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Original Article

Concentrations of perfluoroalkyl substances in foods and the dietary exposure among Taiwan general population and pregnant women

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ABSTRACT

This study quantified five perfluorocarboxylic acids (PFCAs) and two perfluorosulfonic acids in cereals, meats, seafood, eggs, pork liver, and milk in Taiwan using ultra-performance liquid chromatography-tandem mass spectrometry and evaluated the dietary exposure of the general population and pregnant women using per capita consumption and a questionnaire, respectively. Perfluorooctanoic acid (PFOA) and PFCAs of 10–12 carbons were found in almost all of the samples in considerable concentrations in rice and pork liver, reaching as high as 283 ng/g (PFOA in pork liver); the levels are two to three orders of magnitude higher than previous reports. Perfluorooctane sulfonate (PFOS), the most frequently mentioned perfluoroalkyl substance, was rarely detected in many food items (detection frequencies <20% in rice, flour, pork, chicken, salmon, squid, eggs, and milk) at <0.4 ng/g, except for beef, pork liver and some seafood (detection frequencies: 100%, GMs: 0.05–3.52 ng/g). Compared to populations in Western countries, people in Taiwan are exposed to much more perfluorohexanoic acid, PFOA, perfluorodecanoic acid, and perfluoroundecanoic acid (11.2, 85.1, 44.2, and 4.45 ng/kg b.w./day, respectively), mainly due to the higher contaminations in food. The exposure of 8.0 μg PFOA/person/day in the 95 percentile of pregnant women was due to their frequent consumption of pork liver.

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1. Introduction

Perfluoroalkyl substances (PFASs), including perfluorocarboxylic acids (PFCAs), perfluorosulfonic acids (PFSAs), and their salts are chemically-stable, water-proof, oil-proof, and heat-resistant, and thus they are widely used in the industry [1,2]. PFASs and their impurities are released into the environment in all stages of production, use, and disposal. It is estimated that 45 thousand tons of perfluorooctane sulfonate (PFOS) may have entered the air or environmental bodies of water between 1970 and 2012 globally [3]. Perfluorinated compounds have been gradually phased out in the world. However, due to their persistency and global ocean circulation, previously released PFASs have accumulated in the environment. The bioaccumulation factors of PFASs in fish are positively associated with fluorinated carbon chain lengths, and range from 1000 to 5000 in fish [4]. In general, PFOS is the most frequently detected and is found at higher concentrations than other PFASs in wild animals, followed by PFOA [5–9]. As high as 225 and 380 ng/g of PFOS has been observed in wild fish in Germany and in the United States, respectively [10,11].

Toxicological studies, mostly focusing on PFOS and PFOA, have reported PFASs to have adverse effects on reproductive, endocrine, and immune systems, and to be carcinogenic [12–15]. In humans, PFAS exposure was positively correlated with triglyceride, total cholesterol, low-density lipoprotein cholesterol levels, and the increase in bladder cancer mortality [16,17]. In addition, high PFAS levels in blood have been associated with prolonged time to pregnancy and low semen quality in adults, as well as preterm birth and low birth weight in the new-born [18–20].

The major route of exposure to PFASs is through the ingestion of contaminated foods, especially long-chain, large-molecule PFASs from foods of animal origin [21–24]. These compounds tend to bind cytosolic proteins and thus they are frequently found in meat, seafood, and dairy products [4,25–27]. In China, Gulkowska et al. found sub-to low ng/g of PFOS in all their samples of fish, molluscs, crabs, shrimps, and other shellfish and observed PFOA and perfluoroundecanoic acid (PFUnDA) in more than half of their samples [28]. In Norway, Haug et al. detected up to 12 PFASs in cod liver, fish, eggs, chicken, pork, and milk, and found PFOS and PFUnDA to be the most abundant [29]. A similar result was reported by Eriksson et al., showing PFUnDA to be the most abundant in fish (<24–290 pg/g) and milk (<130–190 pg/g), followed by PFOA (<100–240 pg/g and <67–77 pg/g, respectively) [30]. Regarding the effect of dietary frequency, one market basket study in Sweden showed that people who consume more meat and fish are exposed to higher amounts of perfluorodecanoic acid (PFDA) and perfluorononanoic acid (PFNA) as well as PFOS and PFUnDA than those who eat more cereals and vegetables [31]. In a study of a one-day composite of diet samples containing more seafood in South Korea, Kim et al. reported higher concentrations of long-chain PFASs (C_{11}–C_{14}) than those of short-chain PFASs such as perfluorohexanoic acid (PFHxA) [32].

Among the PFASs with various carbon-chain lengths, PFOA and PFOS in foods are the most frequently detected and reported to date, especially for seafood and meat. Besides, compared to the Western countries, people in East and Southeast Asia consume less meat [33], more rice than wheat, and more seafood than those in Europe and America. An investigation on the exposure to PFASs through the East Asian diet is needed. This study measured seven PFASs in 140 samples of 14 foods primarily consumed in Taiwan, and estimated the daily intake of PFASs based on these measured concentrations and the diet frequency obtained from per capita consumption and a questionnaire.

2. Methods

2.1. Samples

Ten batches of 14 types of food (rice, flour, pork, chicken, beef, salmon, grass carp, oysters, clams, shrimps, squids, eggs, pork liver, and milk) were collected between September 2010 and April 2011. The 14 foods were chosen based on per capita consumption data for 2008 obtained from the Taiwan Council of Agriculture [34], which lists the most consumed foods in the four categories: (1) cereals: rice (59%) and wheat (41%); (2) meats: pork (51%), poultry (41%), and beef (5%); (3) seafood: fish (45%) and shellfish (38%) and (4) dairy products: milk (78%, Table 1). Because liver is a target organ of PFASs [16,35] and pork liver is a food very commonly consumed by pregnant women in Taiwan, pork liver was also included in the samples. The foods, except for milk, were purchased from two traditional markets in Taipei City, the capital of Taiwan. The milk was purchased from convenience stores. There are very limited agricultural activities in Taipei City, where raw food and food products are from the entire Taiwan, which is a small island (area 35,883 km^2) with well-organized food transportation systems.

2.2. Chemicals and reagents

The standard solutions of seven analytes including (a) five PFCAs: PFHxA, PFOA, PFDA, PFUnDA, and perfluorododecanoic acid (PFDoDA) and (b) two PFSAs: perfluorohexane sulfonate (PFHxS) and PFOS, as well as five stable isotope-labeled compounds (perfluoro-*n*-[1,2,3,4,6-$^{13}C_5$] hexanoic acid, perfluoro-*n*-[1,2,3,4-$^{13}C_4$]octanoic acid, perfluoro-*n*-[1,2,3,4-$^{13}C_4$]undecanoic acid, sodium perfluoro-1-hexane[$^{18}O_2$]sulfonate, and sodium perfluoro-1-[1,2,3,4-$^{13}C_4$] octanesulfonate) all had > 98% of purity at 50 μg/mL in 1.2 mL in methanol and were purchased from Wellington Labs (Guelph, Ontario, Canada).

Methanol of LC/MS grade was purchased from J.T. Baker (Phillipsburg, NJ, USA) as the organic mobile phase on liquid chromatography. Methanol, acetonitrile, acetone, *n*-heptane, and dichloromethane of LC grade, and ammonium hydroxide (28–30%), potassium hydroxide (85%), and analytical-grade formic acid (88%), which were used for sample preparation, were also purchased from J.T. Baker. *N*-methylmorpholine of analytical grade (95.5%) was purchased from Sigma–Aldrich (Saint Louis, MO, USA).

Table 1 – The 14 selected foods based on the per capita consumption for 2008 by the population in Taiwan.

Category	Per capita consumption for 2008[a]			Collected samples in this study
	Item	Daily intake (g)/day/person	Proportion of consumption in a category	
Cereal	Rice	131	59%	Rice
	Wheat	86.8	41%	Flour
Meat	Pork	102	51%	Pork
	Poultry	81.6	41%	Chicken
	Beef	10.6	5%	Beef
Seafood	Fish	42.2	45%	Salmon (oceanic) and grass carp (freshwater)
	Shellfish	36.7	38%	Oyster, shrimp, clam, and squid
Dairy products	Milk	40.5	78%	Milk
Other	Egg	45.0	–	Egg
	Pork liver	0.08	–	Pork liver

[a] Council of Agriculture, Executive Yuan, Taiwan (2008) [34].

2.3. *Analytical methods*

The qualification and quantification of PFASs were described in a previous study [36]. Briefly, rice was ground to powder with mortar and pestle while meats and seafood were homogenized using a laboratory blender. One-gram sample was spiked with 100 μL of the 0.5-ng/μL isotope-labeled internal standards and was digested for 2 h in a methanol-prewashed homogenization tube (DT-20, IKA Works, Staufen, Germany) with 10 mL of 0.5-N potassium hydroxide in methanol on Ultra-Turrax Tube Disperser (IKA Works). Afterward the sample was centrifuged at 3000 rpm (1410 × g) for 30 min and the supernatant was collected and diluted with 500-mL acidified Milli-Q water (pH 3.5). As for the milk, a 25-mL sample was added with 100 μL of the 0.5-ng/μL internal standards and 450 mL of 0.5-N potassium hydroxide$_{(aq)}$, shaken for 30 min, and acidified to pH 3.5 with nine-mL formic acid. After filtering with glass fiber filters (pore size 0.45 μm), the acidified samples were extracted using conditioned Atlantic HLB disks (47 mm, Horizon Technology, Salem, NH, USA) using automated solid phase extractors (SPE-DEX 4790, Horizon Technology). The eluent of 20-mL 0.1% ammonium hydroxide in methanol was filtered through a nylon membrane and was concentrated to one mL using a SpeedVac. Eight hundred microliters of Milli-Q water were added to the eluent and the sample was concentrated again to one mL.

A Waters ACQUITY UPLC coupled with a Waters Quattro Premier XE triple-quadrupole mass spectrometer (UPLC-MS/MS; Waters, Milford, MA, USA) set at negative electrospray ionization mode was used to measure the PFASs in foods. Analytes were separated on a fused-core Kinetex C18 column (2.1 × 50 mm, 2.6 μm, Phenomenex, Torrance, CA, USA) at 40 °C. The flow rate of the mobile phases, methanol (A) and 10-mM *N*-methylmorpholine$_{(aq)}$ (pH 9.6, B), was 0.9 mL/min with a gradient starting from 10% A and held for 0.2 min. Mobile phase A was then increased to 100% within 3 min, held for 1 min, and returned to the initial 10% in 0.3 min. The column was re-equilibrated for 1.1 min. The analytes were eluted within 3 min, the chromatographic time totaling 5.6 min. Analytes were detected at selected reaction monitoring mode, in which a precursor ion and two product ions were selected as ion pairs for quantification and confirmation, respectively. The capillary voltage was 2.0 kV. The ionization temperature and desolvation temperatures were set at 150 °C and 500 °C, respectively. The flow rates of cone gas and desolvation gas (nitrogen) were 150 L/hr and 950 L/hr, respectively. Argon was used as the collision gas at collision cell pressure of 3.22×10^{-3} mbar.

2.4. *Quality control and data analysis*

To prevent contamination, laboratory materials containing PFASs were avoided. Glassware was cleaned with tap water and Milli-Q water, followed by rinsing with acetone, *n*-heptane, dichloromethane, and methanol, respectively. Filter membranes were prewashed with methanol. Methanol was injected three times before each batch subjected to instrumental analysis to ensure that any residual PFAS in the UPLC-MS/MS system was removed and background interference was reduced. Isotope dilution techniques were used to quantify the PFASs. A process blank, a duplicate of a food sample, and a quality control (QC) sample spiked with 100 μL of 0.1-ng/μL PFASs were included in each batch of 14 samples for all the ten batches. The limits of detection (LODs) mostly ranged from 0.01 ng/g to 0.07 ng/g, except for PFHxA in beef and oyster (0.28 and 0.13 ng/g, respectively), PFUnDA in eggs (0.10 ng/g), and PFOS in pork liver (0.31 ng/g, Table S1) [36]. The background levels obtained from process blanks ranged from < LOD to sub-ng/g for PFUnDA, PFDoDA, PFHxS, and PFOS, and at low ng/g levels for PFHxA, PFOA, and PFDA. The randomly selected duplicates for each batch in the ten batches turned out to be oyster, liver, rice, salmon, liver, clam, oyster, oyster, oyster, and liver, which proved precise quantification with most relative percent differences (RPDs) less than 15% between duplicates. The spiked QC matrixes for the ten batches were clam, beef, clam, grass carp, oyster, oyster, liver, salmon, beef, and clam, and the average differences in concentrations between the spiked and non-spiked samples ranged from 8.67 (PFDoDA) to 14.8 ng/g (PFUnDA), which was accurate comparing with the spiked level of 10 ng/g.

2.5. *Evaluation of daily intake*

Daily intake of each food for each PFAS per person was calculated based on per capita consumption data for the year 2008 (Table 1) and the geometric mean (GM) concentrations of PFASs. In order to avoid overestimation, the PFASs with positive rates lower than 50% in a food item were not included in the estimation of daily intake; all the included data were those detected in nine or all of samples (n = 10). We calculated both the GMs and the medians of PFASs because the concentrations did not follow normal distributions; GMs instead of medians were chosen in the following assessments in this study because GMs would be more appropriate for representing central values of the measured concentrations. PFAS intakes from wheat were calculated using their concentrations in flour. The intake from cereals represented those from rice and flour. We summed the intake from salmon (a wild oceanic fish) and grass carp (a farmed freshwater fish) to constitute the total intake of fish. Similarly, meat included pork, poultry, and beef; shellfish covered oyster, shrimp, clam, and squid. The daily intake per person was divided by the average body weight of an adult in Taiwan (65 kg) to calculate the exposure dose per kilogram body weight.

In addition to the general population, we also evaluated the exposure in pregnant women in Taiwan. This study was approved by the Research Ethics Committee, National Taiwan University Hospital (#200812144R), and informed consent was obtained from each individual. Sixty-two questionnaires on food consumption were administered to pregnant women visiting gynecology clinics of National Taiwan University Hospital between October 2010 and June 2011. The questionnaire was composed of two sections, basic information and diet. The former contained the participants' weight, height, ethnic group, and education. The latter was a food intake questionnaire, in which the participants answered the consumption frequency and amount of each food item in a week. For example, they checked the frequency of oceanic fish consumption among "always", "frequent", "sometimes", "seldom", and "never", and the amount for each consumption among "< 1", "1–2", "2–3", "3–4", and "> 5" portions, which one portion was pre-defined and illustrated with both a picture and its weight on the questionnaire. The results were used to calculate the participants' daily intake of each food item. Batch Fit analyses were conducted using Oracle Crystal Ball Fusion Edition Release 11.1.2.1.0 (Oracle Corporation, Redwood Shores, CA, USA) to estimate the optimized exposure model. Based on the model, the GM concentrations of PFASs were applied to one million times of Monte Carlo trials to obtain the cumulative intake from foods of 25%, 50%, 75%, and 95% probability among pregnant women.

3. Results and discussion

3.1. *Distributions in foods*

PFCAs were detected in most foods at GM concentrations ranged from sub-to < 30 ng/g with detection frequencies of 90% or 100% (Table 2). The GM and median concentrations were comparable (Table 2). PFOA was found in all of the samples and was the most abundant PFCA in most food items with GM concentrations ranging from 5.73 ng/g (eggs, n = 10) to 12.1 ng/g (beef, n = 10), except for 1.44 ng/mL in milk (n = 10). PFOA concentrations in salmon (GM: 7.48 ng/g), oyster (GM: 8.56 ng/g), pork liver (GM: 10.0 ng/g), and eggs (GM: 5.73 ng/g) were only lower than those of PFDA (GMs: 7.99, 12.3, 20.7, and 22.2 ng/g, respectively, Table 2). Compared with PFCAs, the two PFSAs were less frequently detected; for example, PFHxS was observed in five beef, one squid, one liver, and three milk samples, and PFOS was found in none to three samples of rice, flour, pork, chicken, salmon, oyster, squid, egg, and milk (n = 10 for each food item, Table 3). The concentrations of PFSAs were found at GMs ranging from 0.04 to 0.73 ng/g, with the exception of PFOS in squid (1.06, detection frequency 10%) and pork liver (3.52 ng/g, detection frequency 100%, Table 3).

In general, this study found higher concentrations than those in previous reports. The concentrations of PFHxA and PFOA in rice (GMs: 1.10 and 8.90 ng/g, respectively) and flour (GMs: 1.33 and 8.84 ng/g, respectively) were two to three orders of magnitude higher than those reported for cereals in Sweden, which PFHxA and PFOA were at 0.004–0.011 ng/g and 0.011–0.062 ng/g, respectively [31]. PFOA in meats (GMs: 8.78–12.1 ng/g) were two orders of magnitude higher than those in Spain, Italy, and Norway, where PFOA was not detectable or lower than 0.1 ng/g in pork, beef, and chicken [27,29,37]. The concentrations of C_{10}–C_{12} PFCAs in meats (GMs: 3.06–3.80 ng/g, 0.13–0.24 ng/g, and 1.19–1.58 ng/g, respectively) were ten to a few hundred times higher than those reported by Haug et al. for Norway [29]. In this study, the detection frequencies and concentrations of PFCAs found in fish (mostly 100%, GMs: 0.62–7.99 ng/g) were much higher than those reported for freshwater fish in Canada and for rainbow trout in Sweden (<0.102 ng/g) [26,38]; the PFHxA (GMs: 0.90–1.06 ng/g) and PFOA (GMs: 7.48–9.67 ng/g) in seafood were at least five times higher than those reported in China [25]. The concentrations of the PFASs in pork liver (GMs: 0.73–20.7 ng/g) were higher than those of PFHxA, PFOA, and PFOS reported by Jogsten et al. for lamb liver (<0.05–0.33 ng/g) [39], and those for the liver of wild animals including fish, birds, and marine mammals [40–42].

In contrast to considerable concentrations of PFOS in foods found by other studies [28,29,43], PFOS was only frequently detected in beef, grass carp, shrimp, and clam at low levels (GMs: 0.12, 0.53, 0.06, and 0.05 ng/g, respectively; n = 10, Table 3) and in pork liver at 3.52 ng/g (n = 10) in this study. The PFOS concentrations we found in beef (0.03–0.35 ng/g, GM: 0.12 ng/g) was more than ten times lower comparing with that in Italy (mean: 2.11 ng/g) but was similar to that of a beef sample in Norway (0.06 ng/g) [27,29]. Concentrations of PFOS in fish and other seafood were often reported higher than those of other PFASs [27,29,38,44]; however, we could rarely find it in salmon, oyster, and squid. This discrepancy could result from local differences in contamination [45]. The information on environmental concentrations of PFOS in Taiwan is limited to rivers that receive industrial or domestic wastewater [46,47]; the concentrations vary a lot with 64.4–7165 ng/L in river water, 95–1828 ng/g in river fish muscle, and 110 to 28,933 ng/g in river fish liver [47]. Because the above river water is not

Table 2 – Concentrations of perfluorocarboxylic acids in foods (ng/g w.w.; ng/mL for milk; n = 10).

Food item	PFHxA			PFOA			PFDA			PFUnDA			PFDoDA		
	DF	GM	Median	DF	GM	Median	DF	GM	Median	DF	GM	Median	DF	GM	Median
Rice	100%	1.10	1.07	100%	8.90	5.37	100%	5.67	5.12	100%	0.48	0.50	100%	1.62	1.63
Flour	100%	1.33	1.39	100%	8.84	6.44	90%	1.97	2.21	100%	0.11	0.11	90%	1.98	1.87
Pork	100%	1.31	1.02	100%	10.7	5.91	100%	3.22	3.63	100%	0.18	0.18	90%	1.32	1.68
Beef	100%	1.16	1.21	100%	12.1	8.27	100%	3.80	3.70	100%	0.24	0.30	90%	1.58	1.63
Chicken	100%	1.17	1.02	100%	8.78	6.49	100%	3.06	3.35	100%	0.13	0.19	90%	1.19	1.30
Salmon	100%	1.06	1.08	100%	7.48	5.39	100%	7.99	8.55	100%	0.62	0.72	100%	1.44	1.78
Grass Carp	100%	1.02	1.04	100%	7.84	5.95	100%	6.79	7.59	100%	1.17	1.19	90%	1.60	1.78
Oyster	100%	0.94	1.20	100%	8.56	5.71	90%	12.3	10.5	100%	1.39	1.39	100%	5.38	6.28
Shrimp	100%	0.90	0.87	100%	7.75	8.23	100%	6.58	7.36	100%	0.80	0.78	100%	3.69	4.63
Clam	100%	1.05	0.98	100%	8.25	5.60	100%	6.60	7.05	100%	0.80	0.86	100%	2.30	3.07
Squid	100%	1.05	1.07	100%	9.67	6.40	100%	5.94	7.84	100%	0.49	0.66	100%	6.90	9.93
Liver	40%	1.58	1.69	100%	10.0	5.87	100%	20.7	26.5	100%	2.19	2.18	100%	15.7	15.9
Egg	100%	0.95	0.82	100%	5.73	5.35	100%	22.2	23.1	100%	0.94	0.95	100%	6.49	7.87
Milk	100%	0.03	0.03	100%	1.44	1.70	100%	0.94	1.53	100%	0.06	0.02	10%	0.07	0.07

DF: detection frequencies; number of detectable samples divided by the sample number of a food item (n = 10).
GM: geometric means of detectable concentrations.
PFDA: perfluorodecanoic acid.
PFDoDA: perfluorododecanoic acid.
PFHxA: perfluorohexanoic acid.
PFOA: perfluorooctanoic acid.
PFUnDA: perfluoroundecanoic acid.

Table 3 – Concentrations of perfluorosulfonic acids in foods (ng/g w.w.; ng/mL for milk, n = 10).

Food item	PFHxS			PFOS		
	DF	GM	Median	DF	GM	Median
Rice	100%	0.04	0.04	10%	0.23	0.23
Flour	100%	0.07	0.07	10%	0.34	0.34
Pork	100%	0.08	0.07	20%	0.26	0.28
Beef	50%	0.15	0.12	100%	0.12	0.11
Chicken	100%	0.09	0.11	20%	0.14	0.16
Salmon	100%	0.07	0.08	20%	0.13	0.29
Grass Carp	100%	0.06	0.07	100%	0.53	0.52
Oyster	100%	0.08	0.08	30%	0.19	0.38
Shrimp	100%	0.22	0.20	100%	0.06	0.12
Clam	100%	0.11	0.17	100%	0.05	0.06
Squid	10%	0.26	0.26	10%	1.06	1.06
Liver	10%	0.73	0.73	100%	3.52	5.65
Egg	100%	0.05	0.06	10%	0.29	0.29
Milk	30%	0.01	0.01	0%	<14.9	<14.9

DF: detection frequencies; number of detectable samples divided by the sample number of a food item (n = 10).
GM: geometric means of detectable concentrations.
PFHxS: perfluorohexane sulfonate.
PFOS: perfluorooctane sulfonate.

allowed for irrigation or aquaculture, the reported PFOS concentrations would not be directly relevant to those in foods in our study. Our results may also reflect the overall decline of PFOS in the environment, which was brought about by reducing the production and use by companies such as 3M since 2002 as well as by the fact that PFOS was added to the list of controlled compounds of Stockholm Convention in 2009 [48,49].

The PFAS profiles were different among food categories, with higher portions of C_{10}–C_{12} PFCAs in eggs, pork liver, and seafood but more PFOA in cereals and meat (Fig. 1). The C_{10}–C_{12} PFCAs were the most abundant in eggs (81%), followed by pork liver (71%), shellfish (57%), fish (52%), milk (42%), cereals (36%), and meat (29%). Meat was predominated by PFOA (62%) and contained the least C_{10}–C_{12} PFCAs. Lau et al. demonstrated that the elimination of PFASs differs between terrestrial species and is not necessarily dependent on the chain lengths [16]; however, the comparisons were with rodents, dogs, and primates, and were limited to C_4, C_6, and C_8 PFASs. Cereals also contained relatively lower proportions of C_{10}–C_{12} PFCAs than most foods of animal origin; this observation is consistent with the report of Blaine et al., showing that crops accumulate more shorter-chain PFCAs than longer-chain PFCAs [50]. Liver contained not only high proportions of C_{10}–C_{12} PFCAs but also the highest of the PFDoDA (29%) and PFOS (6.5%) than other food items. This trend was somewhat consistent with a previous study on cattle liver, which contained higher proportions of PFUnDA (10.8%) and PFOS (58.6%) than cattle muscle (PFUnDA was lower than the method detection limit (MDL) and PFOS was 56.6%, respectively) [51].

3.2. *Profiles in specific food categories*

The studied PFASs, except for PFOS, were found in almost all the samples of rice and flour at GMs ranging from 0.04 ng/g (PFHxS) to 8.90 ng/g (PFOA) and 0.07 ng/g (PFHxS) to 8.84 ng/g (PFOA), respectively (Tables 2 and 3). The concentrations, especially at shorter-chain PFASs, are comparable or even higher than those in foods of animal origin. Rice is one of the staples in Asia, and flour is used to make noodles as well as bread. However, the PFAS contaminations of these two staples have been rarely reported. D'Hollander et al. studied 14 PFASs in Europe and all the analytes were below the LODs in rice, and there were only 0.18 ng/g of PFHxA, <0.01 ng/g of PFOA, and 0.02 ng/g of PFDA in wheat [52]. Haug et al. reported the

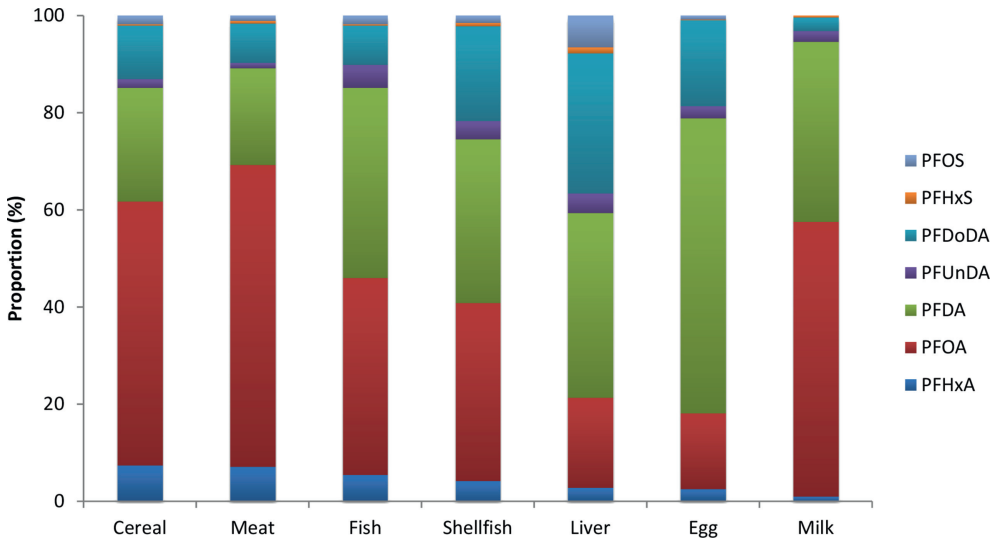

Fig. 1 – The proportion of each perfluoroalkyl substance (PFAS) by food categories. PFDA: perfluorodecanoic acid, PFDoDA: perfluorododecanoic acid, PFHxA: perfluorohexanoic acid, PFHxS: perfluorohexane sulfonate, PFOA: perfluorooctanoic acid, PFOS: perfluorooctane sulfonate, PFUnDA: perfluoroundecanoic acid.

concentrations of 10 PFASs in bread of Oslo, Norway, instead of flour, ranged from <0.0015 ng/g (perfluorobutane sulfonic acid) to 0.051 ng/g (PFOA) [29]. Eriksson et al. analyzed eight PFASs in potato and none of them was detected [30]. Pérez et al. reported sub ng/g of total PFASs in cereal mixtures according to the consumption in Brazil, Saudi Arabia, Serbia, and Spain [53]. The above findings would not be applicable to East or Southeast Asian countries.

Table 4 – Daily perfluoroalkyl substance (PFAS) intake (ng/person/day) and the proportion of total PFASs (%) among the general population in Taiwan.

Food item	PFHxA	PFOA	PFDA	PFUnDA	PFDoDA	PFHxS	PFOS	Total PFASs
Cereals								
Rice	145 (6.18[a])	1175 (50.0)	748 (31.8)	63.4 (2.70)	214 (9.10)	5.28 (0.22)	–[b]	2351 (20.1[c])
Flour	131 (9.29)	870 (61.7)	194 (13.8)	10.8 (0.77)	195 (13.8)	6.89 (0.49)	–	1408 (12.0)
Meats								
Pork	137 (7.79)	1117 (63.7)	336 (19.2)	18.8 (1.07)	138 (7.85)	8.35 (0.48)	–	1755 (15.0)
Beef	13.3 (6.11)	139 (63.7)	43.7 (20.0)	2.76 (1.26)	18.2 (8.32)	–	1.38 (0.63)	218 (1.86)
Chicken	97.1 (8.11)	728 (60.9)	254 (21.2)	10.8 (0.90)	98.7 (8.25)	7.47 (0.62)	–	1196 (10.2)
Fish								
Salmon	54.0 (5.68)	381 (40.1)	407 (42.8)	31.6 (3.32)	73.3 (7.72)	3.56 (0.38)	–	950 (8.12)
Grass carp	51.9 (5.37)	399 (41.2)	346 (35.7)	59.6 (6.15)	81.4 (8.42)	3.05 (0.32)	27.0 (2.79)	968 (8.27)
Seafood								
Oyster	13.8 (3.22)	126 (29.4)	181 (42.2)	20.5 (4.77)	79.2 (18.4)	1.18 (0.27)	–	422 (3.60)
Shrimp	13.2 (4.49)	114 (38.7)	96.9 (32.8)	11.8 (3.99)	54.3 (18.4)	3.24 (1.10)	0.88 (0.30)	294 (2.51)
Clam	15.5 (5.48)	121 (43.1)	97.2 (34.4)	11.8 (4.18)	33.9 (12.0)	1.62 (0.57)	0.74 (0.26)	282 (2.41)
Squid	4.86 (4.37)	44.8 (40.2)	27.5 (24.7)	2.27 (2.04)	31.9 (28.7)	–	–	111 (0.94)
Liver	–	0.80 (18.9)	1.67 (39.6)	0.17 (3.98)	1.21 (28.6)	–	0.32 (7.57)	4.17 (0.036)
Egg	42.8 (2.61)	258 (15.8)	999 (61.1)	42.3 (2.59)	292 (17.8)	2.25 (0.14)	–	1636 (14.0)
Milk	1.25 (1.21)	60.0 (58.3)	39.2 (38.1)	2.50 (2.43)	–	–	–	103 (0.88)
All foods	721 (6.15)	5534 (47.3)	3771 (32.2)	289 (2.47)	1311 (11.2)	42.9 (0.37)	30.3 (0.26)	11,698

PFDA: perfluorodecanoic acid.
PFDoDA: perfluorododecanoic acid.
PFHxA: perfluorohexanoic acid.
PFHxS: perfluorohexane sulfonate.
PFOA: perfluorooctanoic acid.
PFOS: perfluorooctane sulfonate.
PFUnDA: perfluoroundecanoic acid.
[a] The proportion of the compound to the total PFASs in the single food item.
[b] A PFAS in which its detection frequency did not exceed 50% in a food item was not included in the estimation of daily intake.
[c] The proportion of the total PFASs in a food item to those of summed PFASs from all items.

Table 5 – Comparison of the estimated daily intake between Taiwan and other countries.

Compound	Country	Daily intake (ng/kg body weight/day)	Reference
PFHxA	Taiwan (this study)	11.2	
	Germany	4.30	Fromme et al. (2007) [21]
PFOA	Taiwan (this study)	85.1	
	China	9.83	Zhang et al. (2010) [61]
	Korea	0.17–1.68	Heo et al. (2014) [62]
	Germany	2.90	Fromme et al. (2007) [21]
	UK	70.0	U.K. Food Standards Agency, (2006) [44]
	North America and Europe	1–130	Trudel et al. (2008) [23]
	Canada	0.10–0.50	Ostertag et al. (2009) [42]
	Canada	0.20–0.40	Ostertag et al. (2009) [60]
	Norway	0.60	Haug et al. (2010) [63]
	Italy	5.74 (for men) 4.10 (for women)	Renzi et al. (2013) [45]
PFDA	Taiwan (this study)	44.2	
	Canada	0.10–0.30	Ostertag et al. (2009) [60]
PFUnDA	Taiwan (this study)	4.45	
	Norway	0.34	Haug et al. (2010) [63]
PFHxS	Taiwan (this study)	0.65	
	Germany	2.00	Fromme et al. (2007) [21]
PFOS	Taiwan (this study)	0.46	
	China	1.19	Zhang et al. (2010) [61]
	Korea	0.60–3.03	Heo et al. (2014) [62]
	Germany	1.40	Fromme et al. (2007) [21]
	UK	100	U.K. Food Standards Agency, (2006) [44]
	Spain	1.07	Ericson et al. (2008) [37]
	North America and Europe	3–220	Trudel et al. (2008) [23]
	Canada	4.00	Tittlemier et al. (2008) [38]
	Canada	0.20–2.40	Ostertag et al. (2009) [42]
	Canada	0.10–0.20 (1990) 0.80–2.00 (1998–2004)	Ostertag et al. (2009) [60]
	Norway	1.50	Haug et al. (2010) [63]
	Italy	5.71 (for men) 4.08 (for women)	Renzi et al. (2013) [45]

PFDA: perfluorodecanoic acid.
PFHxA: perfluorohexanoic acid.
PFHxS: perfluorohexane sulfonate.
PFOA: perfluorooctanoic acid.
PFOS: perfluorooctane sulfonate.
PFUnDA: perfluoroundecanoic acid.

In terms of seafood, PFOA and PFDA were found at higher concentrations (GMs: 7.48–9.67 ng/g and from 5.94 to 12.3 ng/g, respectively) than the other three PFCAs (low ng/g levels, Table 2). Tittlemier et al. also reported higher concentrations of PFDA in seafood than longer-chain PFUnDA and PFDoDA, although they did not find PFOA [38]. On the other hand, the levels of PFOA and PFDA in our study were six to 30 times lower than those previously reported for tilapia and oysters in a polluted wastewater area in Taiwan [54].

The concentrations of PFASs found in pork liver were higher than those in any other food item (except for PFOA) (Tables 2 and 3). This finding is consistent with other reports on the liver of cattle and aquatic animals [41,55]. In Taiwan, pork liver is occasionally consumed by the general population, but is consumed much more often by pre- and postnatal women as a nutritious supplement. The high amount of PFASs in pork liver may pose health risks to pregnant women and there are several studies have suggested that PFASs could be transmitted to their offspring through cord blood and breast milk [56–58].

3.3. *Intake from foods*

The estimated total intake of PFASs was 11.7 μg/person/day in the general population in Taiwan based on the studied foods (Table 4). The predominant compounds were PFOA (5.5 μg/person/day, 47.3% of the total PFASs) and PFDA (3.8 μg/person/day, 32.2%). People there ingest most of the PFASs from rice (2.4 μg/person/day, 20.1%), pork (1.8 μg/person/day, 15.0%), and eggs (1.6 μg/person/day, 14.0%, Table 4). The major contributed food categories were cereals (32%), meats (27%), and fish (16%). The total daily intake for PFOA and PFDA in this study was 179 and 290 times higher, respectively, than those reported by Haug et al. for the general Norwegian population [29]. In our study, the daily ingestion of PFOA from meats (1.98 μg/person/day) was comparable to that from cereals (2.05 μg/person/day). This finding is inconsistent with those of Vestergren et al., which PFOA intake could be dominated by large consumption of cereals, vegetables, and dairy products rather than meats and fish products [31]. This difference may result from a relatively lower ratio of PFOA from cereals to that

Table 6 – Simulated upper limits of daily perfluoroalkyl substance (PFAS) intake with 95% percentile among pregnant women in Taiwan (ng/person/day).

Food item	PFHxA	PFOA	PFDA	PFUnDA	PFDoDA	PFHxS	PFOS
Rice	311	2517	1604	136	458	11.3	–[a]
Flour	157	1045	233	7.09	234	8.27	–
Pork	95.6	780	235	13.1	96.3	3.65	–
Beef	58.0	605	190	12.0	78.9	–	6.00
Chicken	68.2	511	178	6.41	69.3	5.24	–
Ocean fish	50.1	353	377	29.3	68.1	2.36	–
Fresh fish	29.8	228	198	34.1	46.7	0.58	15.5
Oyster	42.2	384	552	62.4	241	3.59	–
Shrimp	40.3	347	294	35.9	165	9.86	2.69
Clam	47.1	370	296	35.9	103	4.04	2.24
Squid	18.5	170	104	37.8	121	–	–
Liver	–	142	297	29.9	214	–	56.9
Egg	11.4	69	267	11.3	78.1	0.60	–
Milk	8.97	431	281	17.9	–	–	–
Total	**938**	**4390**	**3502**	**469**	**1973**	**49.5**	**83.3**

PFDA: perfluorodecanoic acid.
PFDoDA: perfluorododecanoic acid.
PFHxA: perfluorohexanoic acid.
PFHxS: perfluorohexane sulfonate.
PFOA: perfluorooctanoic acid.
PFOS: perfluorooctane sulfonate.
PFUnDA: perfluoroundecanoic acid.
[a] A PFAS which its detection frequency did not exceed 50% in a food item was not included in the estimation of daily intake.

from meats in this study (1.18:1) than theirs (5.54:1). Yamada et al. presented that seafood and water contribute more to the exposure to PFASs when values <LODs are considered as zero, but breads and dairy products contribute more when values <LODs are replaced by the LODs [59]. Their findings on seafood and breads would be similar to ours, but are dissimilar on dairy products.

The exposure to PFASs among the general population in Taiwan ranged from 0.46 ng/kg b.w./day for PFOS to 85.1 ng/kg b.w./day for PFOA (Table 5). The exposure to PFHxS and PFOS (0.65 and 0.46 ng/kg b.w./day, respectively) was comparable or slightly lower than other reports. However, the current study revealed that people in Taiwan are exposed to much higher levels of PFHxA, PFOA, PFDA, and PFUnDA (11.2, 85.1, 44.2, and 4.45 ng/kg b.w./day, respectively) than those in other countries (Table 5), although they consume a comparable amount of meat to those in European Union and North America [21,23,29,37,38,42,44,45,60–63]. The estimated daily intake of PFOA in China (9.83 ng/kg b.w./day) and in Korea (0.17–1.68 ng/kg b.w./day) did not include cereals; excluding the sources of rice and flour, the exposure to PFOA in Taiwan (53.7 ng/kg b.w./day) remained five to 300 times higher than that in China and Korea [61,62]. The higher exposure might be mainly attributed to the higher concentrations of PFASs in foods found in the current study than those in previous reports. Moreover, the estimated average daily intake of PFOA in this study was only 18 times lower than the tolerable daily intake (TDI) suggested by European Union and 35 times lower than that suggested by the U.K. (1500 and 3000 ng/kg b.w./day, respectively) [44,64]. Because the high exposure group may exceed these TDIs, the exposure of the Taiwanese to PFOA deserves further attention.

Regarding pregnant women in Taiwan, PFOA was the highest exposed PFASs; the upper limit of 95% probability from each food item ranged from 69.0 (eggs) to 2517 ng/person/day (rice), in a total of 4390 ng/person/day (Table 6). The next was PFDA, which ranged from 104 (squid) to 1604 ng/person/day (rice), in a total of 3502 ng/person/day. The 95% upper limit of total PFASs from liver for pregnant women (740 ng/person/day in total) were at least two orders of magnitude higher than that of the general population (4.17 ng/person/day in total). Liver was a major source of PFOS consumed by the pregnant women. It also contributed significantly to the exposure to other PFASs (Tables 4 and 6). The upper limits of PFOA of 25% and 50% probability of exposure for pregnant women were 1671 ng/person/day and 2634 ng/person/day, respectively (Fig. 2), indicating that these women had at least 75-percent probability of being exposed to PFOA at an amount of 1.7 μg/person/day and 50-percent likelihood of being exposed to ≥2.5 μg/person/day or approximately 40 ng/kg b.w./day.

Levels of PFOA in the serum of women in Taiwan have been similar from 2001 to present, but those of PFOS decreased gradually. Wang et al. reported median concentrations of 12.7 ng/mL for PFOS and 2.39 ng/mL for PFOA in the serum of pregnant women collected in 2001 [65]. The serum GM of PFOS and PFOA in the women aged 20–30 in 2006–2008 were 8.21 ng/mL and 2.52 ng/mL, respectively [66]. In the serum of Taiwan females collected in 2011, the PFOS levels further decreased (median 6.01 ng/mL) but the PFOA levels remained unchanged (median 2.48 ng/mL) [67]. The gradual drop of PFOS in serum would indicate reduced exposure of Taiwan women to PFOS in the past years. Although the PFOS concentrations in the serum collected in 2011 were still higher than those of PFOA, this may result from previous long-term exposure and the long half-life of PFOS (5.4 years) in humans [16]. Given the overriding PFOA intake and the overall PFAS exposure found in this study, more studies are needed to develop dietary

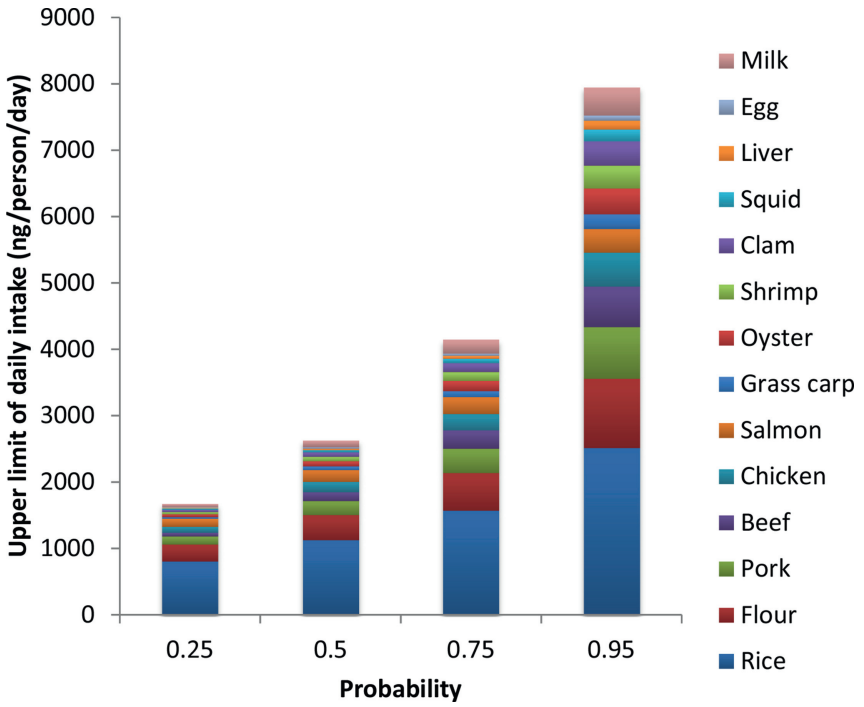

Fig. 2 – The simulated daily perfluorooctanoic acid intake against the accumulative probabilities among pregnant women in Taiwan.

guidelines to pregnant women to reduce risks of vertical transmission of these compounds and their potential adverse development effects [20,57,68].

4. Conclusion

This study measured five PFCAs and two PFSAs in fourteen of the most often consumed foods in Taiwan using UPLC-MS/MS, and found PFHxA, PFOA, PFDA, PFUnDA, and PFDoDA to be ubiquitous in most of the foods. These levels were much higher than those of most previous reports, especially in the long-chain PFCAs in foods of animal origin. This study observed considerable PFAS concentrations in the matrixes of rice and pork liver, which are seldom studied in western countries, but rice is a major staple in Asia and pork liver is a specialty food commonly consumed by pregnant and postnatal women in Taiwan. This is the first daily intake estimation of these PFASs in foods including staple for East and Southeast Asia, and the findings differ from those reports from western countries with varied ingestion amounts and profiles of PFASs in foods.

Conflicts of interest statement

The authors declare no conflicts of interest.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jfda.2017.12.011.

REFERENCES

[1] Prevedouros K, Cousins IT, Buck RC, Korzeniowski SH. Sources, fate and transport of perfluorocarboxylates. Environ Sci Technol 2006;40:32–44.
[2] Richardson SD. Environmental mass spectrometry: emerging contaminants and current issues. Anal Chem 2008;80:4373–402.
[3] Paul AG, Jones KC, Sweetman AJ. A first global production, emission, and environmental inventory for perfluorooctane sulfonate. Environ Sci Technol 2009;43:386–92.
[4] Conder JM, Hoke RA, De Wolf W, Russell MH, Buck RC. Are PFCAs bioaccumulative? A critical review and comparison with regulatory criteria and persistent lipophilic compounds. Environ Sci Technol 2008;42:995–1003.
[5] Kannan K, Choi JW, Iseki N, Senthilkumar K, Kim DH, Masunaga S, et al. Concentrations of perfluorinated acids in livers of birds from Japan and Korea. Chemosphere 2002;49:225–31.
[6] Kannan K, Newsted J, Halbrook RS, Giesy JP. Perfluorooctanesulfonate and related fluorinated hydrocarbons in mink and river otters from the United States. Environ Sci Technol 2002;36:2566–71.
[7] Shi YL, Pan YY, Yang RQ, Wang YW, Cai YQ. Occurrence of perfluorinated compounds in fish from Qinghai-Tibetan Plateau. Environ Int 2010;36:46–50.
[8] Tomy GT. Fluorinated organic compounds in an eastern Arctic marine food web. Environ Sci Technol 2004;38:6475–81.

[9] Fang S, Chen X, Zhao S, Zhang Y, Jiang W, Yang L, et al. Trophic magnification and isomer fractionation of perfluoroalkyl substances in the food web of Taihu Lake, China. Environ Sci Technol 2014;48:2173–82.
[10] Schuetze A, Heberer T, Effkemann S, Juergensen S. Occurrence and assessment of perfluorinated chemicals in wild fish from Northern Germany. Chemosphere 2010;78:647–52.
[11] Giesy JP. Global distribution of perfluorooctane sulfonate in wildlife. Environ Sci Technol 2001;35:1339–42.
[12] Abbott BD. Review of the expression of peroxisome proliferator-activated receptors alpha (PPARα), beta (PPARβ), and gamma (PPARγ) in rodent and human development. Reprod Toxicol 2009;27:246–57.
[13] Butenhoff JL, Chang SC, Ehresman DJ, York RG. Evaluation of potential reproductive and developmental toxicity of potassium perfluorohexanesulfonate in Sprague Dawley rats. Reprod Toxicol 2009;27:331–41.
[14] Kudo N, Kawashima Y. Toxicity and toxicokinetics of perfluorooctanoic acid in humans and animals. J Toxicol Sci 2003;28:49–57.
[15] Peden-Adams MM, Stuckey JE, Gaworecki KM, Berger-Ritchie J, Bryant K, Jodice PG, et al. Developmental toxicity in white leghorn chickens following in ovo exposure to perfluorooctane sulfonate (PFOS). Reprod Toxicol 2009;27:307–18.
[16] Lau C, Anitole K, Hodes C, Lai D, Pfahles-Hutchens A, Seed J. Perfluoroalkyl acids: a review of monitoring and toxicological findings. Toxicol Sci 2007;99:366–94.
[17] Steenland K, Tinker S, Frisbee S, Ducatman A, Vaccarino V. Association of perfluorooctanoic acid and perfluorooctane sulfonate with serum lipids among adults living near a chemical plant. Am J Epidemiol 2009;170:1268–78.
[18] Fei C, McLaughlin JK, Lipworth L, Olsen J. Maternal levels of perfluorinated chemicals and subfecundity. Hum Reprod 2009;24:1200–5.
[19] Joensen UN, Bossi R, Leffers H, Jensen AA, Skakkebæk NE, Jørgensen N. Do perfluoroalkyl compounds impair human semen quality? Environ Health Perspect 2009;117:923–7.
[20] Chen MH, Ha EH, Wen TW, Su YN, Lien GW, Chen CY, et al. Perfluorinated compounds in umbilical cord blood and adverse birth outcomes. PLoS One 2012;7:e2474.
[21] Fromme H, Schlummer M, Moller A, Gruber L, Wolz G, Ungewiss J, et al. Exposure of an adult population to perfluorinated substances using duplicate diet portions and biomonitoring data. Environ Sci Technol 2007;41:7928–33.
[22] Halldorsson TI, Fei CY, Olsen J, Lipworth L, McLaughlin JK, Olsen SF. Dietary predictors of perfluorinated chemicals: a study from the Danish National Birth Cohort. Environ Sci Technol 2008;42:8971–7.
[23] Trudel D, Horowitz L, Wormuth M, Scheringer M, Cousins IT, Hungerbuhler K. Estimating consumer exposure to PFOS and PFOA. Risk Anal 2008;28:251–69.
[24] Yamaguchi M, Arisawa K, Uemura H, Katsuura-Kamano S, Takami H, Sawachika F, et al. Consumption of seafood, serum liver enzymes, and blood levels of PFOS and PFOA in the Japanese population. J Occup Health 2013;55:184–94.
[25] Xu J, Guo CS, Zhang Y, Meng W. Bioaccumulation and trophic transfer of perfluorinated compounds in a eutrophic freshwater food web. Environ Pollut 2014;184:254–61.
[26] Johansson JH, Berger U, Vestergren R, Cousins IT, Bignert A, Glynn A, et al. Temporal trends (1999-2010) of perfluoroalkyl acids in commonly consumed food items. Environ Pollut 2014;188:102–8.
[27] Guerranti C, Perra G, Corsolini S, Focardi SE. Pilot study on levels of perfluorooctane sulfonic acid (PFOS) and perfluorooctanoic acid (PFOA) in selected foodstuffs and human milk from Italy. Food Chem 2013;140:197–203.
[28] Gulkowska A, Jiang QT, So MK, Taniyasu S, Lam PKS, Yamashita N. Persistent perfluorinated acids in seafood collected from two cities of China. Environ Sci Technol 2006;40:3736–41.
[29] Haug LS, Salihovic S, Jogsten IE, Thomsen C, van Bavel B, Lindstrom G, et al. Levels in food and beverages and daily intake of perfluorinated compounds in Norway. Chemosphere 2010;80:1137–43.
[30] Eriksson U, Karrman A, Rotander A, Mikkelsen B, Dam M. Perfluoroalkyl substances (PFASs) in food and water from Faroe Islands. Environ Sci Pollut Res 2013;20:7940–8.
[31] Vestergren R, Berger U, Glynn A, Cousins IT. Dietary exposure to perfluoroalkyl acids for the Swedish population in 1999, 2005 and 2010. Environ Int 2012;49:120–7.
[32] Kim HY, Kim SK, Kang DM, Hwang YS, Oh JE. The relationships between sixteen perfluorinated compound concentrations in blood serum and food, and other parameters, in the general population of South Korea with proportionate stratified sampling method. Sci Total Environ 2014;470:1390–400.
[33] Allievi F, Vinnari M, Luukkanen J. Meat consumption and production - analysis of efficiency, sufficiency and consistency of global trends. J Clean Prod 2015;92:142–51.
[34] Council of Agriculture. Executive Yuan, Taiwan. Annual report for food supply and demand. Taipei. 2009. Available at: http://agrstat.coa.gov.tw/sdweb/public/book/Book.aspx. [Accessed 10 October 2016].
[35] Kennedy GL, Butenhoff JL, Olsen GW, O'Connor JC, Seacat AM, Perkins RG, et al. The toxicology of perfluorooctanoate. Crit Rev Toxicol 2004;34:351–84.
[36] Chang YC, Chen WL, Bai FY, Chen PC, Wang GS, Chen CY. Determination of perfluorinated chemicals in food and drinking water using high-flow solid-phase extraction and ultra-high performance liquid chromatography/tandem mass spectrometry. Anal Bioanal Chem 2012;402:1315–25.
[37] Ericson I, Marti-Cid R, Nadal M, Van Bavel B, Lindstrom G, Domingo JL. Human exposure to perfluorinated chemicals through the diet: intake of perfluorinated compounds in foods from the Catalan (Spain) Market. J Agric Food Chem 2008;56:1787–94.
[38] Tittlemier SA, Pepper K, Seymour C, Moisey J, Bronson R, Cao XL, et al. Dietary exposure of Canadians to perfluorinated carboxylates and perfluorooctane sulfonate via consumption of meat, fish, fast foods, and food items prepared in their packaging. J Agric Food Chem 2007;55:3203–10.
[39] Jogsten IE, Perello G, Llebaria X, Bigas E, Marti-Cid R, Karrman A, et al. Exposure to perfluorinated compounds in Catalonia, Spain, through consumption of various raw and cooked foodstuffs, including packaged food. Food Chem Toxicol 2009;47:1577–83.
[40] Reiner JL, O'Connell SG, Moors AJ, Kucklick JR, Becker PR, Keller JM. Spatial and temporal trends of perfluorinated compounds in Beluga Whales *(Delphinapterus leucas)* from Alaska. Environ Sci Technol 2011;45:8129–36.
[41] Quinete N, Wu Q, Zhang T, Yun SH, Moreira I, Kannan K. Specific profiles of perfluorinated compounds in surface and drinking waters and accumulation in mussels, fish, and dolphins from southeastern Brazil. Chemosphere 2009;77:863–9.
[42] Ostertag SK, Tague BA, Humphries MM, Tittlemier SA, Chan HM. Estimated dietary exposure to fluorinated compounds from traditional foods among Inuit in Nunavut, Canada. Chemosphere 2009;75:1165–72.
[43] D'Hollander W, de Voogt P, De Coen W, Bervoets L. Perfluorinated substances in human food and other sources of human exposure. In: Whitacre DM, de Voogt P, editors.

Reviews of environmental contamination and toxicology, vol. 208. New York: Springer; 2010. p. 179–215.
[44] U.K, Food standards agency, chemical safety division. Fluorinated chemicals: UK dietary intakes. Food survey information sheet 11/06, London. 2006. Available at: ftp://71.4.232.119.ptr.us.xo.net/NFPA_Archive/Food_Standards_Agency_(GB)/fsis1106.pdf. [Accessed 10 October 2016].
[45] Renzi M, Guerranti C, Giovani A, Perra G, Focardi SE. Perfluorinated compounds: levels, trophic web enrichments and human dietary intakes in transitional water ecosystems. Mar Pollut Bull 2013;76:146–57.
[46] Bach CC, Bech BH, Brix N, Nohr EA, Bonde JPE, Henriksen TB. Perfluoroalkyl and polyfluoroalkyl substances and human fetal growth: a systematic review. Crit Rev Toxicol 2015;45:53–67.
[47] Lin YC, Lai WWP, Tung HH, Lin AYC. Occurrence of pharmaceuticals, hormones, and perfluorinated compounds in groundwater in Taiwan. Environ Monit Assess 2015;187:256. https://doi.org/10.1007/s10661-015-4497-3.
[48] Butt CM, Berger U, Bossi R, Tomy GT. Levels and trends of poly- and perfluorinated compounds in the arctic environment. Sci Total Environ 2010;408:2936–65.
[49] Benskin JP, Yeung LWY, Yamashita N, Taniyasu S, Lam PKS, Martin JW. Perfluorinated acid isomer profiling in water and quantitative assessment of manufacturing source. Environ Sci Technol 2010;44:9049–54.
[50] Blaine AC, Rich CD, Hundal LS, Lau C, Mills MA, Harris KM, et al. Uptake of perfluoroalkyl acids into edible crops via land applied biosolids: field and greenhouse studies. Environ Sci Technol 2013;47:14062–9.
[51] Vestergren R, Orata F, Berger U, Cousins IT. Bioaccumulation of perfluoroalkyl acids in dairy cows in a naturally contaminated environment. Environ Sci Pollut Res 2013;20:7959–69.
[52] D'Hollander W, Herzke D, Huber S, Hajslova J, Pulkrabova J, Brambilla G, et al. Occurrence of perfluorinated alkylated substances in cereals, salt, sweets and fruit items collected in four European countries. Chemosphere 2015;129:179–85.
[53] Pérez F, Llorca M, Köck-Schulmeyer M, Škrbić B, Oliveira LS, da Boit Martinello K, et al. Assessment of perfluoroalkyl substances in food items at global scale. Environ Res 2014;135:181–9.
[54] Tseng CL, Liu LL, Chen CM, Ding WH. Analysis of perfluorooctanesulfonate and related fluorochemicals in water and biological tissue samples by liquid chromatography-ion trap mass spectrometry. J Chromatogr A 2006;1105:119–26.
[55] Lupton SJ, Huwe JK, Smith DJ, Dearfield KL, Johnston JJ. Distribution and excretion of perfluorooctane sulfonate (PFOS) in beef cattle (Bos taurus). J Agric Food Chem 2014;62:1167–73.
[56] Tao L, Kannan K, Wong CM, Arcaro KF, Butenhoff JL. Perfluorinated compounds in human milk from Massachusetts, USA. Environ Sci Technol 2008;42:3096–101.
[57] Kim SK, Lee KT, Kang CS, Tao L, Kannan K, Kim KR, et al. Distribution of perfluorochemicals between sera and milk from the same mothers and implications for prenatal and postnatal exposures. Environ Pollut 2011;159:169–74.
[58] von Ehrenstein OS, Fenton SE, Kato K, Kuklenyik Z, Calafat AM, Hines EP. Polyfluoroalkyl chemicals in the serum and milk of breastfeeding women. Reprod Toxicol 2009;27:239–45.
[59] Yamada A, Bemrah N, Veyrand B, Pollono C, Merlo M, Desvignes V, et al. Dietary exposure to perfluoroalkyl acids of specific French adult sub-populations: high seafood consumers, high freshwater fish consumers and pregnant women. Sci Total Environ 2014;491:170–5.
[60] Ostertag SK, Chan HM, Moisey J, Dabeka R, Tittlemier SA. Historic dietary exposure to perfluorooctane sulfonate, perfluorinated carboxylates, and fluorotelomer unsaturated carboxylates from the consumption of store-bought and restaurant foods for the Canadian population. J Agric Food Chem 2009;57:8534–44.
[61] Zhang T, Sun HW, Wu Q, Zhang XZ, Yun SH, Kannan K. Perfluorochemicals in meat, eggs and indoor dust in China: assessment of sources and pathways of human exposure to perfluorochemicals. Environ Sci Technol 2010;44:3572–9.
[62] Heo JJ, Lee JW, Kim SK, Oh JE. Foodstuff analyses show that seafood and water are major perfluoroalkyl acids (PFAAs) sources to humans in Korea. J Hazard Mater 2014;279:402–9.
[63] Haug LS, Thomsen C, Brantsaeter AL, Kvalem HE, Haugen M, Becher G, et al. Diet and particularly seafood are major sources of perfluorinated compounds in humans. Environ Int 2010;36:772–8.
[64] European Food Safety Authority. Perfluorooctane sulfonate (PFOS), perfluorooctanoic acid (PFOA) and their salts scientific opinion of the panel on contaminants in the food chain. ERA J 2008;653:1–131. https://doi.org/10.2903/j.efsa.2008.653.
[65] Wang Y, Rogan WJ, Chen PC, Lien GW, Chen HY, Tseng YC, et al. Association between maternal serum perfluoroalkyl substances during pregnancy and maternal and cord thyroid hormones: Taiwan Maternal and Infant Cohort Study. Environ Health Perspect 2014;122:529–34.
[66] Lin CY, Lin LY, Wen TW, Lien GW, Chien KL, Hsu SHJ, et al. Association between levels of serum perfluorooctane sulfate and carotid artery intima-media thickness in adolescents and young adults. Int J Cardiol 2013;168:3309–16.
[67] Hsu JY, Hsu JF, Ho HH, Chiang CF, Liao PC. Background levels of persistent organic *pollutants* in humans from Taiwan: perfluorooctane sulfonate and perfluorooctanoic acid. Chemosphere 2013;93:532–7.
[68] Lee YJ, Kim MK, Bae J, Yang JH. Concentrations of perfluoroalkyl compounds in maternal and umbilical cord sera and birth outcomes in Korea. Chemosphere 2013;90:1603–9.