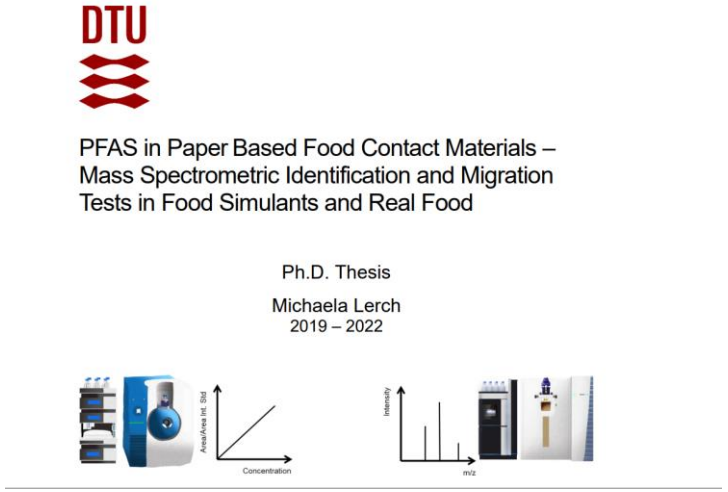

DTU

EFSA FCM network – Parma, November 23, 2022

Danish project on per- and polyfluorinated alkyl substances in paper and board for food contact – migration study in real food and food simulants

Michaela Lerch and Gitte Alsing Pedersen,
DTU National Food Institute

Danish project on per- and polyfluorinated alkyl substances in paper and board for food contact – migration study in real food and food simulants



PhD thesis by Michaela Lerch (2019-2022)

DTU national Food Institute

Title:

PFAS in Paper Based Food Contact Materials – Mass Spectrometric Identification and Migration Tests in Food Simulants and Real Food.

Aim of the PhD study is to answer the following questions:

- What do we know about migration of PFAS from paper based FCM's?

- Is the use of PFAS treated paper based FCM's safe?

- Are we missing something? - Identification of PFAS in food simulants (these data are under publication and will not be part of this presentation)

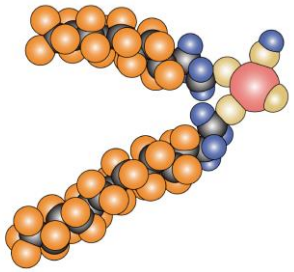
Four Hypothesis were studied to answer the questions

Per- and polyfluorinated alkylsubstances (PFAS)

- **Per- and polyfluorinated alkylsubstances (PFAS):** A **wide group** of anthropogenic chemicals (over 4000 compounds listed in libraries from the US EPA)

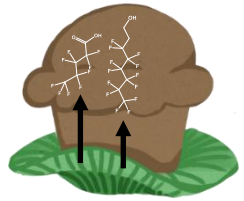
- Food is a major source of human exposure to PFAS due to contamination of the food

- PFAS are
  - used in paper and board FCM as surfactant (repellent to water and fat)
  - added as coating or added during the paper production process
  - a potential source of PFAS in packaged food



However only limited knowlegde exists on the migration of PFAS into real food and its potential contribution to human PFAS exposure.

~ What do we know about migration of PFAS from paper based FCMs? ~
Migration studies



Hypothesis I:

The use of **food simulants** to study PFAS migration from paper based FCMs can **lead to an over- or underestimation** of PFAS migration into real food.

Literature review of migration studies

Manuscript I

"Food simulants and real food - What do we know about the migration of PFAS from paper based FCMs?

Knowledge gaps

→ **Little knowledge regarding migration into real food**

→ **No combined analysis of all critical PFAS classes**

→ Only cartridge based SPE applied for sample preparation

→ Only targeted quantitation of small number of well studied PFAS

Starting point experimental study (Manuscript II)

Experimental migration study:

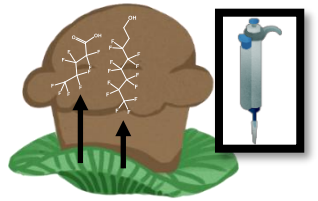
→ Migration of PFAS into real food using realistic contact conditions

→ Combined analysis of four PFAS classes

→ Investigate alternative sample preparation methods

→ **Comparison of migration into real food and food simulants**

~ What do we know about migration of PFAS from paper based FCMs? ~
Migration studies



FCM samples

→ Sampled on the Scandinavian Market (2017 to 2019)

→ Known to contain PFAS (part of previous studies)

→ Samples for high temperature conditions:

→ Microwavable disposable paper plates (n=3)

→ Muffin cups (n=3)

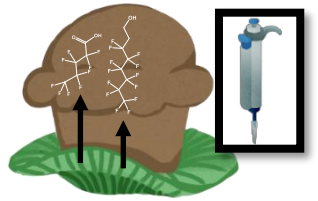
Food/food simulants & Contact Conditions	Test Food	Food Simulants
Selection	Muffins (dough with 15% fat) Oatmeal Porridge (8% fat) Tomato Soup (3% fat)	50% Ethanol 50% Ethanol 20% Ethanol
Migration conditions	High-temperature application: Baking Microwave	Total immersion of FCM sample

→ **Comparison of migration into real food and food simulants**

→ **Using realistic high temperature conditions with the food**

~ What do we know about migration of PFAS from paper based FCMs? ~

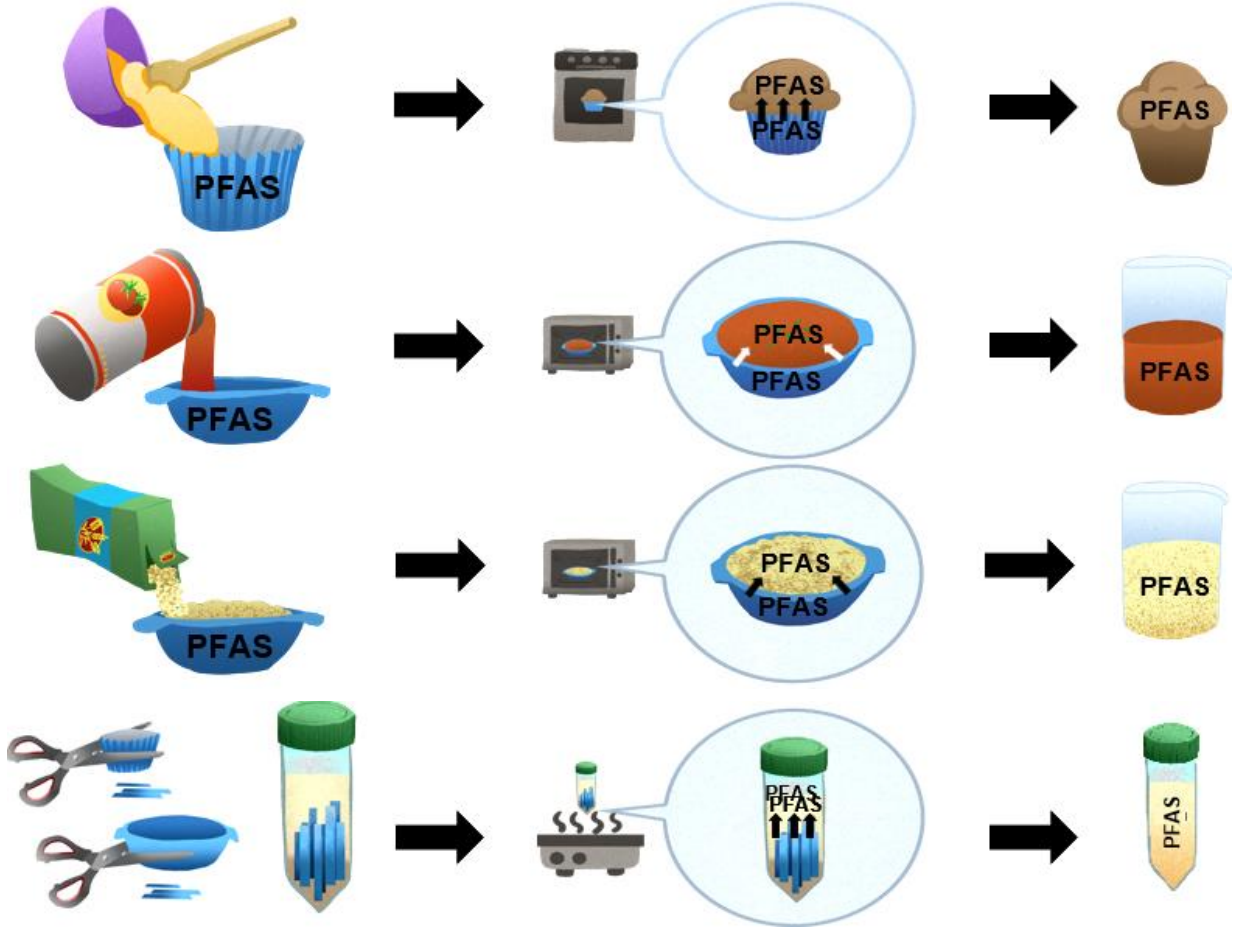
Test conditions



Migration tests

- **Food**
  - **Baking**
    13 min at 200° C
  - **Microwaving**
    1 min at 800 W
- **Food Simulants**
  Incubation in water bath: 2 h for 70 ° C (EC 10/2011)

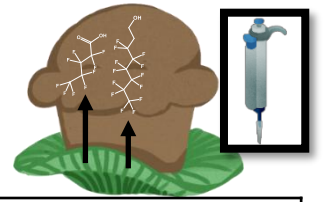
Migration of PFAS into real food using **realistic contact conditions:**

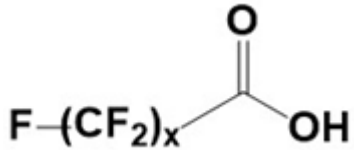
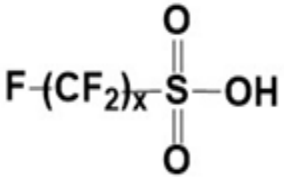
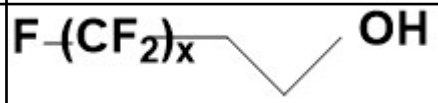
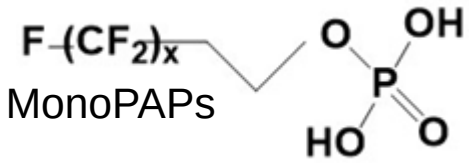
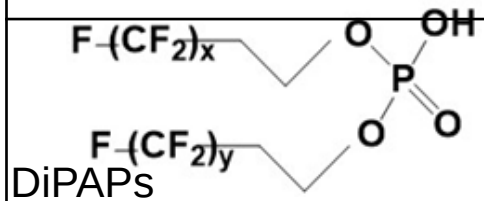


~ What do we know about migration of PFAS from paper based FCMs? ~

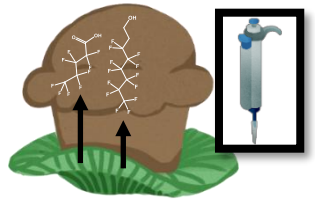
Migrant → PFAS

Targeted analysis of 23 PFAS



		Analyzed Compounds	Characteristic
Perfluoroalkyl carboxylic acids (**PFCAs**) (n=11)		PFBA (C4), PFPeA (C5), PFHxA (C6), PFOA (C8), PFNA (C9), PFDeA (C10), PFUnA (C11), PFDoDA (C12), PFTrDA (C13), PFTeDA (C14), PFHxdA(C16), PFODA (C18)	Strong acids (pKa ~ 1) → Ionic PFAS → log k_d
Perfluorinated sulfonic acids (**PFSAs**) (n=4)		PFBS (C4), PFHxS (C6), PFOS (C8), PFDeS (C10)	Strong acids (pKa ~ 1) → Ionic PFAS → log k_d
Fluorotelomer alcohols (**FTOHs**) (n=4)		4:2 FTOH, 6:2 FTOH, 8:2 FTOH, 10:2 FTOH	→ Neutral PFAS → Log K_{ow}
Polyfluoro alkyl phosphate esters (**PAPs**) (n=4)	 MonoPAPs	6:2 MonoPAP, 8:2 MonoPAP	Ionic PFAS → log k_d
	 DiPAPs	6:2 DiPAP, 8:2 DiPAP	

~ What do we know about migration of PFAS from paper based FCMs? ~



Migration studies

PFAS analysis → **Sample Preparation** → **Food** / **Food Simulants**

Food:

Food Simulants: → No further sample preparation was needed

Goal for the experimental study:

→ Combined analysis of 4 critical PFAS classes
→ Investigate alternative sample preparation methods

Cartridge based SPE method (DTU)

Solvent Extraction → Saponificat-ion → SPE (WAX) → Concentrate & Filter

Required time: ~ 3 days

Combined detection of 3 PFAS groups:
PFCAs, PFSAs, PAPs

QuEChERS based dSPE (Zielinski & Riemenschneider, 2020)

Solvent Extraction → dSPE → Concentrate & Filter

Required time: ~1 days

Combined detection of all 4 PFAS groups:
PFCAs, PFSAs, PAPs and FTOHs

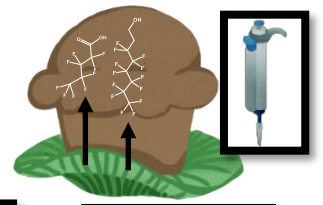
Detection method: LC-MS/MS

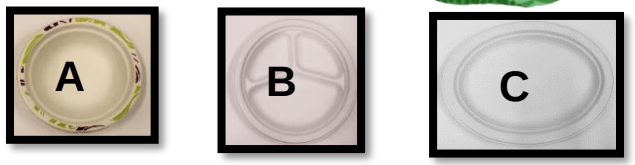
~ What do we know about migration of PFAS from paper based FCMs? ~

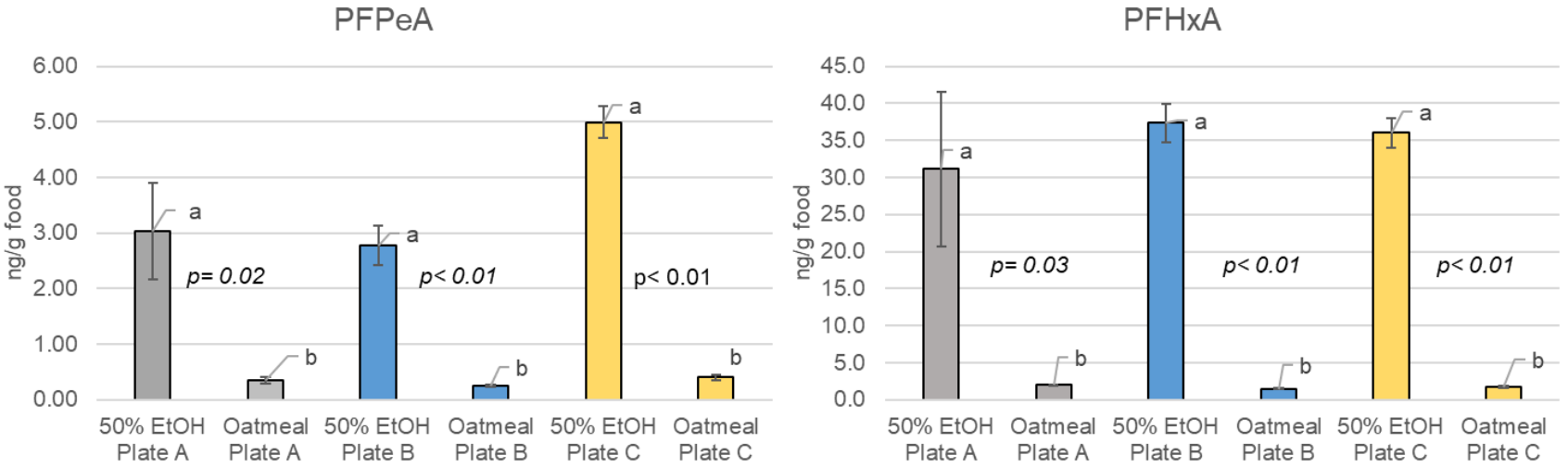
Results migration into oatmeal porridge

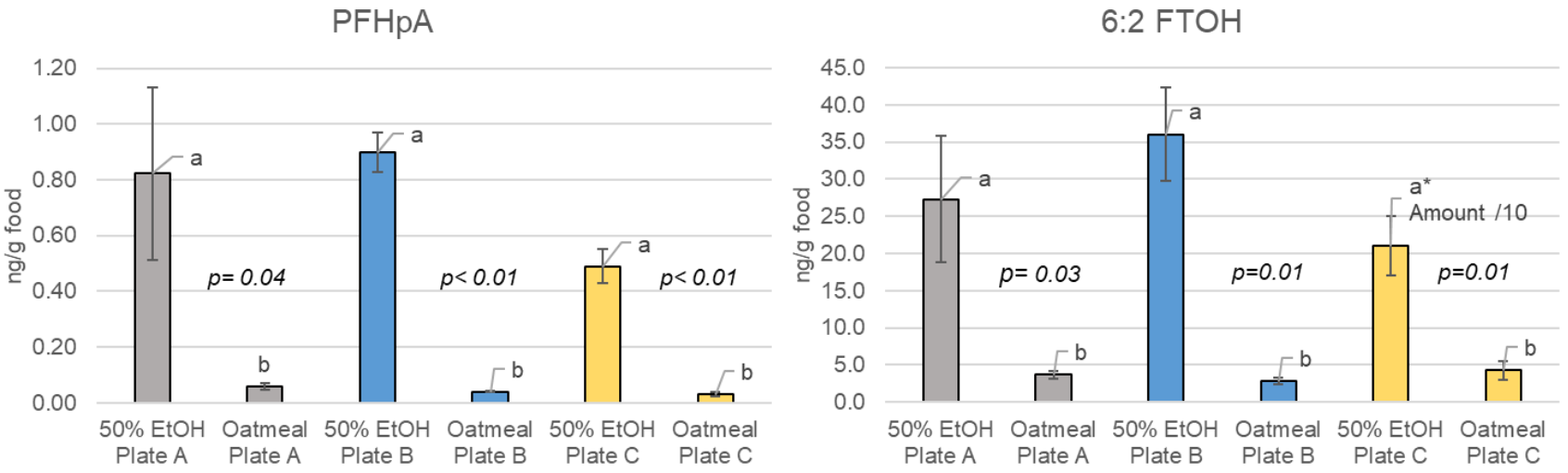
Results

Food vs Food simulants









- Migration into 50% ethanol significantly higher
- Only detected in 50% ethanol: PFOA, PFNA, PFDeA
- However, 6:2 diPAP only detected (<LOQ) in OMP

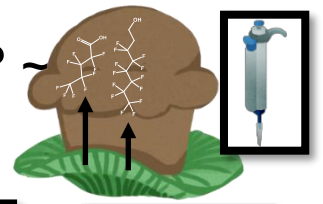
→ Presence of emulsifiers in OMP could increase migration (lowered surface tension)

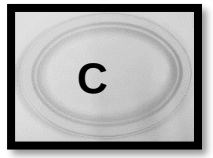
~ What do we know about migration of PFAS from paper based FCMs? ~

Results migration into tomato soup

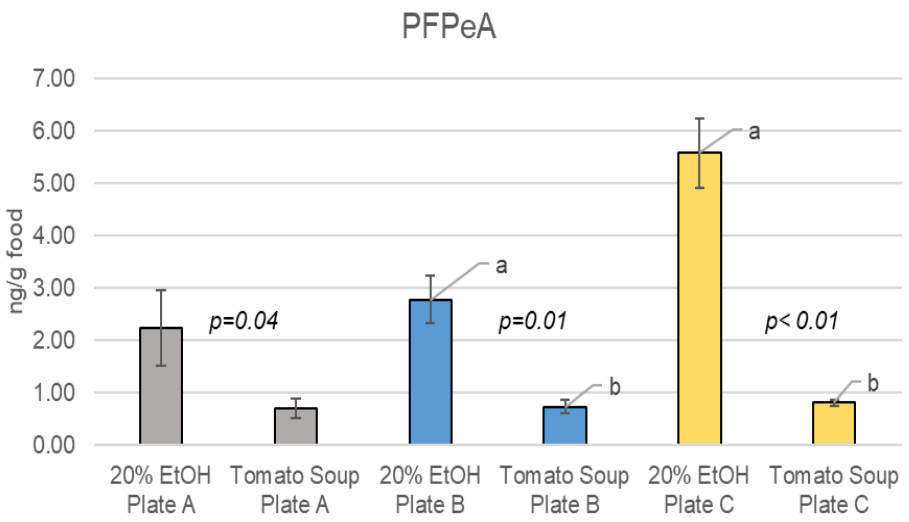
Results

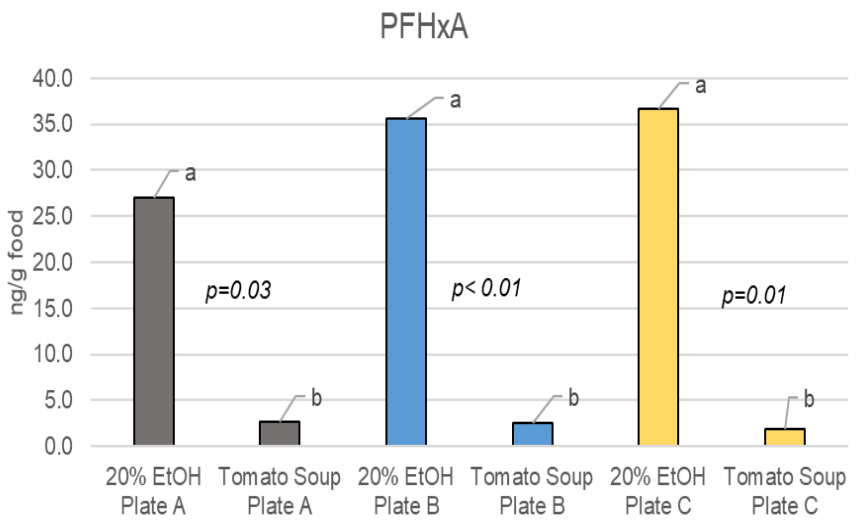
Food vs Food simulants

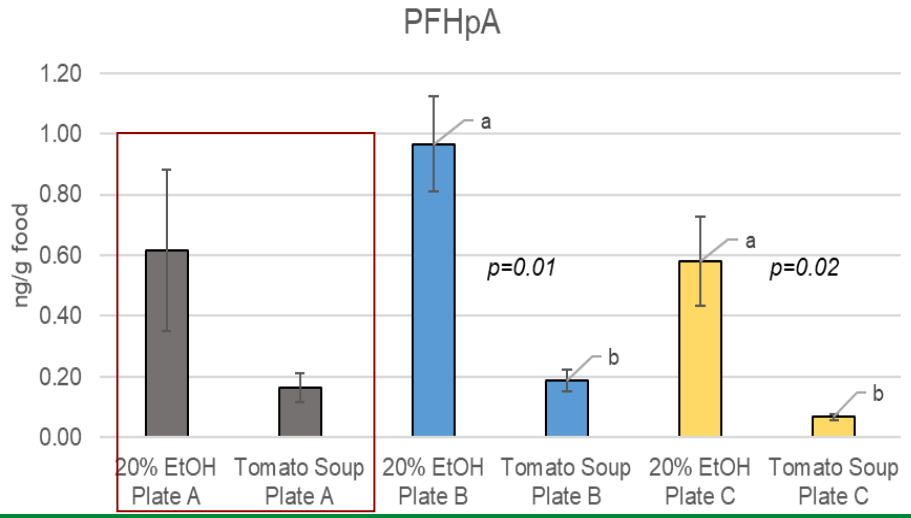


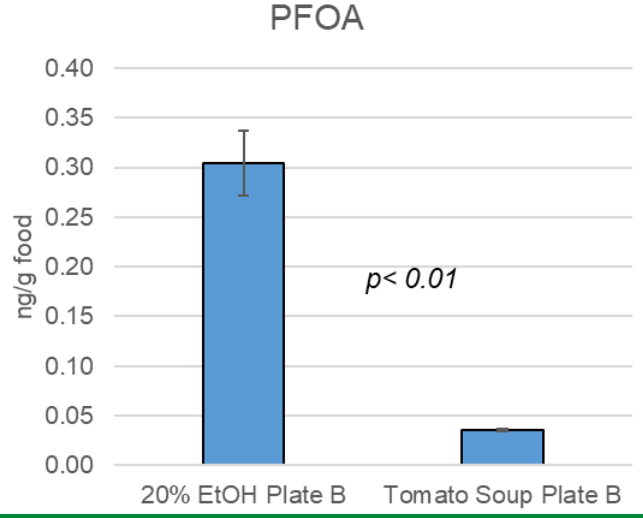


20% EtOH









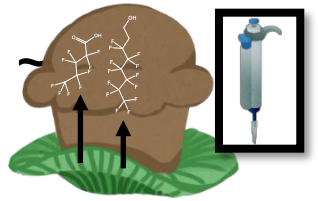
- Migration of PFCAs into 20% ethanol significantly higher (PFHpA not significant in plate A)

- 6:2 FTOH does not follow this trend (log K_{OW}= 4.54)

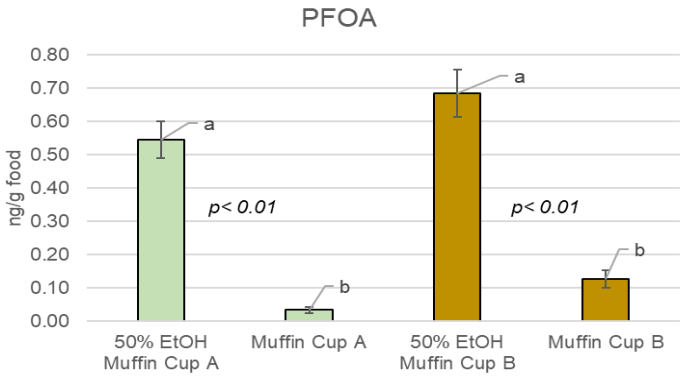
→ Not detected in 20% EtOH but in tomato soup (11.3 ng/g for plate C)

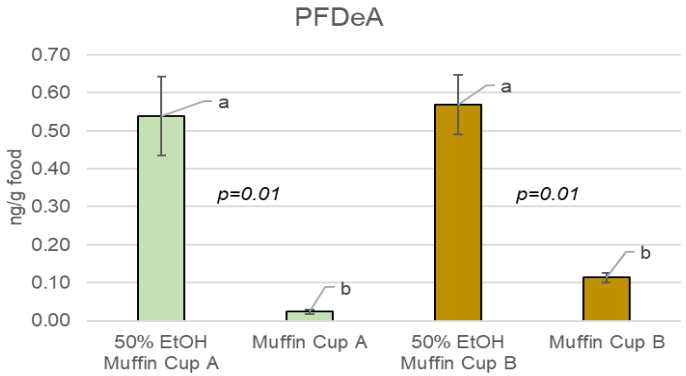
~ What do we know about migration of PFAS from paper based FCMs? ~

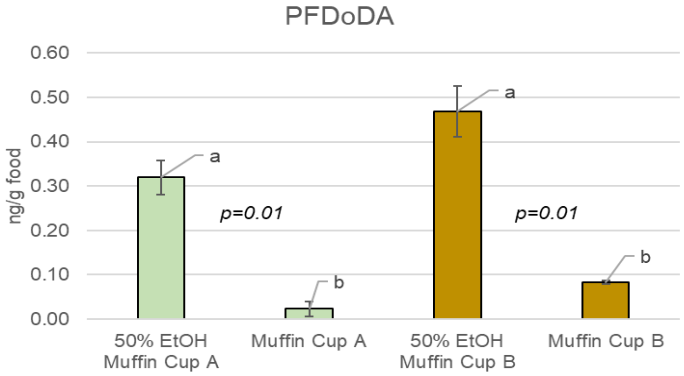
Results migration into muffins

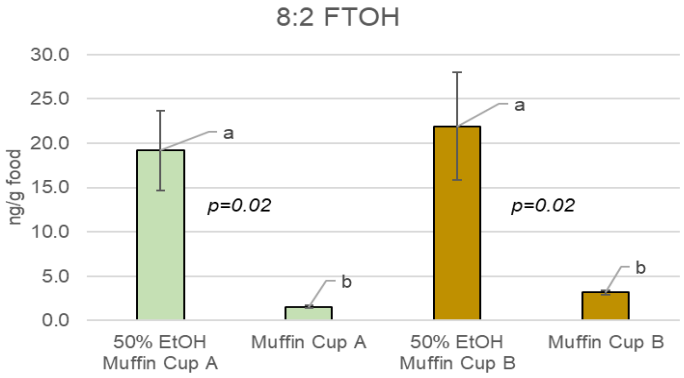


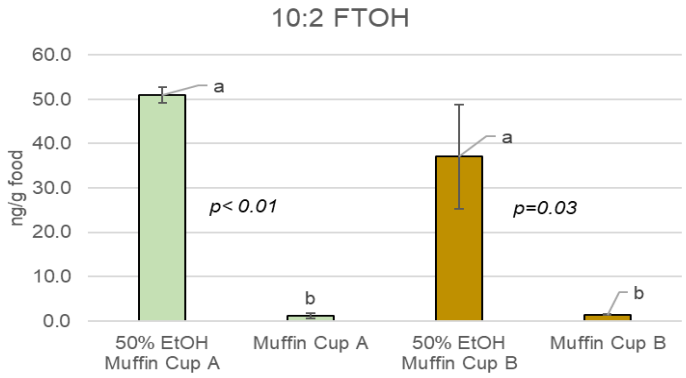
50% EtOH











- Migration of PFCAs and FTOHs into 50% ethanol significantly higher than into food

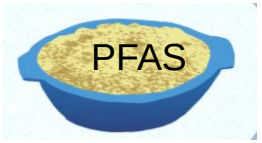
- Only detected in 50% ethanol:

  PFPeA, PFHxA, PFHpA, PFTrDA, PFTeDA

  The short chain PFCA's are potentially lost during baking (200ºC)

Migration of PFAS substances into the given food (muffins, oatmeal porridge and tomato soup):

- PFCAs, FTOHs and PAPs were detected in real food
- In total 12 PFAS were detected in the given foods
- PFSAs were not detected in either food or food simulants
- FTOHs were detected (> LOQ) in all 3 kind of food: Muffins, oatmeal porridge and tomato soup.
- The results indicate that analysis of PFCAs and PFSAs alone is not sufficient to assess PFAS migration from FCM.



PFPeA
Perfluorpentanoic acid

PFHxA
Perfluorhexanoic acid

PFHpA
Perfluorheptanoic acid

PFOA
Perfluoroctanoic acid

PFNA
Perfluorononanoic acid

PFDeA

PFUnA

PFDoDA

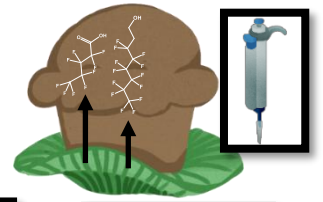
6:2 FTOH

8:2 FTOH

10:2 FTOH

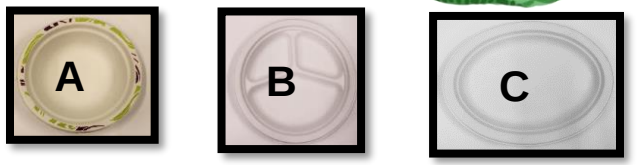
6:2 DiPAP

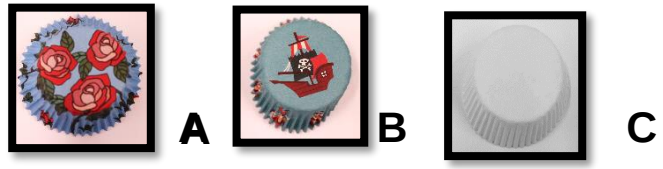
Migration studies



Results

Food vs Food simulants





Can real food be simulated with food simulants?

Possible application of 50% ethanol

- The application of 50% ethanol to mimic food with lipophilic properties (oatmeal porridge and muffins) showed an overestimation of migration for PFCAs and FTOHs.

Approach with caution application of 20% ethanol

- The application of 20% ethanol to mimic food with light-lipophilic properties (Tomato Soup) provide an overestimation of results for the migration of PFCAs but not for **FTOHs (underestimation of FTOHs into tomato soup with light-lipophilic character)**

50% EtOH

20% EtOH

- Hypothesis I was confirmed: The use of **food simulants** to study PFAS migration from paper-based FCMs can **lead to an over- or underestimation** of PFAS migration into real food.

~ Is the use of PFAS treated paper based FCMs safe? ~

Safety threshold (EFSA, 2020):

- Tolerable weekly intake (TWI) 4.4 ng/kg bw/week for PFOA,PFOS, PFHxS, & PFNA (PFAS4). Critical effect: Immunotoxiciy.
- Also protective for other potential critical endpoints (increase serum cholesterol, reduced birth weight, high serum levels of alanine aminotransferase (ALT) (indicating effects on liver cells) (EFSA, 2020)

Compound selection:

- The four PFASs contribute most to the levels observed in human serum (EFSA, 2020)
- Amongst the most commonly found PFAS in food (occurrence study did not consider migration from FCMs)

Current state of knowledge:

→ **Unclear how much PFAS migration from FCMs contributes to human dietary exposure:**

- → Migration studies investigating migration into real food are scarce and only consider max. 3 relevant PFAS subclasses (PFCAs, PFSAs and PAPs)
- → Typical migration studies of FCM do not assess dietary exposure or consumer risk

→ **Limitation of the toxicological reference value to 4 PFAS**

- → In the given study, 10 additional PFAS were found to migrate into real food

~ *Is the use of PFAS treated paper based FCMs safe?* ~

Hypothesis II:

Migration of PFAS from paper-based FCMs can **contribute** considerably to **consumers' dietary exposure** to potentially toxic chemicals and cause health risks.

Hypothesis III:

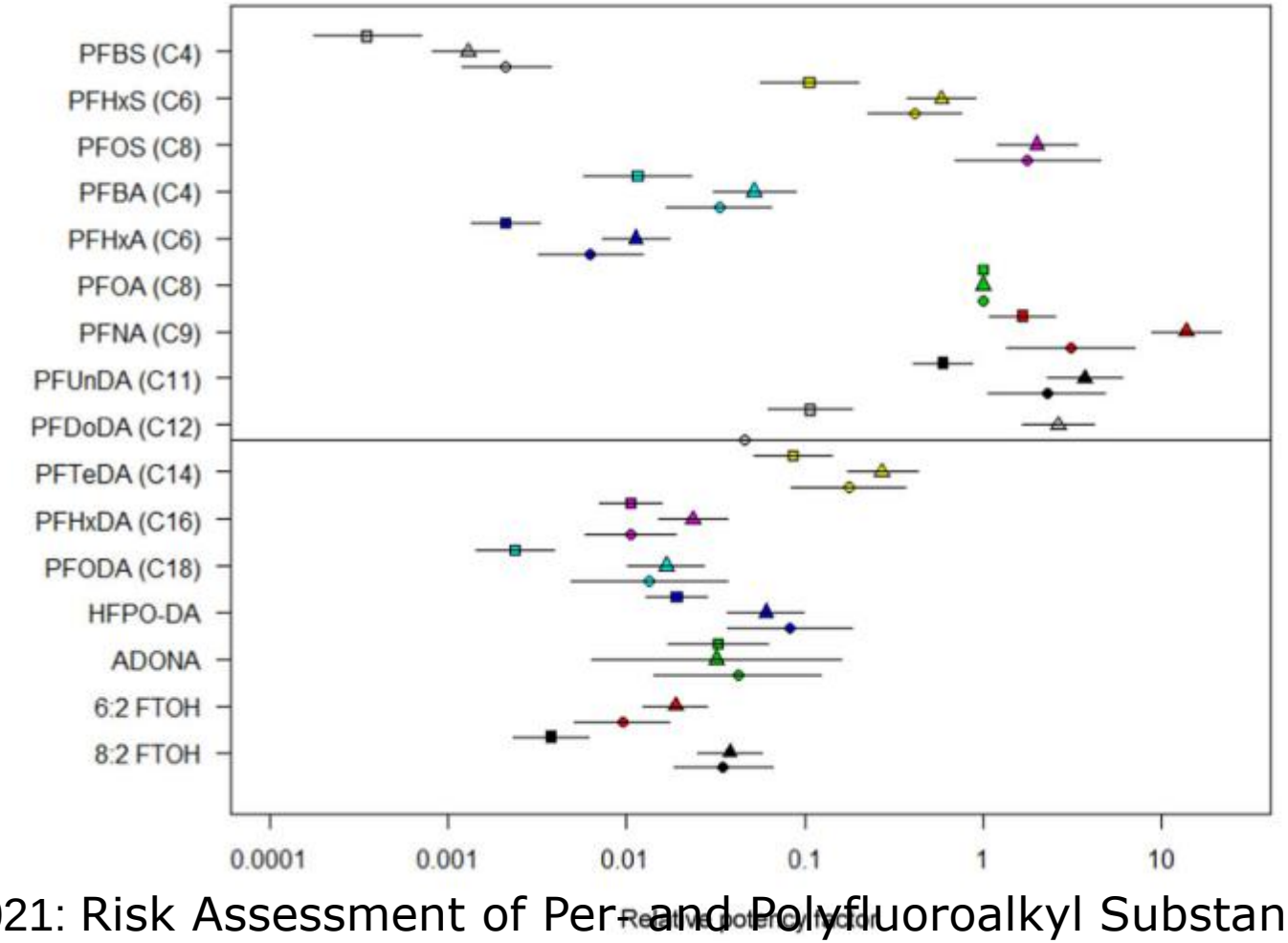
Risk assessment procedures that only consider exposure to **four targeted PFAS** may lead to an **underestimation of consumer risk**

- Estimate the possible contribution of migrated PFAS to dietary exposure:
  - → By use of experimentally determined PFAS migration (PAPs, PFCAs, PFSAs and FTOH) in oatmeal porridge, tomato soup, and muffins using **high-temperature applications**

- Estimate the dietary exposure and assess the possible consumer risk
  - → By applying and comparing different approaches for the dietary exposure calculation

Relative potency factor (RPF) approach (relative to PFOA)

The relative potencies of 16 per- and polyfluoroalkyl substances based on liver toxicity (liver is one of the main target organs of PFAS):



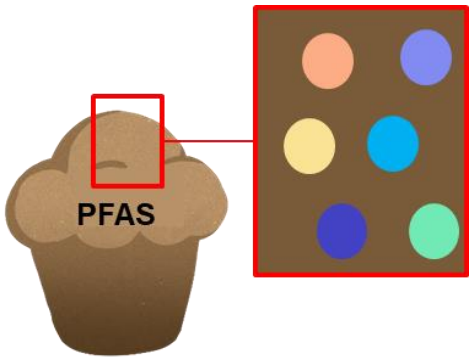
Perfluoroctanoic acid (PFOA)

Bil et al., 2021: Risk Assessment of Per- and Polyfluoroalkyl Substance Mixtures: A Relative Potency Factor Approach. Environmental Toxicology and Chemistry—Volume 40, Number 3—pp. 859–870.

Conversion of PFAS compounds into PFOA equivalents by the relative potency factor of PFAS

The relative potency factor for each of the detected 12 PFAS migrating into the food :

PFAS:	RPF:
PFOA	1
» PFPeA	0.05
» PFHxA	0.01
» PFHpA	0.01
» PFNA	10
» PFDeA	10
» PFUnA	4
» PFDoDA	3
» 6:2 DiPAP	0.02
» 6:2FTOH	0.02
» 8:2FTOH	0.04
» 10:2	0.04



~ *Is the use of PFAS treated paper based FCMs safe?* ~
For high-temperature applications

Dietary exposure assessment based on migration into food and the use of 3 different approaches

$$Dietary\ exposure = \Sigma \left(PFAS \left[\frac{ng}{g\ food} \right] \right) x \frac{weight\ of\ each\ serving [g]}{body\ weight\ [kg]}$$

Dietary exposure =	**Occurrence estimation x**		**Consumption estimation**
Total PFAS $\Sigma\ (PFAS)$	Sum of all detected PFAS concentrations in food		**Single consumption** → One portion per day Weight per serving e.g., one plate of tomato soup (TS)
PFAS4 $\Sigma\ (PFOA, PFOS, PFNA, PFHxS)$	Sum of PFOA and PFNA (no PFOS and PFHxS detected)	✖	weight TS: 208 g weight OMP: 164 g weight muffin: 43 g
Relative Potency Factor (RPF) - Approach $\Sigma\ (PFOA\ equivalent)$ Bil et al. (2021)	Each compound → define a RPF value based on hepatoxicity and is relative to the toxicity of PFOA C_{PFAS} x RPF = PFOA equivalent Sum of PFOA equivalents		**Body weight:** Children (3-10 years): 23.1 kg Adult (18-65 years): 70 kg

~ *Is the use of PFAS treated paper based FCMs safe?* ~

For high-temperature applications

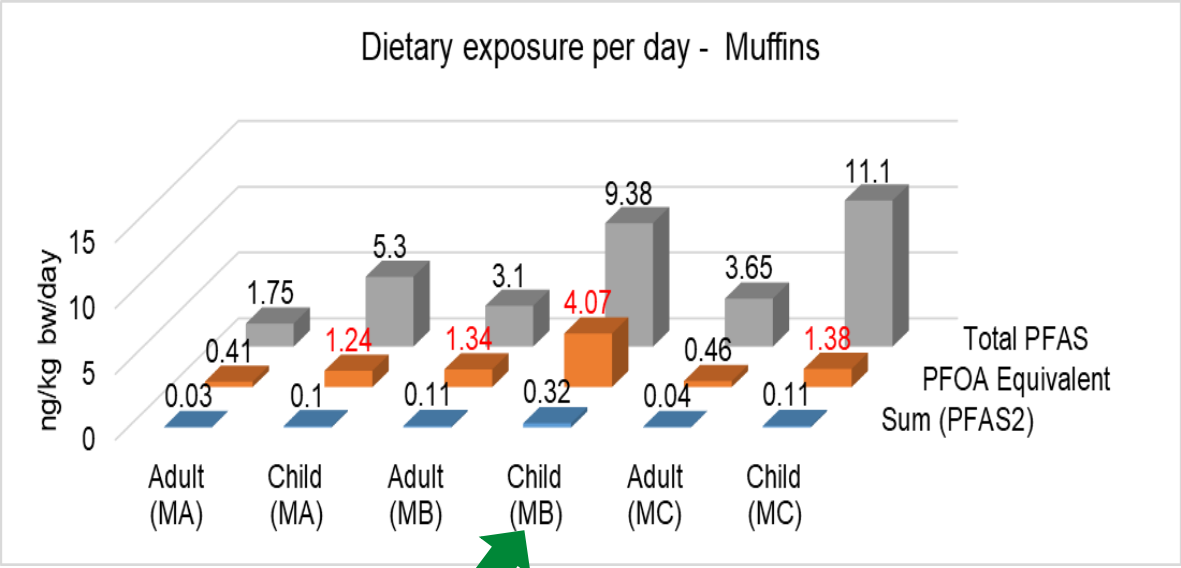
Migration (ng/g) into food and dietary exposure (ng/kg bw/day) by 3 different approaches **TWI = 0.63 ng/kg bw/day for PFAS 4**

			Paper Plate A		Paper Plate B		Paper Plate C		Muffin Cup A	Muffin Cup B	Muffin Cup C
			Oatmeal Porridge	Tomato Soup	Oatmeal Porridge	Tomato Soup	Oatmeal Porridge	Tomato Soup	Muffin	Muffin	Muffin
Total PFAS		Total Σ (PFAS) [ng/g food]	6.13	3.50	4.70	3.54	6.48	14.1	2.83	5.01	6.00
	Adult	Dietary exposure per serving [ng/kgbw/day]	14.3	10.4	11.0	10.5	15.1	41.9	1.75	3.10	3.65
	Child	Dietary exposure per serving [ng/kgbw/day]	43.4	31.5	33.3	31.8	45.9	127	5.30	9.38	11.1
Sum of PFOA/PFNA		Σ (PFOA/PFNA) [ng/g food]	0.03	0.00	0.03	0.04	0.00	0.05	0.06	0.17	0.06
	Adult	Dietary exposure per serving [ng/kgbw/day]	0.06	0.00	0.06	0.12	0.00	0.15	0.03	0.11	0.04
	Child	Dietary exposure per serving [ng/kgbw/day]	0.18	0.00	0.18	0.36	0.00	0.45	0.10	0.32	0.11
RPF Approach		Σ (PFOA equivalent) [ng/g food]	0.20	0.22	0.15	0.29	0.15	0.63	0.66	2.17	0.75
	Adult	Dietary exposure per serving [ng/kgbw/day]	0.46	0.66	0.35	0.87	0.36	1.87	0.41	1.34	0.46
	Child	Dietary exposure per serving [ng/kgbw/day]	1.39	1.99	1.06	2.63	1.09	5.67	1.24	4.07	1.38

~ *Is the use of PFAS treated paper based FCMs safe?* ~
For high-temperature applications

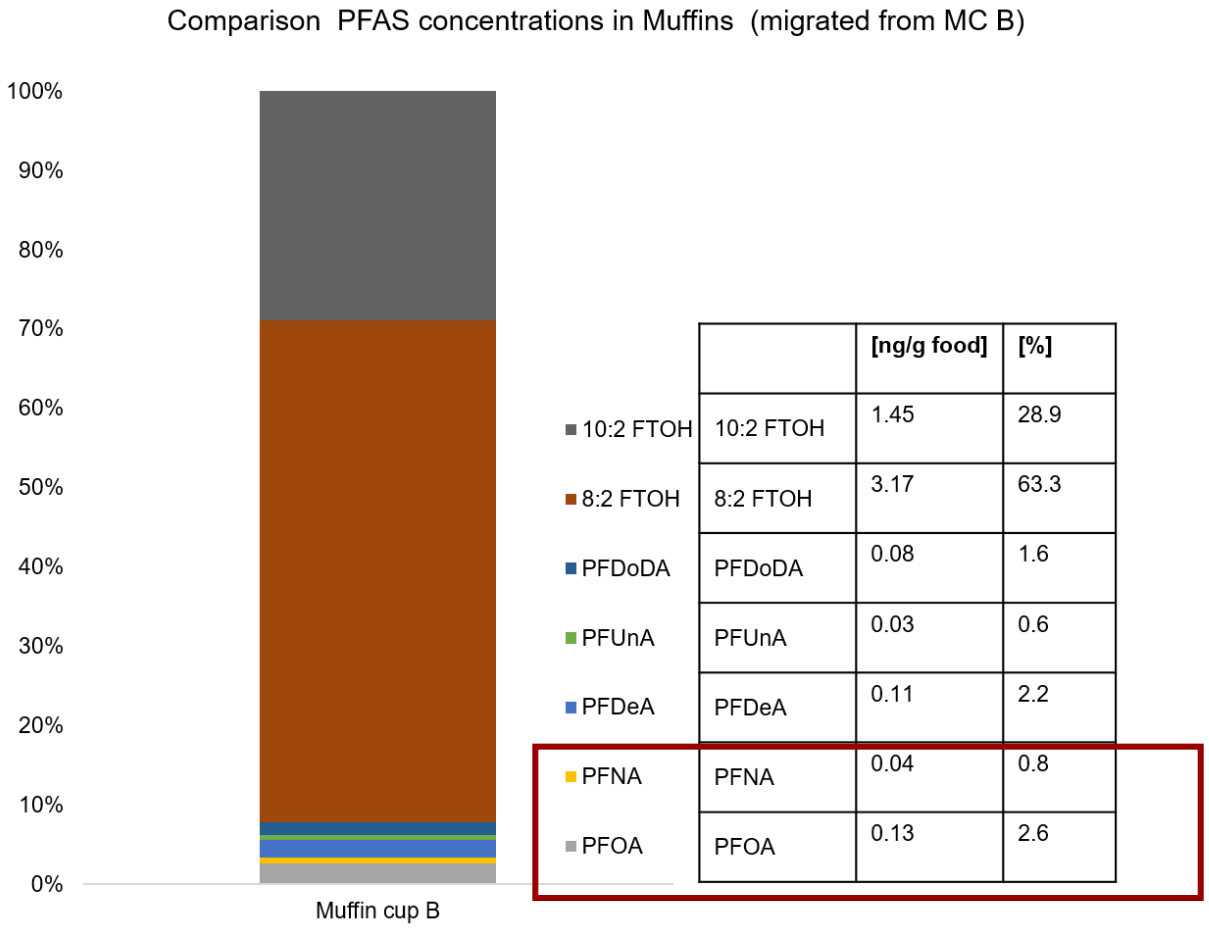
Dietary exposure estimates for muffins by different approaches

TWI = 0.63 ng/kg bw/day for PFAS 4



	Children muffin cup B	
Dietary exposure per serving [ng/kgbw/day]	Sum (PFAS2)	0.32
	RPF-Approach	**4.07**

Dietary exposure estimated to be more than 12 times higher by the RPF approach.



	[ng/g food]	[%]
10:2 FTOH	1.45	28.9
8:2 FTOH	3.17	63.3
PFDoDA	0.08	1.6
PFUnA	0.03	0.6
PFDeA	0.11	2.2
PFNA	0.04	0.8
PFOA	0.13	2.6

Migration of 5.01 ng/g PFAS into the muffin (MB) was set to100%

~ Is the use of PFAS treated paper based FCMs safe? ~
For high-temperature applications

Risk Assessment based on migration values from the experimental migration study

Summary:

❖ Comparison of exposure estimate considering a wide PFAS range (total PFAS) with exposure estimated by applying the EFSA-proposed procedure for food (PFAS4 approach)

EFSA proposed PFAS4 approach	**RPF approach**
→ PFAS migration did not exceed the proposed tolerable weekly intake → No consumer risk	PFAS migration exceeded the tolerable weekly intake: → All daily dietary exposures calculated for children (1.06 to 5.67 ng/kg bw/day) exceeded the guide value by up to nine times → Adults: all tomato soup and muffins baked in muffin cup B → Could indicate the risk for consumer

→ Comparable results were found in a risk assessment based on migration values found in literature (Manuscript I)

Publication of results

Hypothesis II and III were confirmed:

- Hypothesis I: Migration of PFAS from paper based FCMs can contribute considerably to consumers dietary exposure to potentially toxic chemicals and cause health risk

- Hypothesis II: Risk assessment procedures that only consider exposure to four targeted PFAS can lead to an underestimation of consumer risk.

- **Publication of the results:**

Michaela Lerch * , Khanh Hoang Nguyen , Kit Granby:

Is the use of paper food contact materials treated with per- and polyfluorinated alkyl substances safe for high-temperature applications? – Migration study in real food and food simulants. Food Chemistry, vol 393, 2022, 133375.

~ *Are we missing something? – Identification of PFAS in food simulants* ~

Hypothesis IV**:**

The **high number of individual PFAS** used in industry for producing water and fat-resistant FCMs in combination with **targeted quantitation** may cause the presence of **unknown undetected PFAS** in FCMs, posing a risk of their migration into food.

Identification study:

Suspect screening approach to identify PFAS in food simulants after contact with paper based FCM by high resolution mass spectrometry.

The results are under publication

Contact information:

Michaela Lerch: Lerch.michaela@web.de

Kit Granby, DTU Food: kgra@food.dtu.dk