Formation of polychlorinated naphthalenes during the heating of cooking oil in the presence of high amounts of sucralose

Shujun Dong, Guorui Liu, Bing Zhang, Lirong Gao, Minghui Zheng*

State Key Laboratory of Environmental Chemistry and Ecotoxicology, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 100085, China

ARTICLE INFO

Article history:

Received 4 May 2012

Received in revised form

1 November 2012

Accepted 1 November 2012

Keywords:

Polychlorinated aromatic compounds

Vegetable oil

Sucralose

Oil fumes

ABSTRACT

Sucralose, an artificial sweetener, is being used in increasingly large amounts in foodstuffs and beverages worldwide. Information pertaining to its ability to participate in chlorination reactions during cooking and generate toxic compounds, however, is scarce. In this study, the formation and distribution of polychlorinated naphthalenes (PCNs), which are a group of highly toxic polychlorinated aromatic compounds, in oil heated in the presence of sucralose was investigated. The concentrations of the PCNs present in the cooking oils and oil fumes generated during the heating process were determined by isotope dilution according to a HRGC/HRMS method. The results suggested that the heating of cooking oil in the presence of sucralose promoted the formation of toxic PCNs. Although PCNs were detected in the oil fumes, no PCNs were found in the heated oils. The total concentrations of the PCNs found in peanut and olive oil fumes were 490 and 240 pg g⁻¹, respectively. The degree of chlorination for the PCNs was calculated to be 5.3 for both the peanut and olive oil fumes. To quantify the newly produced PCNs, sucralose used in the experiments were about 2 or 3 orders of magnitude higher than in reality. PCNs were not detected with real proportions under the current experimental conditions.

© 2012 Elsevier Ltd. All rights reserved.

1. Introduction

There have been growing concerns about polychlorinated naphthalenes (PCNs) because of their structural similarities to polychlorinated dibenzo-*p*-dioxins and dibenzofurans (PCDD/Fs) (Bidleman, Helm, Braune, & Gabrielsen, 2010; Domingo, 2004). The toxicity of PCNs is also similar to that of PCDD/Fs, and is measured using relative potency factors (RPFs) or toxic equivalency factors (TEFs) (Noma, Yamamoto, & Sakai, 2004; Puzyn, Falandysz, Jones, & Giesy, 2007). Some studies reported that, in samples from some locations, the proportion of PCNs was relatively high among dioxin-like compounds (Bidleman et al., 2010; Domingo, 2004). In Korea, PCNs in human serum samples accounted for 26.8% of the total toxic equivalents (TEQs) of PCDD/Fs, polychlorinated biphenyls (PCBs) and PCNs (Park, Kang, Baek, & Chang, 2010). PCNs have recently been proposed for listing under the Stockholm Convention (Stockholm Convention, 2012).

Human exposure to PCNs and related compounds occurs mainly through food intake (Domingo, 2004; Li, Wu, Zhang, & Zhao, 2007). Cooking is an important process in food preparation and could

affect the content of toxic compounds in foodstuffs. Recently, Domingo (2011) summarized published studies on the influence of cooking on the concentrations of toxic metals and organic contaminants in foodstuffs. Generally, cooking tended to reduce the concentrations of organic contaminants in food because fat is released during heating. Yet, cooking processes could promote the formation of polycyclic aromatic hydrocarbons (PAHs) (Domingo, 2011). Although the generation of PAHs in cooking processes has been intensively studied (Alomirah et al., 2011; Chen & Chen, 2001; Chiang, Wu, & Ko, 1999; Chiang et al., 1997; Farhadian, Jinap, Abas, & Sakar, 2010; Purcaro, Navas, Guardiola, Conte, & Moret, 2006), investigations on the release of polychlorinated aromatic compounds during cooking, such as PCNs, are scarce. PAHs are condensed aromatics which could be chlorinated in this process. Although it is possible for chlorinated anthracenes and other aromatics to be produced, PCNs were investigated in the current study because of their impact on human health and their simple condensed aromatic backbone, i.e. naphthalene.

PAHs can be formed through the grilling and smoking of food (Alomirah et al., 2011; Farhadian et al., 2010) or from heated cooking oils (Chen & Chen, 2001; Chiang et al., 1999, 1997; Purcaro et al., 2006). The formation of PCNs may take place through the chlorination of naphthalene or as a consequence of *de novo* synthesis from PAHs (Jansson, Fick, & Marklund, 2008; Weber et al.,

* Corresponding author. Tel./fax: +86 10 6284 9172.

E-mail address: zhengmh@rcees.ac.cn (M. Zheng).

2001). A variety of different types of chlorine-containing compounds can be found in foodstuffs, and in food additives and flavorings, that could participate in the formation of PCNs during cooking.

Sucralose (1,6-Dichloro-1,6-dideoxy- β -D-fructofuranosyl-4-chloro-4-deoxy- α -D-galactopyranoside) is an artificial sweetener and has been declared safe by public health authorities worldwide, including the Food and Drug Administration (FDA) (Grotz & Munro, 2009). Sucralose is being used in increasingly large amounts as a sugar substitute in a broad range of foods and beverages, including products baked at high temperatures. In a recent report, however, sucralose was found not to be stable under high temperatures. Using thermoanalytical techniques, Bannach, Almeida, Lacerda, Schnitzler, and Ionashiro (2009) found that the thermal decomposition of sucralose occurred at 119 °C with the liberation of constitutional water and hydrogen chloride. Rahn and Yaylayan (2010) also reported the thermal degradation of sucralose and found that it was able to chlorinate glycerol to generate toxic chloropropanols at 250 °C. Thus, it has been speculated that PCNs could be formed during cooking because of the generation of PAHs and the presence of chlorine-containing compounds in cooking processes, although the formation of PCNs during cooking has not yet been reported.

In the current study, a simulated cooking system was set up to confirm and investigate the formation and distribution of PCNs during cooking. The concentrations and distributions of dioxin-like PCBs (dl-PCBs) and PCDD/Fs formed together with PCNs were investigated to evaluate the relative importance of these polychlorinated aromatic compounds.

2. Material and methods

2.1. Materials

Hexane, dichloromethane and acetone were purchased in pesticide grade from J. T. Baker (Phillipsburg, NJ, USA). Sucralose (purity >98%, HPLC grade) was purchased from Sigma–Aldrich, Inc. (St. Louis, MO, USA). Sodium chloride (purity >99.8%, GR grade) was purchased from Sinapharm Chemical Reagent Co., Ltd (Shanghai, China). ^{13}C -labeled standards of the PCNs were purchased from Cambridge Isotope Laboratories, Inc. (Andover, MA, USA) and ^{13}C -labeled standards of PCDD/Fs and PCBs were purchased from the Wellington Laboratories Inc. (Guelph, ON, Canada). Peanut oil and extra virgin olive oil were purchased from a supermarket in Beijing, China.

2.2. Cooking process and sampling

A schematic representation of the stainless steel system used in the current study has been provided elsewhere by Dong, Wu, Liu, Zhang, and Zheng (2011). In each experiment, 50 g of cooking oil (peanut oil or olive oil) and 5 g of sucralose or sodium chloride were poured into a stainless steel bowl. Sucralose is hydrophilic and consequently insoluble in the oil. Thus, the raw materials were mixed carefully with a glass rod to make the sucralose suspension in the oil as homogeneous as possible. The mixtures were heated on an electric stove for 15 min, reaching a temperature of 200 ± 5 °C or 245 ± 5 °C. The temperatures of the mixtures and the oil fumes generated during the heating process were recorded using a thermo sensor. An air pump, with an air flow rate of $1.5 \text{ m}^3 \text{ h}^{-1}$ was turned on during the heating process and left running for an additional 10 min during the cooling phase to trap any oil fumes. Approximately 20 g of XAD-2 resin (Supelco, Bellefonte, PA, USA) was used in each sample to absorb the oil fumes generated during the heating process. The XAD-2 resin was pre-extracted with

a solvent mixture of dichloromethane and hexane (1:1, v/v) for approximately 48 h, stored in dichloromethane, and dried under N_2 prior to use.

2.3. Chemical analysis

The tetra- to octachloro-CN congeners were analyzed by isotope dilution high-resolution gas chromatography and high-resolution mass spectrometry (HRGC/HRMS). Prior to extraction, 1 ng of each of the ^{13}C -labeled internal standards (CN 27, 42, 52, 67, 73 and 75) was added to the samples. The oil fumes absorbed in the XAD-2 resin were Soxhlet extracted with a solvent mixture of acetone and hexane (1:1, v/v) for about 24 h. The concentrated fume extracts, as well as the oil samples taken before and after heating, were cleaned up according to the following procedures. First, a gel permeation chromatography (GPC) column, packed with Boibeads SX-3 (Bio-Rad Laboratories, Inc., Hercules, CA, USA), was used to remove the high molecular weight interfering compounds. After loading, the extracts were eluted with 160 mL of a mixture of dichloromethane and hexane (1:1, v/v). The first 60 mL of the eluent was discarded and the following 100 mL was collected and concentrated for further purification. The concentrated extracts were then subjected to a further round of purification on an acid silica gel column packed with (from bottom to top) 5 g of acidic silica gel (44%, w/w), 5 g of acidic silica gel (22%, w/w), and 1–2 cm of anhydrous sodium sulfate. The third column was a multilayer silica gel column packed with (from bottom to top) 1 g of activated silica gel, 2 g of AgNO_3 silica gel (10%, w/w), 1 g of activated silica gel, 4 g of basic silica gel (33%, w/w), 1 g of activated silica gel, 8 g of acidic silica gel (44%, w/w), and 1–2 cm of anhydrous sodium sulfate. Finally, a basic alumina column was employed to obtain the PCN fraction. Prior to injection, the concentrated extracts were spiked with a ^{13}C -labeled standard (CN 64) for quantification of recovery.

Analyses of PCNs were conducted on a gas chromatograph (GC) coupled with a DFS mass spectrometer (Thermo Fisher Scientific, Hudson, NH, USA) with a resolution of approximately 10,000 using an electron impact (EI) source (45 eV), in selected ion monitoring (SIM) mode. A DB-5 capillary column (60 m $\times$ 0.25 mm i.d. $\times$ 0.25 μm , J&W) was used for the separation of the PCN congeners with the following GC oven program. Following an 80 °C hold period for 2 min the temperature was increased at a rate of $20 \text{ }^\circ\text{C min}^{-1}$ to 180 °C (1 min), then at the rate of $2.5 \text{ }^\circ\text{C min}^{-1}$ to 280 °C, and finally at a rate of $10 \text{ }^\circ\text{C min}^{-1}$ to 290 °C (5 min). The injector and the interface temperatures were set to 260 and 290 °C, respectively. The carrier gas flow of helium was held at 1 mL min^{-1} . A sample size of 1 μL was injected in the split-less mode. Peaks corresponding to the individual PCN congeners were identified on the basis of their retention times relative to those of internal standards as well as on their ion ratios. Analyses of the 17 toxic PCDD/F and 12 dl-PCB congeners were carried out according to the US EPA Methods 1613 and 1668A, respectively. Sample extraction, cleanup and instrument analysis of the PCDD/Fs and dl-PCBs were conducted according to the methods of Wu, Dong, Liu, Zhang, and Zheng (2011) and Dong et al. (2011).

2.4. Quality assurance and control

All experiments were run at least in duplicate. The relative percent difference (RPD) of the concentrations of the target compounds measured for duplicate experiments was within 25%. The recoveries of the ^{13}C -labeled standards (CN 27, 42, 52, 67, 73 and 75) of the PCNs were in the range of 35–100%. In the samples of the oil fumes, the recoveries were all greater than 51%. In the oil samples, however, the recovery of CN 27 was much lower than that of the other five internal standards, which reached a value 35% as its

lowest point. The recoveries of CN 42, 52, 67, 73 and 75 were all greater than 48% in the oil samples. The recoveries of the ^{13}C -labeled standards of the dl-PCBs and PCDD/Fs were in the range of 35–110 and 25–120%, respectively.

The concentrations of the PCNs, dl-PCBs and PCDD/Fs in the oil fumes and oils before and after heating were calculated on the basis of the original weight of oil (50 g) used in the experiments. The limits of detection (LOD, equivalent to a signal-to-noise ratio of 3) of the PCNs, dl-PCBs and PCDD/Fs in the current study were 0.01–0.09, 0.009–0.07 and 0.006–0.08 pg g^{-1} , respectively. The concentrations of the PCN, dl-PCB and PCDD/F congeners below the LOD were replaced with a value equivalent to half the LOD.

PCNs were not detected in either the peanut or olive oils prior to heating. In the laboratory blanks, the concentrations of the PCN congeners were all below the LOD. Heating experiments with only peanut oil or olive oil were conducted as experimental blanks. In the experimental blanks, few target compounds were detected in the cooking oil fumes and their levels were less than 5% of those in the cooking oil fumes from oil heated in the presence of sucralose. Thus, there was no blank correction in this study.

3. Results and discussion

3.1. Effects of chlorine-containing compounds and temperature on PCN formation

To quantify the newly produced PCNs with rather simple experiments, cooking oils and large amounts of sucralose (5 g) were used in the current study to produce detectable amounts of PCNs. The proportions of raw materials used in the current study were far greater than those one would expect to find in a real-life cooking scenario. The PCN levels were below those of the LODs and could not be quantitatively detected with realistic proportions under the current experimental conditions.

In the heating experiments of sodium chloride in cooking oil (peanut oil or olive oil) performed at 200 and 245 °C, and in the experiments with cooking oil carried out in the presence of sucralose at 200 °C, PCNs were not detected in the heated oils or in the oil fumes. When the cooking oil was heated with sucralose at 245 °C, however, relatively high levels of PCNs were present in the cooking oil fumes, whereas PCNs were not detected in the heated oils. This result was in agreement with reports on the generation of PAHs from cooking oils, which described the presence of large amounts of PAHs in the oil fumes from different types of cooking oils (Chen & Chen, 2001, 2003; Chiang et al., 1999, 1997). Also, no appreciable differences in PAH loads were observed in the oil before and after heating (Purcaro et al., 2006). The formation and distribution of PCNs is in accordance with previous observations that *de novo* produced dl-PCBs and PCDD/Fs were mainly present in the cooking oil fumes (Dong et al., 2011; Wu et al., 2011).

Sucralose is not stable under high temperatures and has the potential to participate in chlorination reactions during cooking. Bannach et al. (2009) reported the thermal decomposition of sucralose, with the release of constitutional water and hydrogen chloride. Hydrogen chloride released by sucralose could react with glycerol to generate toxic chloropropanols (Rahn & Yaylayan, 2010). The decomposition of sucralose and its participation in chlorination reactions was also observed in the current study. Although PCNs were found in the oil fumes during the heating of the cooking oil and sucralose at 245 °C, PCN congeners were not detected when only sucralose or the cooking oil were heated under the same conditions. This suggested that the formation of PCNs occurred as a consequence of joint effects resulting from both the cooking oil and the sucralose. Sucralose predominantly acted as a chlorine source, whereas the cooking oil acted as a carbon source for PCN

formation. Thus, sucralose is not suitable to be used under high temperatures.

Temperature also influenced the formation of PCNs and related compounds (Altarawneh, Dlugogorski, Kennedy, & Mackie, 2009; Jansson et al., 2008). In the current heating system, the temperature of the oil fumes during the heating stage were detected as being approximately 100 °C, representing a temperature below that required for PCN formation. The temperatures of the raw materials and gas phase close to the oil surface during the heating stage, however, were high enough to reach the temperature required for the formation of PCNs. With this in mind, it is possible that PCNs might have been formed in the field close to the thermal sources and subsequently evaporated into the oil fumes.

3.2. Concentrations and profiles of PCNs in oil fumes

Decreases in the weights of the raw materials after heating were observed in all of experiments. With only cooking oil heated at 245 °C, approximately 0.15 g fat was trapped in the resin. It was difficult, however, to identify the weight of fat actually trapped in the resin in the case of cooking oil heated with sucralose, because the oil fumes trapped in the resin were mixtures of fumes both from the oil and the sucralose. To compare the concentrations of PCNs in different samples, the calculation of those compounds were all based on the weight of oil (50 g) used prior to heating.

The total concentrations of tetra- to octachloro-CN in the peanut and olive oil fumes were found to be 490 and 240 pg g^{-1} , respectively. The homolog profiles of the PCNs did not undergo a notable change in these two types of cooking oil fumes (Fig. 1). In these two samples, the PCN profiles were clearly dominated by the tetra-chlorinated homolog, which constituted approximately 35% of the total PCNs. The degree of chlorination (d_c) of the PCNs in the oil fumes was calculated using Eq. (1), where the d_c value is defined as the sum of the products of the concentration fraction f_i and the number of chlorine atoms n_i for each homolog of the PCNs. The degree of PCN chlorination was calculated to be 5.3 for both the peanut oil fumes and the olive oil fumes. The homolog and degree of chlorination revealed that the concentration distributions of the PCNs in the oil fumes were dominated by the lower chlorination homologs.

$$d_c = \sum_{i=4}^8 f_i \times n \quad (1)$$

Fig. 2 shows the concentration profiles of the tetra- to octachloro-CN congeners generated in the peanut and olive oil fumes. These two congener profiles were similar, indicating that the PCNs were produced according to similar pathways in both oils,

Fig. 1. Concentration profiles of PCN homologs in the cooking oil fumes.

Fig. 2. Concentration profiles of PCN congeners in the cooking oil fumes.

even though their fatty acid compositions were different. CN 73 and CN 74 were major contributors, accounting for more than 15% of the total concentration of PCNs. The concentration of CN 73 in the fume samples was close to that of CN 74. This was quite different from the patterns of the PCNs produced in the combustion processes, where CN 73 dominated over CN 74 (Jansson et al., 2008; Park et al., 2010). GC/MS chromatograms of the PCN congeners in the oil fume samples can be found in the supplementary materials (Figs. 1S–5S).

3.3. Comparison of dl-PCNs, dl-PCBs and PCDD/Fs

To evaluate the relative importance of the PCNs, PCBs, PCDDs and PCDFs produced during cooking, the concentrations of 12 dl-PCB and 17 toxic PCDD/Fs congeners in the cooking oil and oil fumes were also determined. As with the PCNs, the dl-PCBs and PCDD/Fs were found at high levels in the cooking oil fumes generated from the oil heated with sucralose at 245 °C. The TEQs of the individual PCN congeners were calculated according to the RPFs proposed by Noma et al. (2004). The WHO-TEF₂₀₀₅ values proposed by Van den Berg et al. (2006) were adopted for the calculation of the TEQs of the dl-PCBs, PCDDs and PCDFs.

The total concentrations and TEQs of the dioxin-like PCNs (dl-PCNs), dl-PCBs, PCDDs and PCDFs in the peanut and olive oil fumes are shown in Table 1. The total concentrations of the dl-PCNs found in the peanut and olive oil fumes were 200 and 98 pg g⁻¹, respectively. These values were higher than those of the dl-PCBs, PCDDs and PCDFs, representing over 40% of the total concentrations of the dl-PCNs, dl-PCBs, PCDDs and PCDFs. The total TEQs of the dl-PCNs in the peanut and olive oil fumes were 0.25 and 0.12 pg TEQ g⁻¹, respectively, representing values higher than those of the dl-PCBs, but lower than those of the PCDDs and PCDFs. CN 66/67 and CN 73 were the dominant congeners and accounted for approximately 70% of the total TEQs of the PCNs. The congener

patterns of the dl-PCBs and PCDD/Fs in the oil fumes were similar to those previously reported, and will therefore be discussed no further in the current paper (Dong et al., 2011; Wu et al., 2011).

Identification of potential precursors of PCNs, such as PAHs, in the heated oil and oil fumes could be of assistance in investigating the formation mechanisms of PCNs. However, the system used here could not effectively collect and quantify PAHs. Unchlorinated backbones in the raw materials might act as precursors of PCNs, dl-PCBs and PCDD/Fs. The addition of sucralose could help to chlorinate those unchlorinated backbones. Further studies would be needed to improve the system to collect those precursors and investigate the formation mechanisms of PCNs, dl-PCBs and PCDD/Fs.

4. Conclusions

Large amounts of sucralose heated together with cooking oils at high temperatures confirmed the formation and distribution of PCNs, as well as dl-PCBs and PCDD/Fs. The newly produced PCNs, dl-PCBs and PCDD/Fs were predominantly observed in the oil fumes. More attention should be paid to the combined use of sucralose and other organic chlorine-containing food additives and flavorings with cooking oil at high temperatures because of the formation of toxic polychlorinated aromatic compounds in the oil fumes. Cooking processes such as deep frying should be avoided to reduce the potential for human exposure to those unintentionally produced toxic compounds.

Conflict of interest statement

The authors declare that there is no conflict of interest.

Acknowledgments

This study was supported by the Knowledge Innovation Program of the Chinese Academy of Sciences (KZCX2-YW-JS406) and the National Natural Science Foundation of China (20777086 and 20921063).

Appendix A. Supplementary material

Supplementary material related to this article can be found at <http://dx.doi.org/10.1016/j.foodcont.2012.11.001>.

Table 1

Concentrations and TEQs of dl-PCNs, dl-PCBs, 2,3,7,8-substituted PCDDs and 2,3,7,8-substituted PCDFs in the cooking oil fumes (pg g⁻¹).

	Concentrations		TEQs	
	Peanut oil	Olive oil	Peanut oil	Olive oil
∑dl-PCNs	200	98	0.25	0.12
∑dl-PCBs	18	14	0.12	0.08
∑2,3,7,8-substituted PCDDs	54	28	2.0	0.91
∑2,3,7,8-substituted PCDFs	130	86	8.3	5.1
Total	400	230	11	6.2

References

- Alomirah, H., Al-Zenki, S., Al-Hooti, S., Zaghloul, S., Sawaya, W., Ahmed, N., et al. (2011). Concentrations and dietary exposure to polycyclic aromatic hydrocarbons (PAHs) from grilled and smoked foods. *Food Control*, 22, 2028–2035.
- Altarawneh, M., Dlugogorski, B. Z., Kennedy, E. M., & Mackie, J. C. (2009). Mechanisms for formation, chlorination, dechlorination and destruction of polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs). *Progress in Energy and Combustion Science*, 35, 245–274.
- Bannach, G., Almeida, R. R., Lacerda, L. G., Schnitzler, E., & Ionashiro, M. (2009). Thermal stability and thermal decomposition of sucralose. *Eclética Química*, 34, 21–26.
- Bidleman, T. F., Helm, P. A., Braune, B. M., & Gabrielsen, G. W. (2010). Polychlorinated naphthalenes in polar environments—A review. *Science of the Total Environment*, 408, 2919–2935.
- Chen, B., & Chen, Y. (2001). Formation of polycyclic aromatic hydrocarbons in the smoke from heated model lipids and food lipids. *Journal of Agricultural and Food Chemistry*, 49, 5238–5243.
- Chen, Y., & Chen, B. (2003). Determination of polycyclic aromatic hydrocarbons in fumes from fried chicken legs. *Journal of Agricultural and Food Chemistry*, 51, 4162–4167.
- Chiang, T., Wu, P., & Ko, Y. (1999). Identification of carcinogens in cooking oil fumes. *Environmental Research*, 81, 18–22.
- Chiang, T., Wu, P., Wang, L., Lee, H., Lee, C., & Ko, Y. (1997). Mutagenicity and polycyclic aromatic hydrocarbon content of fumes from heated cooking oils produced in Taiwan. *Mutation Research/Fundamental and Molecular Mechanisms of Mutagenesis*, 381, 157–161.
- Domingo, J. L. (2004). Polychlorinated naphthalenes in animal aquatic species and human exposure through the diet: a review. *Journal of Chromatography A*, 1054, 327–334.
- Domingo, J. L. (2011). Influence of cooking processes on the concentrations of toxic metals and various organic environmental pollutants in food: a review of the published literature. *Critical Reviews in Food Science and Nutrition*, 51, 29–37.
- Dong, S., Wu, J., Liu, G., Zhang, B., & Zheng, M. (2011). Unintentionally produced dioxin-like polychlorinated biphenyls during cooking. *Food Control*, 22, 1797–1802.
- Farhadian, A., Jinap, S., Abas, F., & Sakar, Z. I. (2010). Determination of polycyclic aromatic hydrocarbons in grilled meat. *Food Control*, 21, 606–610.
- Grotz, V. L., & Munro, I. C. (2009). An overview of the safety of sucralose. *Regulatory Toxicology and Pharmacology*, 55, 1–5.
- Jansson, S., Fick, J., & Marklund, S. (2008). Formation and chlorination of polychlorinated naphthalenes (PCNs) in the post-combustion zone during MSW combustion. *Chemosphere*, 72, 1138–1144.
- Li, J., Wu, Y., Zhang, L., & Zhao, Y. (2007). Dietary intake of polychlorinated dioxins, furans and dioxin-like polychlorinated biphenyls from foods of animal origin in China. *Food Additives & Contaminants*, 24, 186–193.
- Noma, Y., Yamamoto, T., & Sakai, S. I. (2004). Congener-specific composition of polychlorinated naphthalenes, coplanar PCBs, dibenzo-p-dioxins, and dibenzofurans in the Halowax series. *Environmental Science & Technology*, 38, 1675–1680.
- Park, H., Kang, J. H., Baek, S. Y., & Chang, Y. S. (2010). Relative importance of polychlorinated naphthalenes compared to dioxins, and polychlorinated biphenyls in human serum from Korea: contribution to TEQs and potential sources. *Environmental Pollution*, 158, 1420–1427.
- Purcaro, G., Navas, J. A., Guardiola, F., Conte, L. S., & Moret, S. (2006). Polycyclic aromatic hydrocarbons in frying oils and snacks. *Journal of Food Protection*, 69, 199–204.
- Puzyn, T., Falandysz, J., Jones, P. D., & Giesy, J. P. (2007). Quantitative structure–activity relationships for the prediction of relative in vitro potencies (REPs) for chloronaphthalenes. *Journal of Environmental Science and Health Part A*, 42, 573–590.
- Rahn, A., & Yaylayan, V. A. (2010). Thermal degradation of sucralose and its potential in generating chloropropanols in the presence of glycerol. *Food Chemistry*, 118, 56–61.
- Stockholm Convention. (2012). *Chemicals proposed for listing under the convention*. <http://chm.pops.int/Convention/ThePOPs/ChemicalsProposedforListing/tabid/2510/Default.aspx>.
- Van den Berg, M., Birnbaum, L. S., Denison, M., De Vito, M., Farland, W., Feeley, M., et al. (2006). The 2005 World Health Organization reevaluation of human and mammalian toxic equivalency factors for dioxins and dioxin-like compounds. *Toxicological Sciences*, 93, 223–241.
- Weber, R., Iino, F., Imagawa, T., Takeuchi, M., Sakurai, T., & Sadakata, M. (2001). Formation of PCDF, PCDD, PCB, and PCN in de novo synthesis from PAH: mechanistic aspects and correlation to fluidized bed incinerators. *Chemosphere*, 44, 1429–1438.
- Wu, J., Dong, S., Liu, G., Zhang, B., & Zheng, M. (2011). Cooking process: a new source of unintentionally produced dioxins? *Journal of Agricultural and Food Chemistry*, 59, 5444–5449.