sugar	0	0.002	0.012	0.007
Water and beverages	0	0	1.450	1.266
Alcohol beverages	0.014	0	0.086	0.053

Abbreviation: 3-MCPD=3-monochloropropane-1,2-diol; 2-MCPD=2-monochloropropane-1,3-diol; PLAD=provincial-level administrative division; GEs=glycidyl fatty acid esters; TDS=Total Diet Study.