Evaluation of Polychlorinated biphenyls (PCBs) in Iranian dairy products (yogurt, doogh and kashk) by modified QuEChERS extraction and GC- QqQ-MS/MS method: a health risk assessment study

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Abstract

The levels of 6 NDL-PCBs (non-dioxin-like-polychlorinated biphenyls) of were measured in some of Iranian dairy products (yogurt, doogh and kashk). A total of 120 samples were evaluated by modified QuEChERS extraction and gas chromatography-triple-quadrupole mass spectrometry (GC-QqQ-MS/MS) method, also RSD and recovery were determined, 6.33–8.86 and 97.45–102.63 %, respectively. The outcomes of our research exhibited the average levels of 6-NDL-PCBs in all samples were 15.17 ± 3.44 ng/g fat that were lower than the standard level established by EU (40 ng/g fat). Also, results showed kashk samples had maximum mean level of 6-NDL-PCBs (18.66 ± 2.42 ng/g fat) and doogh samples had minimum mean level of 6-NDL-PCBs (12.21 ± 2.22 ng/g fat). The mean level of 6-NDL-PCBs in yogurt samples was 14.65 ± 2.02 ng/g fat. The heat map results depicted the correlation between spectral indicators 6-NDL-PCBs in different dairy products. A risks assessment based on the Monte Carlo method was done by calculating the Estimated Daily Intake (EDI) and Incremental Life Cancer Risk (ILCR) by the technique of Monte Carlo. The EDI values of 6 NDL-PCBs based on the 95 percentile in yogurt, doogh and kashk were 14.3, 1.49 and 0.5 ng/kg.day, respectively. According to the calculated 95 percent ILCR, dietary exposure to 6 NDL-PCBs does not pose a risk to Iranian consumer health.

1. Introduction

People are always exposed to different types of anthropogenic substances. Some chemicals are rapidly eliminated in the human body, while others are stored and gradually metabolized. PCBs are one of the substances that are stored in the body for a long time (Ahmadkhaniha et al. 2017, Ahmadloo et al. 2019, Yaminifar et al. 2021). PCBs are produced by chlorinating aromatics (12-68%), and some are commercially known as Aroclor, Phenoclor and Clophen. There are 209 PCBs, among which 12 are dioxin-like PCBs (dl-PCBs) (PCB-189, -169, -167, -157, -156, -126, -123, -118, -114, -105, -81 and PCB-77). Six PCBs (PCB -180, -153, -138, -101, -52 and PCB-28) have been selected as indicator PCBs (in- PCBs) for residue monitoring in the environment and in foods (Adekunte et al., Amiridou & Voutsas 2011, Bordajandi et al. 2004, Costabeber et al. 2018).

PCB exposure has been related to immunological and neurobehavioral abnormalities in children, as well as diabetes and cancers. The IARC (International Agency for Research on Cancer) and The WHO (World Health Organization's) has classified DDT, HCB and HCH as group 2B, possible carcinogenic substances for humans and PCBs as 2A, probable carcinogenic substances (Ahmadkhaniha et al. 2017, Ahmadloo et al. 2019, Đedićbegović et al. 2019).

The route sources of exposure to dioxins and PCBs are the skin, inhalation of air, drinking water and food in humans. Among these, diet is one of the most important sources of routes to PCBs (Ahmadkhaniha et al. 2017, Cheney et al. 2019, Costabeber et al. 2018, Elangovan et al. 2019).

Milk and dairy products (yogurt, butter, cheese, cream, buttermilk and kashk) are the main sources of human exposure to PCBs due to their regular use in every meal. PCBs enter the body of milk-producing livestock mainly through the consumption of contaminated water and forage (Özdemir et al. 2019, Roszko et al. 2014, Saktrakulkla et al. 2020, Schechter et al. 2010).

Yogurt is a well-known product obtained from the fermentation of milk. Two products made directly from yogurt include doogh and kashk (Kiani et al. 2018, Shiroodi et al. 2012).

Doogh is a traditional dairy-based beverage made from a combination of yogurt set or stirred, water and salt. Despite the fact that doogh (yogurt-based drink) is widely drunk around the world, particularly in Asia, there are clear distinctions between it and comparable products used in Europe owing to the variation in viscosity and the presence of salt (Kiani et al. 2018, Kiani et al. 2019, Kouhpayeh et al. 2017).

Humans have known for thousands of years that drying causes food to be stored for longer. For example, the main purpose of preparing yogurt in powder form (kashk) is easy and stable maintenance of the product. kashk is a concentrated boiled doogh or yogurt that contains a salt additive that comes in flat or round rolls and then dries in the presence of air (Iranmanesh et al. 2018, Shiroodi et al. 2012).

Today, many techniques are applied to detect PCBs in food products, such as GC with an electron capture detector (ECD), GC-MS, GC-QqQ-MS/MS and GC coupled with high-resolution mass spectrometry (GC-HRMS). Among them, GC-QqQ-MS/MS has high sensitivity, high accuracy and has many applications in this field (Reddy et al. 2019, Yaminifar et al. 2021).

For evaluation of PCBs and other contaminants in food products, a method was introduced in 2003 that was quick, easy, cheap, effective, rugged, and safe (QuEChERS) QuEChERS technique is used to extract analytes from food matrix due to its fast, cheap, simple, etc (Özdemir et al. 2019, Rutkowska et al. 2018).

In Iran, contamination of farms and pastures with petroleum and chemical compounds in various ways is one of the most important causes of PCB contamination of dairy products. Considering the lack of a comprehensive study on the evaluation of PCB concentrations in dairy products such as yogurt, kashk, and doogh (in Iran and around the world), as well as the relatively high consumption of these products in the basket of Iranian, determining the level of 6 NDL-PCBs in these samples is critical. The aim of current research to evaluate the health risk and measure the concentration of 6 NDL-PCBs by using modified QuEChERS (quick, easy, cheap, effective, rugged, and safe) extraction and by GC-QqQ-MS/MS technique in kinds of dairy products (yogurt, doogh and kashk) and estimated the possible health risk posed by dairy products ingestion.

2. Materials And Methods

2.1. Sample collection

A total number of 40 samples of yogurt, 40 samples of doogh and 40 samples of kashk were analyzed. These samples have been obtained from the market of Tehran, Iran.

2.2. Chemicals and reagents

The PCBs analytical standards with a purity degree more than 99% (PCB 180, 2,2',3,4,4',5,5'-heptachlorobiphenyl; PCB 138, 2,2',3,4,4',5'-hexachlorobiphenyl; PCB 153, 2,2',4,4',5,5'-hexachlorobiphenyl; PCB 101, 2,2',4,5,5'-Pentachlorobiphenyl; PCB 52, 2,2',5,5'-tetrachlorobiphenyl and PCB 28, 2,4,4'-trichlorobiphenyl) were obtained from *Sigma-Aldrich* (USA). Methylbenzene, acetonitrile, methyl alcohol, MgSO₄, toluene, primary secondary amine (PSA) and NaCl were obtained from Merck Co. (Germany).

2.3. Preparation of standard solution

Thirty two microliters of the solution of original standard (10 ng/μL of 6 PCBs with EC Number of 208-759-1) to prepare the standard stock solution was transferred with a micropipette to laboratory dishes and reaches to 10 mL volume with toluene (Yaminifar et al. 2021).

2.4. Preparation of sample

The yogurt, doogh and kashk samples preparation were performed by using a QuEChERS modified method. First, 5 g of samples was homogenized and poured into a 50 mL tube (glassy). Afterward, acetonitrile (20 mL) and 10 μL of internal standard (PCB29 with a concentration of 10 ng/mL) were added and mixed with vortex. Afterward 6 mg of MgSO₄ and NaCl (2:1) were added to tube (glassy) and shaken by vortex (vigorously). The solution (for ten minutes) was centrifuged at 5000 rpm. Then, the above solution (10 mL) was poured into a 15 mL vial (glassy). Next, the solution was placed (for fifteen minutes) in a freezer at -20°C. Then, 400 mg primary secondary amine (PSA), 40 mg C18 and 1mL toluene were added to vial (glassy). Afterward, poured into a glass tube and shaken for 30 seconds with a vortex and standing for 5 minutes. Finally, one microliter was injected to GC-MS/MS (Xizhi Wang 2016).

2.5. Analytical conditions and instrumentals

The 6 NDL-PCB congeners were evaluated by GC-MS/MS device (Shimadzu GCMS-TQ8040). For separation of 6 NDL-PCBs the column Rxi-5 MS, 30 meters × 0.25 millimeters × 0.25 micrometers was applied. The column oven temp was 50 °C (1 min)-25 °C per minutes-125 °C-10 °C per minutes-300 °C (3.5 min). The Splitless was mode of injection and temperature of injection was 250 °C. The argon was gas of CID and the mode of flow control was linear velocity (47.2 cm/sec). The voltage of detector was tuning result +0.6kv. The temperature of ion source and interface were 200 °C and 250 °C, respectively (Xizhi Wang 2016).

2.6. Quantification method

The quantification of method (precision, recovery, accuracy, linearity, LOQ, LOD and analysis by the GC-MS-MS) were performed according to our previous study (Yaminifar et al.).

2.7. Assessment of human health risk

The present study examined the daily intake and carcinogenic risks owing to the Iranian dairy products consumption (yogurt, doogh and kashk) contaminated with PCB. The model for computing risk was performed according to the previous report (Shariatifar et al. 2021, Yaminifar et al. 2021). Briefly, the average daily intake is used to measure the oral exposure of harmful materials and assessed by the following equation (Kiani et al. 2021a, Kiani et al. 2021b) :

$$EDI = \frac{C \times ED \times EF \times IR}{BW \times AT}$$

In this equation, estimated daily intake (EDI) is based on the ng/kg.day (Eghbaljoo-Gharehgheshlaghi et al. 2020), C is the PCB concentration based on ng/g fat, the definition and description of the above variables are shown in Table 3. To evaluate the cancer risk of exposure of PCB compounds, the incremental lifetime carcinogenic risk (ILCR) model was obtained by the following equation (Kiani et al. 2021a).

$$ILCR = EDI \times SF \text{ Equation (2)}$$

By the guidance of US EPA, where SF is equal to 2 mg/Kg b.w. per day for PCBs was referenced (Falandysz et al. 1999). The definition and description of variables are shown in Table 3.

2.8. Statistical analysis

By using SPSS (ver. 25), a practical and easy statistical analysis was utilized for the values of standard deviation (SD), mean, maximum and minimum. The test of Kolmogorov Smirnov was used to evaluate normal distribution of continuous variables. ANOVA, independent t test, Mann Whitney and Kruskal-Wallis were utilized to evaluate differences between groups. The P-value less than 0.05 was selected as the significant difference for all tests. A data visualization procedure was conducted to explain the correlation among the variables and highlight dairy products' contamination. (Arabameri et al. 2019, Moradi et al. 2021). The Heat map was performed in evaluating the relationships contamination among samples (yogurt, doogh and kashk) online at the site of <https://biit.cs.ut.ee/clustvis/>.

3. Results And Discussion

3.1. Analytical method evaluation performance

The analytical characteristics of the applied technique for analysis of PCB compounds displayed in Table 2. The results displayed the LOQs and LODs for the PCB analytes varied 0.180-0.360 and 0.06-0.12 ng/g fat, respectively. Also, the percent of RSD and recovery of the 6 NDL-PCBs analyte was determined at a range of 6.33 – 8.86 and 97.45–102.63%, respectively.

3.2. Evaluation of PCBs in dairy product samples

Table 3 are showed statistical analysis of our results, which displays mean, max, and min of each PCB analytes in yogurt, doogh and kashk samples. The outcomes of our research exhibited the average levels of Σ 6-NDL-PCBs in all samples were 15.17 ± 3.44 ng/g fat that were lower than the standard levels established by EU (40 ng/g fat). The maximum mean level was PCB180 (9.98 ± 2.04 ng/g fat) and minimum mean level of PCBs in samples was PCB28 (0.09 ± 0.06 ng/g fat).

It is noteworthy that so far no studies have been done on the amount of these contaminants (PCBs) in doogh and kashk, only a few studies have been done on yogurt and other dairy products, which are mentioned below:

Son *et al.* evaluated PCB levels in milk, ice cream, yogurt, cheese and butter and reported the mean levels of Σ 6-NDL-PCBs was 0.09, 0.189, 0.133, 0.161 and 0.449 ng/g fat, respectively that were less than present outcomes (Son et al. 2012). Schechter *et al.* evaluated PCBs in samples of frozen yogurt, cheese and cream cheese, whole milk, butter and ice cream and reported the mean levels of Σ 6-NDL-PCBs was non-detected (ND) in all samples which were lower than present results (Schechter et al. 2010). Witczak A *et al.* assessed PCB levels in milk and yoghurt samples in Poland and exposed the mean level of the Σ Indicator-PCBs was 1.858 and 1.754 ng/g fat, respectively that were less than present study (Witczak & Mituniewicz-Malek 2019). Yaminifar *et al.* measured PCB levels in butter samples in Iran and showed the mean levels of Σ NDL-PCBs was 21.701 ± 9.02 ng/g fat, which was upper than this study (Yaminifar et al. 2021). Uçar *et al.* assessed PCB levels in samples of butter and reported the average of Σ 6 NDL-PCBs was between 0.20–3.04 ng/g fat that was less than the outcomes of this research (Uçar et al. 2011). Cimenci *et al.* evaluated PCB levels in samples of butter and milk and reported the median level of Σ 6 NDL-PCBs was 4.72 ng/g fat for both of them which were less than present outcomes (Cimenci et al. 2013). Santos J. *et al.* assessed PCB concentrations in samples of industrialized and homemade cheese in Brazil and reported the mean level of the Σ Indicator-PCBs was 33.32 ± 25.40 ng/g fat and 26.58 ± 9.91 ng/g fat, respectively that was upper than present outcomes (Santos et al. 2006). Pérez *et al.* evaluated PCB compounds in samples of milk in Mexico and reported the mean level of the Σ Indicator-PCBs was 9.6 ng/g fat that was less than present outcomes (Pérez et al. 2012). Atmaca E evaluated levels of PCBs in samples of milk in Turkey and reported the mean levels of Σ 6-NDL-PCBs was 127.27 ng/g fat which was higher than present research (Atmaca 2019). Miclean M *et al.* assessed PCB levels in samples of milk in Romania and reported the mean level of the Σ Indicator-PCBs was 9.12 ng/g fat, which was less than present research (Miclean et al. 2018). Rusin *et al.* evaluated PCB levels in samples of milk and reported the mean level of the Σ 6 NDL-PCBs was 1.25 ng/g fat that was less than the outcomes of this research (Rusin et al. 2019).

In comparison to other researchers, the outcomes of PCBs contaminate in this research revealed the environmental contaminant (water, soil and air) with pesticides, products of petroleum, contaminants from diesel trucks and paints may cause pollution of livestock feed and agricultural products like mentioned dairy products (yogurt, doogh and kashk). Additionally, the close proximity of farms of animal to the oil refineries, roads and industries may reason in livestock pollution, followed by livestock products like these dairy products. Generally, these compound levels (6 NDL-PCBs) in the samples of yogurt, doogh and kashk in Tehran city that was less than the standard levels established by EU.

3.3. Evaluation of PCBs in kinds of dairy products samples (yogurt, doogh and kashk)

The outcomes exhibited in the Table 4 showed the level of 6 NDL-PCBs in kinds of dairy product samples. Our outcomes showed that kashk samples had maximum mean level of 6-NDL-PCBs (18.66 ± 2.42 ng/g fat) and doogh samples had minimum mean level of 6-NDL-PCBs (12.21 ± 2.22 ng/g fat). The mean level of 6-NDL-PCBs in yogurt samples was 14.65 ± 2.02 ng/g fat. So, in all samples level of 6-NDL-PCBs were lower the EU standard level (40 ng/g fat). Since doogh is obtained by diluting yogurt and kashk from concentrating yogurt, the reason for the lower results of doogh and the higher results of kashk can probably be explained. Therefore, it can be stated that with the concentration of dairy products, the amount of PCBs compound should probably increase as well, although the amount of this increase will not be dangerous for the consumer because it is less than the existing standards. Son *et al.*, Schechter *et al.* and Witczak A *et al.* evaluated PCB concentrations in yogurt samples and reported the mean level of Σ 6-NDL-PCBs were 0.133, ND and 1.754 ng/g fat, respectively that were less than this research (Schechter et al. 2010, Son et al. 2012, Witczak & Mituniewicz-Malek 2019).

3.4. Evaluation of PCBs in different brands

The outcomes revealed that in Table 5 showed, which the level of 6 NDL-PCBs in different brands of dairy product samples. The results showed brand A had the maximum mean level of 6 NDL-PCBs (18.23 ± 3.32 ng/g fat) and brand E had the minimum mean level of 6 NDL-PCBs (12.93 ± 2.78 ng/g fat). The reason for the higher level of PCBs in a brand E can be the use of more polluted livestock fodder, the supply of milk from contaminated environments, the proximity of the factory to urban and industrial centers, the proximity of livestock to contaminated environments and the use of contaminated containers and equipment.

3.5. Human health risk assessment

The results presented in the table 6 show the daily intake of 6 NDL-PCBs in dairy product samples. The yogurt had the maximum mean daily intake of 6 NDL-PCBs (1.43 ng/kg day) and Kashk had the minimum mean daily intake of 6 NDL-PCBs (5.09×10^{-1} ng/kg day). The reason for the higher consumption of yogurt in Tehran (Iran) was associated with an increased risk of NDL-PCBs daily intake. The rank order of 6 NDL-PCBs EDI value based on percentile 95% in yogurt was PCB 180 (2.99×10^{-5}) > PCB 153 (1.35×10^{-5}) > PCB 138 (1.59×10^{-6}) > PCB 52 (4.42×10^{-7}) > PCB 28 (2.82×10^{-7}) > PCB 101 (2.79×10^{-7}); in Doogh was PCB 180 (2.54×10^{-6}) > PCB 153 (1.08×10^{-6}) > PCB 138 (1.28×10^{-7}) > PCB 52 (3.68×10^{-8}) > PCB 101 (2.43×10^{-8}) > PCB 28 (2.34×10^{-8}); in Kashk was PCB 180 (1.11×10^{-6}) > PCB 153 (4.80×10^{-7}) > PCB 138 (5.25×10^{-8}) > PCB 52 (1.51×10^{-8}) > PCB 28 (1.10×10^{-8}) > PCB 101 (1.10×10^{-8}).

The average dietary exposure to NDL-PCBs was far below the WHO's tolerable daily intake (10 ng/kg BW/day) for the general population (Dinc et al. 2019). The EDI distribution among PCBs congeners with the most and least contribution is shown in Fig. 1. In all samples, PCB180 became the most important congener.

Previous studies assessed 6 NDL-PCBs levels in Cow milk from Silesia Province, Poland and exposed the mean level of the 6 NDL-PCBs was 2.1 ng/ kg day (Rusin et al. 2019). In China, Kang *et al.* noted that dietary exposure to PCBs in food was 26.47 ng/kg day than our investigation (Kang et al. 2020). Also, Chung *et al.* reported in Hong Kong the less and higher bound on the intake of PCBs was 0.68 and 1.38 ng/kg day (Chung et al., 2018). The people studied in

Poland were moreover more exposed to NDL-PCB compounds than in the current research. These variations are mostly due to different levels of environmental pollution with persistent organic pollutants and different sources of these compounds' emissions. Other key diet components were not included in the estimates since they were based only on the use of dairy products. As a result, the total health risk from dietary exposure to a complete diet is likely to be upper.

The results presented in the Fig. 2 show the amount of ILCR in different dairy product samples. The ILCR values from the Monte Carlo simulation showed yogurt samples had maximum mean level of ILCR ($4.63\text{E-}5$) and doogh samples had minimum mean level of ILCR ($1.63\text{E-}6$) that exhibited there potency be a low risk of oral cancer for people in Iran.

The cancer risk of PCBs for target population was much smaller than the unacceptable risk (10^{-4}). The oral cancer risk of 6 NDL-PCBs was lower than the unacceptable limit (10^{-4}) for people in Iran. Rusin *et al.* measured total of 18 PCBs (that consist of 6 NDL-PCBs) in popular foods of animal origin that the mean cancer risk resulting from eggs, chicken meat and farm-fresh cow milk intake 6.9×10^{-3} , 3.4×10^{-4} and 2.8×10^{-4} , respectively that was upper than this research (Rusin et al. 2019).

3.4. Analysis based on heat map results

The heat map provides a profile overview of the largest and smallest data in the matrix by clustering similar parameters. The dairy product contamination to PCB congeners was visually stated as a heat map for each sample. The patterns of heat map were markedly various depending on the PCB congener. The first cluster includes PCB 138 and PCB 153, Second cluster contains two sub-groups. The cluster dendrogram is shown in Fig. 3. As the Euclidean space reductions, the samples showed a higher correlation. Hence, PCB 180, PCB 131, and PCB 52 had a high correlation among different samples (yogurt, doogh, and kashk).

4. Conclusion

Conclusively, this study was the first to compare 6 NDL-PCBs residues in kinds of dairy products (yogurt, doogh and kashk) samples of Tehran. The samples were analyzed using modified QuEChERS and by GC-QqQ-MS/MS method which had a very good performance in this regard with recovery more than 97.45%. Our study showed PCB contaminant levels were higher in kashk samples and lower in doogh samples (kashk>yogurt>doogh). The 6 NDL-PCB levels in all samples was less than the EU standard level. The dietary exposure to NDL-PCBs detected in dairy products was much lowers the recommended TDI (10 ng/kg BW/day). The Monte Carlo simulation output exhibited the index of ILCR owing to ingestion of 6-NDL-PCBs lower than the safe level ($\text{ILCR} > 1\text{E-}4$). It is suggested that more control and monitoring be done on dairy products due to high consumption and high sensitivity of these products and other similar studies should be done in other dairy products.

Declarations

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Ethical Approval: "This study does not involve any human or animal testing" or "This study was approved by the Fasa University of Medical Sciences and Health Services

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Consent to publish; All authors agree to publish.

Data availability: The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.'

Author's contributions: **Nabi Shariatifar:** Conceptualization, Supervision, Design of study, Writing- Reviewing and Editing. **Ali Ghanbariasad:** Design of study, Writing- Reviewing and Editing. **Mojtaba Moazzen:** Data curation, Writing- Reviewing and Editing. **Majd Arabameri:** Visualization, Investigation, Software, Methodology. Software, Validation, **Amin Kiani:** Methodology. Software, Validation, Maryam Moazzen: Data curation, Writing- Original draft preparation, **Fahimeh Tooryan:** Design of study, Writing- Reviewing and Editing. **Saeed Shahsavari:** Software, Methodology

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Tables

Table 1
Parameters applied in the present study for health exposure assessment in dairy products

exposure parameters	unit	Reference
SF carcinogenic slope factor of oral intake (2)	(mg (kg d ⁻¹)) ⁻¹	(Kang et al. 2020)
C concentrations of PCBs	µg/Kg	–
EDI estimated daily intake	mgkg ⁻¹	(Karimi et al. 2021)
EF _i exposure frequency	days per year	(Seilani et al. 2021)
IR Average daily intake	Kg/day	(Karami et al. 2021)
ED exposure duration	days	(Roudbari et al. 2021)
AT average time	days	(Cheney et al. 2019)
BW body weight (for children and adults is between 15 and 70)	kg	(Shariatifar et al. 2020)

Table 2
The linear range of concentration, LOQ, LOD, recovery, RSD, inter-day and intra-day reproducibility of validation method.

Compound	Linear range of concentration (ng/mL)	LOD (ng/g)	LOQ (ng/g)	RSD%	Recovery%	Intra-day	Inter-day
PCB 28	0.10 - 40	0.080	0.250	6.33	100.21	7.55	10.58
PCB 52	0.10 - 40	0.080	0.250	8.86	102.63	10.34	14.92
PCB 101	0.10 - 40	0.120	0.360	7.54	98.49	11.44	13.81
PCB 138	0.10 - 40	0.060	0.180	7.49	97.45	9.58	14.98
PCB 153	0.10 - 40	0.100	0.310	8.55	101.38	10.81	15.22
PCB 180	0.10 - 40	0.080	0.250	8.29	98.97	11.83	15.94

Table 3
Statistical analysis of PCBs in dairy product samples (ng/g fat)

	Minimum	Maximum	Mean	Std. Deviation (SD)
PCB 28	0.04	0.26	0.09	0.06
PCB 52	0.04	0.9	0.19	0.21
PCB 101	0.06	0.18	0.1	0.05
PCB 138	0.24	0.76	0.48	0.15
PCB 153	2.65	6.75	4.33	1.23
PCB 180	6.28	13.42	9.98	2.04
Total	9.62	21.71	15.17	3.44

Table 4
Statistical analysis of PCBs in kinds of dairy products (ng/g fat)

Type	Yogurt		Doogh				Kashk						
	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	P value
PCB 28	0.04	0.15	0.09	0.05	0.04	0.11	0.06	0.03	0.04	0.26	0.13	0.08	0.82
PCB 52	0.04	0.24	0.14	0.07	0.04	0.9	0.25	0.37	0.09	0.34	0.17	0.1	1
PCB 101	0.06	0.13	0.09	0.04	0.06	0.14	0.08	0.04	0.06	0.18	0.12	0.06	0.33
PCB 138	0.41	0.61	0.5	0.08	0.24	0.45	0.34	0.09	0.41	0.76	0.61	0.14	0.33
PCB 153	3.24	5.88	4.26	0.99	2.65	4.07	3.33	0.62	4.21	6.75	5.41	1.09	0.33
PCB 180	8.64	10.88	9.58	0.93	6.28	9.74	8.14	1.36	10.82	13.42	12.21	1.1	0.08
Total	12.59	17.89	14.65	2.02	9.62	15.09	12.21	2.22	15.87	21.71	18.66	2.42	0.08

Table 5
Statistical analysis of PCBs in different brands of dairy products (ng/g fat)

brand	A			B			C			D			E	
	Min	Max	Mean±SD	Min	Max	Mean±SD	Min	Max	Mean±SD	Min	Max	Mean±SD	Min	Max
PCB 28	0.11	0.26	0.17±0.08	0.04	0.04	0.04±0.00	0.04	0.09	0.07±0.03	0.09	0.12	0.11±0.02	0.04	0.15
PCB 52	0.24	0.9	0.49±0.36	0.12	0.17	0.15±0.03	0.04	0.09	0.06±0.03	0.13	0.16	0.14±0.02	0.04	0.11
PCB 101	0.13	0.18	0.15±0.03	0.06	0.14	0.11±0.04	0.06	0.06	0.06±0.00	0.06	0.06	0.06±0.00	0.06	0.17
PCB 138	0.45	0.76	0.61±0.16	0.34	0.64	0.49±0.15	0.41	0.7	0.55±0.15	0.27	0.52	0.42±0.13	0.24	0.41
PCB 153	3.75	6.75	5.46±1.54	3.44	5.66	4.48±1.12	4.05	6.06	4.73±1.15	2.76	4.39	3.64±0.82	2.65	4.21
PCB 180	9.74	13.42	11.35±1.88	8.83	12.51	10.36±1.92	8.54	12.97	10.05±2.53	6.28	11.35	9.18±2.61	7.31	10.82
Total	15.09	21.71	18.23±3.32	12.83	19.16	15.63±3.23	13.16	19.97	15.52±3.86	9.62	16.58	13.55±3.56	10.34	15.87

Table 6. Simulation results for EDI of NDL-PCBs detected in dairy products (yogurt, doogh and kashk).

	Percentiles	PCB 28	PCB 52	PCB 101	PCB 138	PCB 153	PCB 180	Total NDL-PCB
Yogurt	5%	5.96E-2	9.15E-2	6.01E-2	3.30E-1	2.78E+0	6.18E+0	9.72E+0
	50%	8.91E-2	1.37E-1	8.74E-2	4.95E-1	4.16E+0	9.26E+0	1.43E+1
	75%	1.06E-1	1.62E-1	1.03E-1	5.79E-1	4.87E+0	1.09E+1	1.68E+1
	95%	1.32E-1	2.09E-1	1.27E-1	7.28E-1	6.19E+0	1.45E+1	2.12E+1
Doogh	5%	3.32E-3	1.38E-2	4.31E-3	1.88E-2	1.78E-1	4.43E-1	6.54E-1
	50%	4.89E-3	2.06E-2	6.42E-3	2.76E-2	2.68E-1	6.68E-1	1.01E+0
	75%	5.79E-3	2.40E-2	7.63E-3	3.32E-2	3.17E-1	7.79E-1	1.19E+0
	95%	7.40E-3	3.08E-2	9.57E-3	4.11E-2	4.05E-1	9.65E-1	1.49E+0
Kashk	5%	2.36E-3	3.00E-3	2.16E-3	1.11E-2	9.60E-2	2.21E-1	3.40E-1
	50%	3.52E-3	4.54E-3	3.25E-3	1.70E-2	1.47E-1	3.34E-1	5.09E-1
	75%	4.19E-3	5.35E-3	3.85E-3	1.99E-2	1.72E-1	3.94E-1	6.05E-1
	95%	5.33E-3	6.88E-3	4.83E-3	2.57E-2	2.20E-1	5.02E-1	7.66E-1

Figures

Figure 1

Contribution to overall EDI and ILCR in dairy products (yogurt, doogh and kashk).

Figure 2

Simulation results for ILCR of NDLCBs detected in dairy products (yogurt, doogh and kashk).

Figure 3

Heat map of 6NDL-PCBs in dairy products (yogurt, doogh and kashk).