Assessment of PFAS in Commercial Moulded Fibre Catering and Takeaway Packaging: Environmental and Food Safety Implications

Tiago Monteiro Vieira[a], Joel Pereira[b], Maria do Céu Selbourne[b], Fátima Poças[ab]

[a] Universidade Católica Portuguesa, CBQF - Centro de Biotecnologia e Química Fina - Laboratório Associado, Escola Superior de Biotecnologia, Rua Diogo Botelho 1327, 4169-005 Porto, Portugal.

[b] CINATE – Escola Superior de Biotecnologia, Universidade Católica Portuguesa

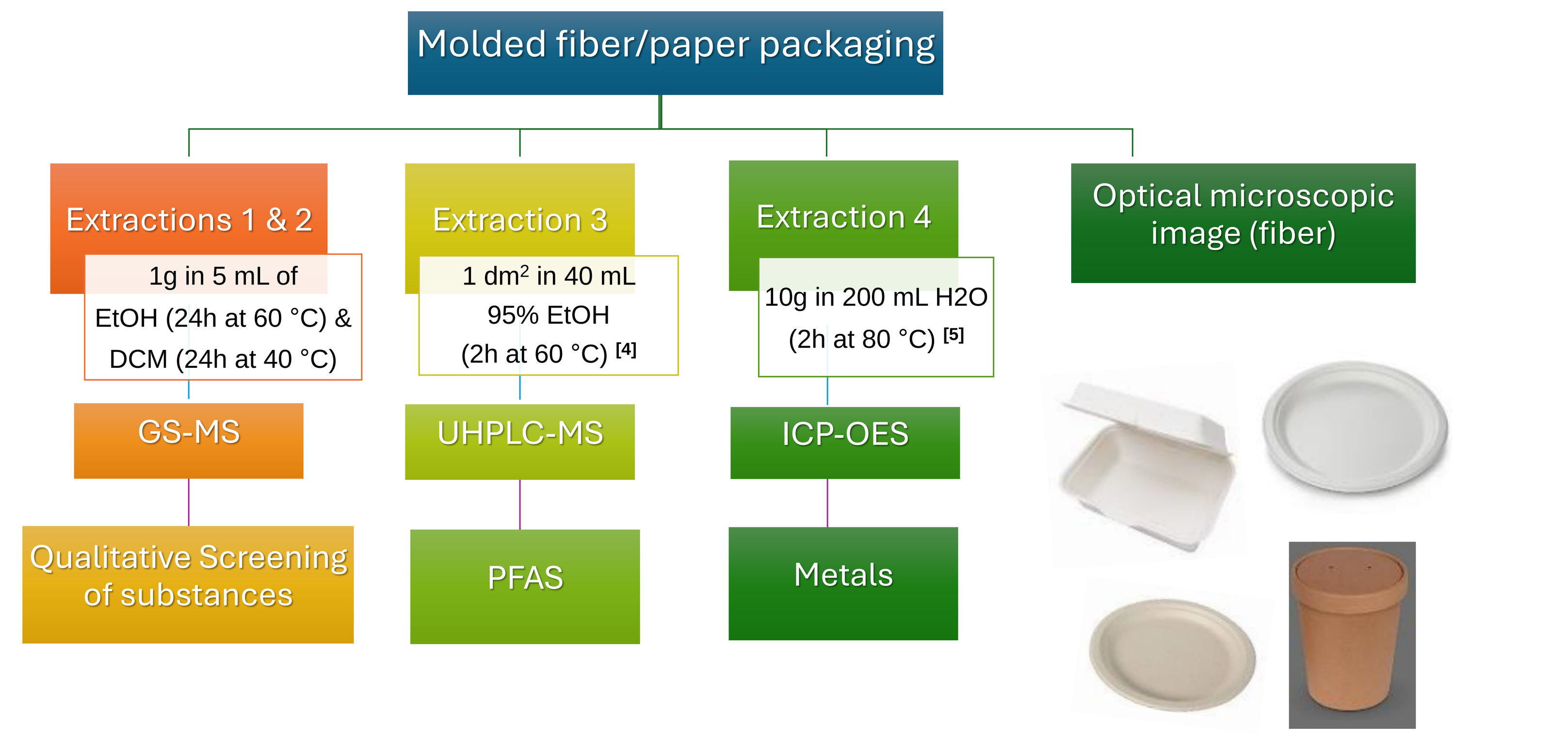
tmvieira@ucp.pt; jppereira@ucp.pt; mselbourne@ucp.pt; fpocas@ucp.pt

CATÓLICA FACULTY OF BIOTECHNOLOGY PORTO

Introduction

Per- and Polyfluoroalkyl Substances (PFAS) are a group of over 5,000 chemicals with amphiphilic properties and environmental persistence, which pose challenges to the food packaging industry, particularly in molded fibre trays. These substances are used to impart water and grease resistance to molded fiber products, which are commonly found in catering and takeaway packaging [1]. However, the incorporation of PFAS into bio-based materials contradicts the principles of the circular economy, which prioritizes sustainability, biodegradability, and plastic waste reduction. As the demand for eco-friendly packaging grows, molded fiber materials, whether virgin or derived from recycled feedstocks, have gained popularity owing to their sustainability potential [2]. Despite these environmental benefits, the presence of PFAS raises concerns about food safety, particularly due to possible chemical migration during "wet-end" treatments in production [1]. Certain PFAS such as perfluoroalkyl carboxylic acids (PFCAs) and perfluoroalkyl sulfonic acids (PFSAs) are hepatotoxic. The toxicity of PFOA has led to its inclusion in the 2020 Stockholm Convention to limit its use. Longer-chain PFCAs/PFSAs such as PFOA are more toxic, prompting the increased use of short-chain compounds such as PFBA [3]. This study evaluates the presence of PFASs in ten commercially available paper-based catering and takeaway packaging products, including both 2D paper, 3D molded fiber articles derived from sugarcane and bamboo, and paperboard.

Methods



Results

Table 1. Selected cellulose moulded fibre and paper-based catering and takeaway packaging samples, collected from the Portuguese market (Dec 31, 2024 - Jan 5, 2025).

Sample Code	Description	Grammage (g/dm²)
WPlate(1)	Molded white fresh-fiber plate (cellulose-based, origin not known)	3.50
BCBox(1)	Brown fresh-fiber paperboard box (750 mL, China-made)	3.39
WBox(2)	Molded white fresh-fiber food box (sugarcane cellulose-based, compostable, China-made)	2.92
Bplate(2)	Molded brown fresh-fiber plate (sugarcane cellulose, Ø 23 cm, compostable, China-made)	3.29
WPlate(3)	Molded white fresh-fiber plate (sugarcane cellulose & bamboo, Ø 22 cm, China-made)	3.87
WPBowl	White paper fresh-fiber bowl (550 mL, biodegradable, origin not known)	2.31
WFPaper(1)	White filter fresh-fiber paper (cellulose-based, origin not known)	0.51
WPCup	White fresh-fiber paperboard cup (sugarcane cellulose-based, biodegradable, origin not known)	2.77
WgKPaper(2)	White gKraft paper (sugarcane cellulose-based, biodegradable, origin not known)	1.22
WPlate(4)	White paper fresh-fiber plate (sugarcane cellulose-based, biodegradable, origin not known)	2.08

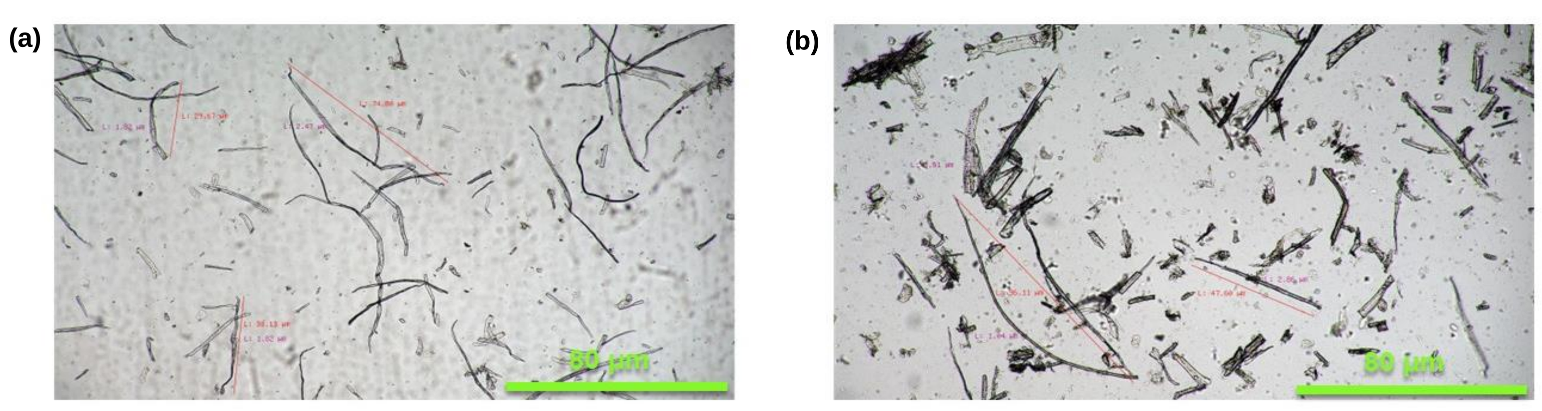


Figure 1. Optical microscopy images of cellulose-based fibers from sample materials: (a) Fibers from a moulded fiber tray, showing dispersed elongated morphology and variable lengths. **(b)** Fibers from paperboard, exhibiting a more fragmented structure with irregular shapes. Both images include fiber length measurements (in red) and a scale bar of 80 µm (green).

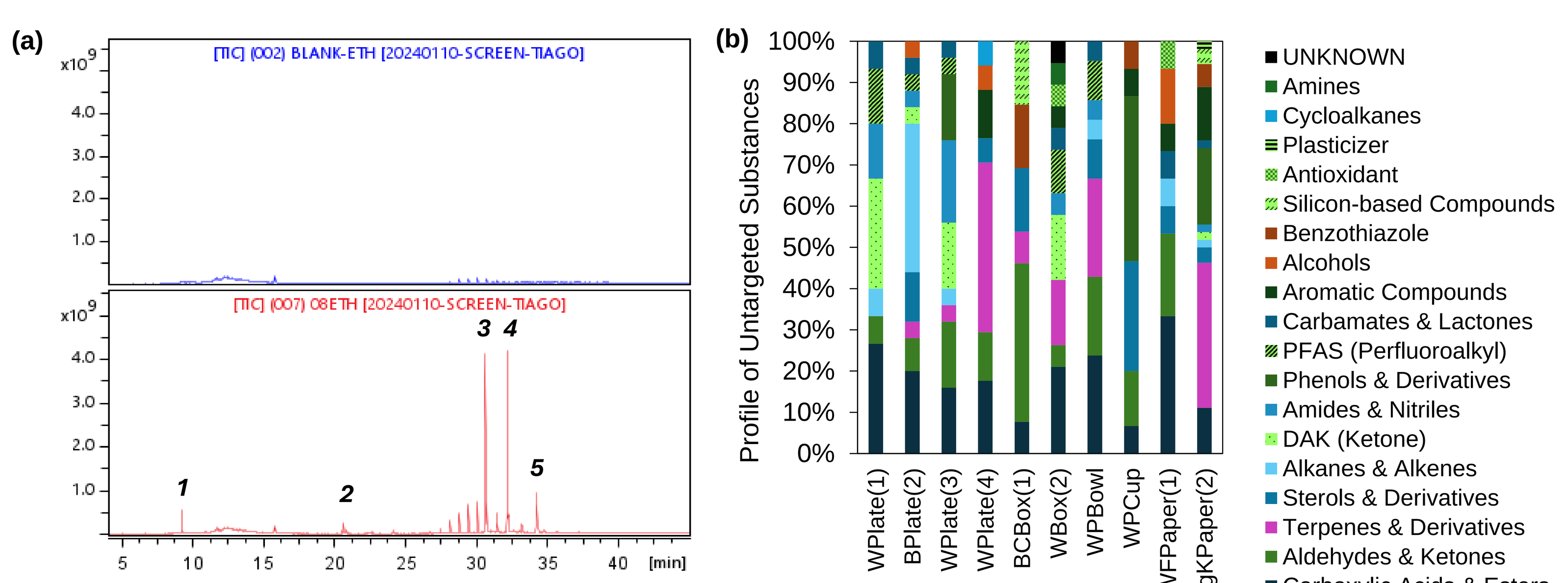


Figure 2. Qualitative screenings analysis by GC-MS: (a) Total ion chromatogram (TIC) from an ethanol extract of a sample (WBox(2)) (bottom, red) and a blank control (top, blue). **(b)** Profile of untargeted substances detected in different samples (the x-axis), categorized by chemical class. The y-axis represents the relative abundance of detected compounds, and the legend indicates substance classifications, including, plasticizers, antioxidants, PFAS, DAK, benzothiazole derivates and various organic compounds.

Table 2. Main additive-related substances detected through GC-MS screenings. The toxicity of each substance according to the Cramer classification is indicated.

Category	Peak Nr.*	Substance	CAS	Toxicity
PFAS	*1*	(Perfluorohexyl)ethyl methacrylate	2144-53-8	High (Class III)
		1H,1H,2H,2H-Perfluorooctan-1-ol	647-42-7	High (Class III)
Benzothiazole derivates		2(3H)-Benzothiazolethione, 3-methyl-	2254-94-6	High (Class III)
	2	2(3H)-Benzothiazolethione (MBTS)	149-30-4	High (Class III)
DAKs (dialkylketones)	*3*	16-Hentriacontanone	502-73-8	Moderate (Class II)
	4	Tritriacontan-16-one	15740-35-9	Moderate (Class II)
	5	18-Pentatriacontanone	504-53-0	Moderate (Class II)
		2-Pentadecanone, 6,10,14-trimethyl-	502-69-2	Moderate (Class II)
		Nonacosan-14-one	34394-11-1	Moderate (Class II)
Plasticizer		Tributyl acetylcitrate	77-90-7	Low (Class I)
Antioxidant		Butylated Hydroxytoluene (BHT)	128-37-0	Moderate (Class II)

** Related to Figure 2(a) (example)*

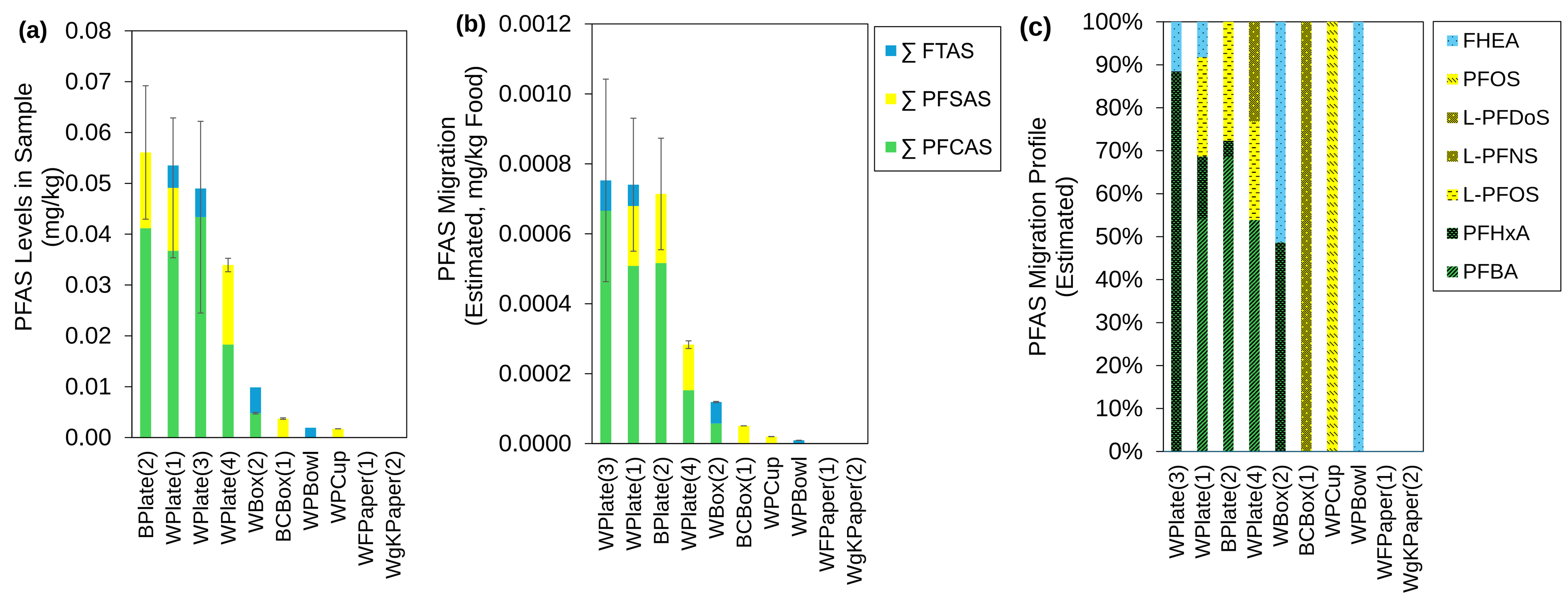


Figure 3. PFAS analysis via UHPLC-MS: (a) PFAS content categorized by main classes detected: PFCAs, PFSAs, and FTAs. **(b)** Estimated PFAS migration based on the assumption of a 6 dm² material surface area per 1 kg of food [6], by PFAS class. **(c)** Profile of individual PFAS, based on migration estimation data. Each bar's color corresponds to its respective PFAS class.

Table 3. Estimated metal migration (mg/kg food) and compliance with specific migration limits (SMLs).

Samples	Al	Ba	Cd	Co	Cr	Cu	Fe	Li	Mn	Ni	Pb	Zn
WPlate(1)	0.04	*<LOD*	*<LOD*	*<LOD*	*<LOD*	*<LOD*	*<LOQ*	*<LOD*	*<LOD*	*<LOD*	*<LOD*	*<LOD*
BCBox(1)	0.34	*<LOD*	*<LOD*	*<LOD*	*<LOD*	*<LOD*	*0.003*	*<LOD*	*<LOQ*	*<LOD*	*<LOD*	*<LOQ*
WBox(2)	0.17	0.002	*<LOD*	*<LOD*	*<LOD*	0.004	0.060	*<LOD*	*<LOQ*	*<LOD*	*<LOD*	0.027
Bplate(2)	0.07	*<LOQ*	*<LOD*	*<LOD*	*<LOD*	*<LOD*	0.003	*<LOQ*	*<LOQ*	*<LOD*	*<LOD*	*<LOD*
WPlate(3)	0.006	0.003	*<LOD*	*<LOD*	*<LOD*	*<LOD*	*<LOD*	*<LOQ*	*<LOD*	*<LOD*	*<LOD*	*<LOD*
WPBowl	**4.57**	0.004	*<LOD*	*<LOD*	*<LOD*	*<LOD*	0.070	*<LOD*	*<LOQ*	*<LOD*	*<LOQ*	*<LOD*
WFPaper(1)	0.001	*<LOD*	*<LOD*	*<LOD*	*<LOD*	*<LOD*	*<LOQ*	*<LOD*	*<LOD*	*<LOD*	*<LOD*	*<LOD*
WPCup	0.013	*<LOD*	*<LOD*	*<LOD*	*<LOD*	*<LOD*	*<LOD*	*<LOD*	*<LOD*	*<LOD*	*<LOD*	*<LOD*
WgKPaper(2)	0.02	*<LOQ*	*<LOD*	*<LOD*	*<LOD*	*<LOD*	*<LOQ*	*<LOD*	*<LOD*	*<LOD*	*<LOD*	*<LOD*
WPlate(4)	0.59	*<LOD*	*<LOD*	*<LOD*	*<LOD*	*<LOD*	0.002	*<LOQ*	*<LOD*	*<LOD*	*<LOD*	*<LOD*
SMLs	1	1	ND *(LOD 0.002)*	0.05	ND *(LOD 0.010)*	5	48	0.6	0.6	0.02	ND *(LOD 0.010)*	5

Legend: *ND – Not Detected; <LOD – Below the Limit of Detection (0.0001-0.005); <LOQ – Below the Limit of Quantification (0.0001-0.005).*

Conclusions

- PFAS were detected in 80% of the tested moulded fibre and paper-based packaging samples, with the dominant compounds belonging to the PFCAs, PFSAs, and FTAs families. Estimated migration shows that some materials could release PFAS in quantities that may raise food safety concerns. Specific PFAS compounds (e.g., short-chain vs. long-chain) exhibit different abundance levels, highlighting the complexity of PFAS mixtures in each material. Shorter-chain PFAS (e.g., PFBA, PFHxA) often appear more frequently but do not necessarily pose less risk, as they still contribute to overall exposure.
- Most samples had metal concentration that result in total migration below SMLs. Aluminum (Al) was the most abundant metal. One sample (WPBowl) exhibited an aluminum level (4.57 mg/kg) exceeding the SML (1 mg/kg), indicating potential risk for aluminum migration.
- GC-MS screening identified other additive-related substances (e.g., benzothiazole biocides and dialkylketones (DAKs), suggesting multiple sources of chemical exposure in these bio-based materials. Identified substances within Cramer Class II–III, suggests moderate to high toxicological concern.
- Optical microscopy showed structural differences in the cellulose fibers, which might affect both PFAS and metal migration.
- The presence of PFAS, additional chemical additives, and occasional elevated metal levels highlight ongoing challenges in ensuring both food safety and sustainability.

Acknowledgments

Authors thanks the support granted by the Recovery and Resilience plan (PRR) and by the Next Generation Eu European Funds to Universidade Católica Portuguesa, through the Green Agenda for business innovation "From Fossil to Forest – Sustainable packaging and products to replace fossil plastic" (Project no. 8 with application C644920945-00000036).

FROM FOSSIL TO FOREST | PRR Plano de Recuperação e Resiliência | REPÚBLICA PORTUGUESA | Financiado pela União Europeia NextGenerationEU

References

1. Tang *et al.* (2024). *Food Packag. Shelf Life*, 43, 101281. doi: 10.1016/j.fpsl.2024.101281
2. Zhang *et al*. (2022). *J. Bioresour. Bioprod.,* 7(1), 14-25. doi: 0.1016/j.jobab.2021.10.003
3. Lerch *et al*. (2022). *Food Chem*., 393, 133375. doi: 10.1016/j.foodchem.2022.133375
4. Trier *et al.* (2011). *ESPR*, 18, 1108-1120. doi: 10.1007/s11356-010-0439-3
5. CEN. (1993). EN 647 – Paper and board in contact with food – Hot water extract preparation. *European Committee for Standardization*.
6. Regulation (EU) No.10/2011. *EUR-Lex*. Doi: http://data.europa.eu/eli/reg/2011/10/oj

ILSI EUROPE