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Preliminary Screening of Per- and Polyfluoroalkyl Substances (PFAS) in Philippine Fast Food Packaging using Liquid Chromatography–Mass Spectrometry (LC-MS)

ELYSON KEITH PONCE ENCARNACION[1]*, ANNE CARDOZA ALCANTARA[1], HAROLD ESPLANA ARMARIO[1], WINNIE PAGADUAN ALEJANDRO[1], ZHAOQI ZHAN[2], ZHE SUN[2], and NG LIN[3]

[1]Industrial Technology Development Institute, Department of Science and Technology, Taguig, Philippines.
[2]Shimadzu (Asia Pacific) Pte. Ltd., Singapore.
[3]School of Chemical and Life Sciences, Singapore Polytechnic, Singapore.

Abstract

Per- and polyfluoroalkyl substances (PFAS) on paper packaging resist water and oil to effectively contain food and beverages. However, previous studies have established correlations between PFAS and several diseases including COVID-19, cancers, and obesity. The goal of this collaborative research between the Philippines and Singapore is to set a baseline for PFAS levels in local packaging with the intended outcome of further increasing awareness on these contaminants in Southeast Asia, providing a starting point for migration experiments and risk assessments on PFAS in commercially-available food contact materials and articles, and initiating policy developments on these substances in the Philippines. In this study, 15 different types of PFAS were analyzed in selected paper packaging used by major quick service restaurants (QSRs) in Metro Manila. Using liquid chromatography-mass spectrometry (LC-MS), PFAS was detected in 100% of the samples with a total PFAS concentration range of 8.20-97.7 ng PFAS/100 cm^2. The highest amount of PFAS compound measured across all samples was PF-3,7-DMOA (89.8 ng/100 cm^2). PFAS compounds regulated in European packaging such as PFHpA, PFOA, PFNA and PFDA were also detected in all samples but at trace levels. Paper wrappers for rice and small burgers were found to have the highest total PFAS of 97.7 ng PFAS/100 cm^2. This value translates to approximately 65.1 ng F/100

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CONTACT Elyson Keith Ponce Encarnacion ekpencarnacion@itdi.dost.gov.ph Industrial Technology Development Institute, Department of Science and Technology, Taguig, Philippines.

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cm^2 which is way below 10,000 ng F/100 cm^2, the currently existing limit for PFAS in packaging set by the Danish Ministry of Environment and Food. While each packaging may be deemed safe compared to regulation, the compounded effects brought by use of multiple packaging, and high frequency and long-term exposures require further investigation.

Introduction

The prevalence of obesity among Filipinos is often associated with the country's fascination with fast food. Before the pandemic, most Filipino consumers had developed a habit of dining outside—38% weekly, 15% twice a week, and 5% daily.[1] Fast-food obesity is observed to be higher among the youth compared with adults.[2] Contributing factors include a strong preference for energy-dense foods and beverages, the unaffordability of healthier diets, and the proximity of accessible quick-service restaurants (QSRs) to residences, schools, and workplaces.[3] While previous studies had already established weight gain from high intakes of carbohydrate-rich and fatty fast food,[2,3,4,5,6] a less-known relationship between obesity and food packaging requires further investigation.

Per- and polyfluoroalkyl substances (PFAS) are large complex compounds manufactured and used to treat paper packaging and cookware among others. They are aliphatic substances that contain one or more carbon atoms on which fluorine atoms have replaced all hydrogen substituents. As a result of their chemical structure, many industries capitalize on their hydrophobic and lipophobic duality[7]—resisting both water and oil and making them effective contact materials for a broad range of food and beverages. In addition, their extremely strong C-F bonds enhance their chemical and thermal stabilities leading to enduring properties.[8] However, while PFAS' prolonged degeneration proves useful for industrial and commercial purposes.[9] their ubiquity in the environment and ability to accumulate in biological systems[10] demonstrate their pollutive and hazardous characteristics.

Human exposure to PFAS is rampant but dependent on geography, environment, occupation, consumer preference, and behavior.[11,12,13] Several studies have linked PFAS to reproductive disorders such as decreased fertility,[11,14] low testosterone levels and abnormal semen morphology,[14] and delayed mammary gland development,[15] increased risk of kidney and testicular cancers,[16,17] and reduced response to vaccines.[18,19,20] But one of the more established health effects of PFAS on laboratory animals and humans is obesity.[21,22,23] In 2009, laboratory rats that were exposed to low levels of perfluorooctanoic acid (PFOA), a regulated type of PFAS, showed a significant increase in body weight, and serum insulin and leptin levels in mid-life.[23] Epidemiological studies concerning PFAS and children in 2017 demonstrated disruption of hormone-mediated processes and excess adiposity apart from neurobehavioral disorders.[22] A more recent study, but on adult females with energy-restricted diets, correlated high baseline levels of PFAS with large weight regains.[21] These repeatable observations that cut across different test subjects confirm a direct relationship between PFAS and obesity despite the small number of peer-reviewed publications.

In contrast, the connection between PFAS and packaging has been evident in literature and industry practices.[24] In a study spearheaded by a non-governmental organization in the U.S. in 2020, PFAS were detected in approximately 50% of the food packaging sampled from major QSRs.[25] The list includes wrappers and clamshells of iconic burgers, bags of fried sides and cookies, and molded fiber bowls of salads and compartmentalized meals. While water and oil repellence is the scientific basis for extensive PFAS treatment of food contact materials (FCMs) and articles (FCAs), the food packaging industry's preference for using these compounds as coating agents and surface enhancers rests primarily on economic reasons. The main hindrance to substitution from PFAS to non-fluorinated alternatives is the cost differential.[24] However, the growing number of studies relating to PFAS and public health has pressured regulatory bodies in the E.U. and U.S. to consider proposals banning the compounds within the next few years.[26,27]

In Southeast Asia, several countries had already undertaken studies on PFAS. A research team from Thailand monitored amounts of perfluorooctane sulfonate (PFOS) and PFOA in selected food packaging.[28] Liquid chromatography coupled with tandem mass spectrometry (LC-MS/MS) was employed to determine said PFAS residues by using a gradient reversed-phase method with ammonium acetate/acetonitrile buffer. The highest concentrations of PFOS (92.48 ng/100 cm^2) were found in fast food container samples while the highest concentrations of PFOA (16.91 ng/100 cm^2) were quantified in ice cream cup samples. In Taiwan, a group of experts analyzed 32 oil-resistant food packaging items after developing and validating a method that uses ultra-performance liquid chromatography/ triple-quadrupole tandem mass spectrometry (UPLC-MS/MS).[29] Among the samples, microwave popcorn paper was identified to contain more types and higher levels of PFAS than others, with perfluoroalkyl acids at 8.3-1960 ng/ 100 cm^2 and fluorotelomer alcohols (FTOHs) at 9.7-7188 ng/100 cm^2. A more recent study by several researchers in Vietnam determined the levels of 13 perfluoroalkyl carboxylic acids (PFCAs) and 4 perfluoroalkyl sulfonates (PFSs) in various food packaging.[30] Low concentrations (median 0.341 ng/g; max 624 ng/g) suggested that the compounds were inadvertently produced rather than intentionally added.

While the Philippines has long implemented the Food Safety Act which includes traceability and risk-based analysis of hazards from packaging materials,[31] the government has yet to build baseline data and craft additional policies on food packaging contaminants.[32,33] such as PFAS. The project team behind this local research had coordinated with the country's Food and Drug Administration to provide scientific information for the drafting and implementation of guidelines that will safeguard the health of the general population and account for the packaging industry's economic concerns. In this preliminary study, various forms of food packaging from major QSRs in Metro Manila are screened for selected PFAS. The results will be used to jumpstart follow-through research focused on chemical migrations to food products, and eliminate these hazardous compounds in packaging, eventually leading to the reduction of risks to cancers, vaccine resistance, and obesity among others.

Materials and Methods

Sample Identification

An international company operating a food delivery application in the Philippines assisted in identifying QSRs with the highest patronage within the 16 cities and 1 municipality of Metro Manila. The identity of the company is withheld for confidentiality purposes. Establishments were ranked first according to frequency of orders throughout the region, and second through display order as dictated by the application's algorithm. The project team coordinated with a large manufacturer supplying paper-based packaging to the QSRs on the list. The identity of the manufacturer is also withheld for confidentiality purposes. Common packaging samples were determined and at least three units were requested for analysis.

Sample Preparation

Due to a lack of capability to determine PFAS in food packaging in the Philippines, the project team sent the samples to a third-party laboratory in Singapore for preparation and analysis. The laboratory adopted the sample treatment[34] developed and used by Schaider *et al*. Each sample was cut into 10 cm x 10 cm (100 cm^2), weighed, and extracted with 20 ml of methanol (Kanto Chemical Co., Inc., LC-MS grade) into a polypropylene centrifuge tube (Fisher Scientific). The tube was placed in a sonicator (Shimadzu) set at ambient temperature for 30 minutes. Approximately 4 mL of the collected extract was cleaned using a solid phase extraction (SPE) cartridge (Supelclean ENVICarb, 600 mL/500 mg). The eluent was evaporated to dryness (BioTag TurboVap LV) with high-purity nitrogen gas. The dried sample was reconstituted with 0.8 mL of 5 mM ammonium acetate solution (Sigma-Aldrich, >99%), and transferred into a 1.5 mL glass vial (Shimadzu, HPLC grade) for LC-MS analysis. Three replicates were performed per sample.

Instrument Optimization and Method Verification

A 2 mg/L mixed standard solution was obtained by adding 40 µL of each individual 50 mg/L PFAS stock solution (Wellington Laboratories Inc.) (Table 1) with 400 µL of pure water (Milli-Q, 18.2 MΩ, 3 mg/L total organic carbon) in a 1.5 mL glass vial (Shimadzu, HPLC grade). PFAS stock solutions were chosen based on the availability of resources and the analytes listed in US EPA Method 537.1.[35] Calibration

series with or without internal standards (M-PFOS with $^{13}C_4$ and M-PFOA with $^{13}C_4$) were prepared from the mixed standard solution with pure water as solvent. Pure water was analyzed as an instrument blank for traces of PFAS compounds to be deducted from the measurements. Using negative mode, two Multiple Reaction Monitoring (MRM) transitions were optimized except for perfluorobutanoic acid (PFBA) and perfluoropentanoic acid (PFPeA) which have one quantifier each. Limits of detection (LOD) and quantification (LOQ) were estimated by analyzing 10 replicates of the lowest calibration solutions of each PFAS compound. Repeatability was estimated by analyzing six replicates of three concentrations: 0.2, 1.0, and 5.0 ng/mL corresponding to single-analyst method precision at low, middle, and high levels for each PFAS compound.

Table 1: Selected PFAS Compounds Used for the Determination of PFAS in Paper Packaging

Full Name	Abbreviation	CAS
Perfluorobutanoic acid	PFBA	375-22-4
Potassium Perfluoro-1-butanesulfonate	K^+PFBS	29420-49-3
Perfluoropentanoic acid	PFPeA	2706-90-3
Perfluorohexanoic acid	PFHxA	307-24-4
Sodium Perfluorohexane sulfonate	Na^+PFHxS	82382-12-5
Perfluoroheptanoic acid	PFHpA	375-85-9
Perfluorooctanoic acid	PFOA	335-67-1
Sodium Perfluorooctane sulfonate	Na^+PFOS	4021-47-0
Perfluoro(3,7-dimethyloctanoic acid)	PF-3,7-DMOA	172155-07-6
Perfluorononanoic acid	PFNA	375-95-1
Perfluorodecanoic acid	PFDA	335-76-2
Sodium Perfluorodecane sulfonate	Na^+PFDS	2806-15-7
Perfluoroundecanoic acid	PFUnA	2058-94-8
Perfluorotridecanoic acid	PFTriA	72629-94-8
Perfluorotetradecanoic acid	PFTA	376-06-7

Instrumental Analysis

The analytical conditions for PFAS determination using LC-MS (Shimadzu LCMS-8050) with C18 column (Shim-pack Velox) are detailed in Table 2.

Table 2: LC-MS and Interface Conditions for the Determination of PFAS in Paper Packaging

Parameter	Condition
Column Dimensions	2.1 x 100 mm, 2.7 µm
Flow Rate	0.4 mL/min
Mobile Phase	A: 5 mM ammonium acetate (Sigma-Aldrich, >99%) in water (Milli-Q, 18.2 MΩ, 3 mg/L TOC) B: acetonitrile (Fisher Scientific, LC-MS grade)
Elution Mode	Gradient elution, 12 mins
Gradient Program	10% (0-0.5 mins) → 80% (0.5-9.0 mins) → 10% (9.0-12.0 mins)
Oven Temperature	40 °C
Injection Volume	10 µL
Interface Type	Heated Electrospray Ionization (ESI)
Interface Temperature	300 °C

Desolvation Line Temperature	250 °C
Heat Block Temperature	400 °C
Nebulizing Gas	2 L/min
Heating Gas Flow	10 L/min
Drying Gas Flow	10 L/min
Mass Spectroscopy Mode	MRM, negative mode

Results

Based on the data generated from the food delivery application, three QSRs were identified as receiving public patronage in all districts of Metro Manila. From this group of companies, seven common packaging samples (P1-P7) were identified and analyzed. P1 and P2 are wrappers for rice, small burgers, sandwiches, etc. They consist of a single layer of paper printed on one side, and coated with a waxy material on the other. P3 are pouches for fried sides and single-served desserts. The materials in them resemble those of P1 and P2 but with a type of adhesive used to connect the ends and create a small bag. P4, P5, and P6 are clamshell containers for large burgers, dry and sauced noodles, full meals, etc. They consist of folded paperboards printed on the outside and coated with a waxy material on the inside. A type of adhesive is used at the corners to hold the shape of the box. P7 is used to contain soups and beverages. Its materials resemble those of P4, P5 and P6 but are folded to take a conical/cylindrical shape. A type of adhesive is used to connect the ends and seal the bottom with a separate paperboard. The topmost edge or rim is rolled to strengthen the cup. Photographs of the samples are not provided for confidentiality purposes.

Optimization and Verification

Retention times, MRM quantifiers, working ranges, limits of detection and quantification, and relative standard deviations at specific concentration levels were determined by the third-party laboratory for 15 different PFAS compounds prior to sample analysis (Table 3). All compounds were eluted within eight minutes using an optimized LC gradient setting. As for MRM transitions, only one was recorded each for PFBA and PFPeA due to their short carbon chain structures. The majority of the PFAS demonstrated linearity from 0.1-10.0 ng/mL with coefficients of determination, R^2, ranging from 0.952-0.999. PFDS, PFTriA, and PFTA were also linear to 10 ng/mL but from 0.2, 0.5, and 1.0 ng/mL, respectively. Nevertheless, all compounds passed the acceptable criteria[36,37] of $R^2 \geq 0.990$. The limits of detection of most PFAS were lower than their first calibration solutions. Only four compounds exhibited otherwise: PFUnA (0.11 > 0.1 ng/mL), PFDS (0.38 > 0.2 ng/mL), PFTriA (0.62 > 0.5 ng/mL), and PFTA (1.58 > 1.0 ng/mL). All of these are long carbon chains which may indicate a possible inverse relationship between molecule size and detection. However, this may require further investigation. Single-analyst precision was very satisfactory at mid and high levels with all PFAS having relative standard deviations (RSD_r) below 30% and 21% respectively.[38] Repeatability was also acceptable (RSDr < 42%) at the low level[38] for most compounds except for PFDS, PFTriA, and PFTA which were not evaluated due to high detections. The results of the optimization and verification indicate that certain characteristics of the method had been proven fit for sample analysis.

Sample Testing

The average concentrations of the selected PFAS in seven packaging samples are summarized in Table 4 along with their corresponding percent relative standard deviations. Values in ng/100 cm^2 were obtained by multiplying instrument readouts (in ng/mL) by a factor of 4 which accounted for the extraction and reconstitution.

Table 3: Results of Instrument Optimization and Method Verification of PFAS in Paper Packaging

Compound	RT (min)	MRM Quantifier	MRM Reference Ion	Ratio	Working Range (ng/mL)	R^2	LOD (ng/mL)	LOQ (ng/mL)	Relative Standard Deviation (%) at		
									Low Level 0.2 ng/mL	Mid Level 1 ng/mL	High Level 5 ng/mL
							(n=10, α=0.05)			(n=6, α=0.05)	
PFBA	1.76	212.9>169.1	N/A	N/A	0.1-10	0.999	0.02	0.05	2.49	1.66	1.21
PFPeA	3.05	262.9>219.1	N/A	N/A	0.1-10	0.999	0.02	0.05	9.52	1.33	0.7
PFBS	3.79	298.9>79.9	298.9>98.9	53.4	0.1-10	0.993	0.02	0.06	7.07	2.29	1.65
PFHxA	3.81	313.0>269.1	313.0>119.1	4.7	0.1-10	0.998	<0.01	0.01	3.09	1.8	0.91
PFHpA	4.37	362.9>319.1	362.9>169.1	27.5	0.1-10	0.999	0.01	0.04	2.51	2.48	2.06
PFOA	4.86	413.0>369.1	413.0>169.1	28.1	0.1-10	0.999	0.01	0.02	3.15	2.36	2
PFHxS	4.96	398.9>79.9	398.9>98.9	56.5	0.1-10	0.996	0.02	0.06	7.67	1.93	2.98
PFNA	5.3	463.0>419.0	463.0>219.1	26.2	0.1-10	0.998	0.01	0.04	7.81	2.04	1.49
PF-3, 7-DMOA	5.45	469.0>269.1	469.0>219.1	25.4	0.1-10	0.996	0.01	0.02	5.12	1.13	2.98
PFDA	5.7	513.0>469.1	513.0>219.1	15	0.1-10	0.987	0.03	0.08	3.34	2.71	2.03
PFOS	5.84	499.0>79.9	499.0>98.9	68.9	0.1-10	0.999	0.05	0.15	7.04	2.63	2.5
PFUnA	6.09	563.0>519.1	563.0>269.1	15.8	0.1-10	0.952	0.11	0.35	12.16	5.65	1.7
PFDS	6.62	599.0>79.9	599.0>99.0	61	0.2-10	0.988	0.38	1.14	-	11.76	3.22
PFTriA	6.84	663.0>619.0	663.0>169.1	17.5	0.5-10.0	0.996	0.62	1.87	-	10.65	7.43
PFTA	7.2	712.9>668.9	712.9>169.1	17.2	1.0-10.0	0.988	1.58	4.78	-	12.62	9.59

Table 4: Average Concentrations in ng/100 cm² and Percent Relative Standard Deviations of Selected PFAS in Seven Different Types of Paper Packaging

Compound	Sample Code							Total amount of each PFAS comp -ound in all samples
	P1	P2	P3	P4	P5	P6	P7	
	Average Concentration in ng/100 cm² (Relative Standard Deviation in %) n=3 / n=2*, a=0.05							
PFBA	19.9 (0.91)	2.60 (0.00)	2.60 (1.54)	7.03 (1.19)	4.43 (2.27)	6.33 (10.3)	3.93 (1.55)	46.8
PFPeA	10.9 (1.65)	1.47 (1.57)	1.45 (8.85)	3.20 (2.50)	1.87 (1.24)	2.49 (5.16)	2.12 (3.27)	23.5
PFBS	-	-	-	0.32 (12.5)	-	-	-	0.32
PFHxA	31.2 (0.59)	1.84 (2.17)	2.39 (1.94)	6.03 (0.77)	3.60 (9.88)	4.36 (6.93)	3.11 (2.97)	52.5
PFHpA	2.65 (3.14)	0.28 (0.00)	0.51 (4.56)	0.67 (6.93)	0.58 (4.88)*	0.53 (8.66)	0.60 (6.67)	5.82
PFOA	1.71 (2.71)	0.40 (10.0)	0.36 (15.7)	0.57 (4.03)	0.58 (14.6)*	0.41 (14.8)	0.48 (0.00)	4.51
PFHxS	-	-	-	-	-	-	-	-
PFNA	0.89 (6.84)	0.23 (10.2)	0.27 (17.3)	0.55 (4.22)	0.40 (14.1)*	0.32 (0.00)	0.32 (0.00)	2.98
PF-3,7-DMOA	29.4 (2.04)	0.79 (12.8)	0.96 (7.22)	53.6 (1.05)	1.92 (5.89)*	1.99 (7.07)	1.15 (7.26)	89.8
PFDA	0.92 (0.00)	0.59 (14.2)	0.75 (15.5)	2.09 (7.72)	2.06 (6.87)*	0.97 (4.75)	0.89 (2.59)	8.27
PFOS	-	-	-	-	-	-	-	-
PFUnA	0.14 (20.2)*	-	-	0.08 (0.00)*	-	-	-	0.22
PFDS	-	-	-	-	-	-	-	-
PFTriA	-	-	-	0.91 (14.18)	0.60 (37.7)*	0.96 (11.8)*	-	2.47
PFTA	-	-	-	2.24 (9.28)	1.36 (16.6)*	1.95 (13.1)	-	5.55
Total PFAS per packaging	97.7	8.2	9.29	77.3	17.4	20.3	12.6	

Despite the trace levels, majority of the measurements demonstrated good repeatability due to the fact that liquid chromatography coupled with tandem mass spectrometry is considered a gold standard technique for the analysis of organic compounds at low concentrations.[39,40] The method's suitability for targeted screening and accurate quantitation is rooted on the instrumentation system's high selectivity and sensitivity.

PFOS, which was banned under the International Stockholm Convention[41] and the EU Persistent Organic Pollutants (POPs) Regulation,[42,43] was not present in any of the samples. However, traces of PFOA, which was included under the 2020 amendment of the POPs Regulation[44] and the Classification, Labelling, and Packaging (CLP) Regulation,[45] were detected in all articles (0.36-1.71 ng/100 cm²) with the highest found in P1. Apart from PFOA, three other PFAS compounds namely PFHpA, PFNA, and PFDA are also listed under the CLP Regulation and were measured in all samples. The concentration ranges of these compounds in the items are 0.23-0.89 ng/100 cm², 0.28-2.65 ng/100 cm², and 0.59-2.09 ng/100 cm² respectively. PFHpA and PFNA had the highest amounts in P1 while the largest values of PFDA were analyzed in P4 and P5. The latter's sulfonic acid derivative, PFDS, was not observed in any sample.

PFHxS, PFHxA, PFUnA, PFTriA, and PFTA are new PFAS compounds being proposed for restriction by some EU countries[41] under the Registration, Evaluation, Authorization, and Restriction of Chemicals (REACH) Regulation, and were also assessed in the study. PFHxS was not confirmed in any of the articles but its carboxylic acid derivative, PFHxA, was quantified in all (1.84-31.2 ng/100 cm²) with the highest amount obtained in P1. The longer chained PFAS compounds—PFUnA, PFTriA, and PFTA—were evident in two or three of the following: P1, P4, P5, and P6. PFBS, an intended replacement

for PFOS and a recently identified Substance of Very High Concern (SVHC), was detected at trace levels (0.32 ng/100 cm^2) and only in P4. However, its carboxylic acid form, PFBA, was confirmed in all samples (2.60-19.9 ng/100 cm^2) with the highest value found in P1.

PFPeA and PF-3,7-DMOA, less discussed in literature and legislation, were present in all items. PFPeA (1.45-10.9 ng/100 cm^2) followed the same trend as PFOA, PFHpA, PFNA, PFHxA, and PFBA in which the largest amounts were analyzed in P1. PF-3,7-DMOA were measured in significantly large amounts most distinctly in P1 (29.4 ng/100 cm^2) and P4 (53.6 ng/100 cm^2) thus surpassing any other PFAS. As a result, the compounds with the highest total across all seven samples are PF-3,7-DMOA (89.8 ng/100 cm2), PFHxA (52.5 ng/100 cm^2), and PFBA (46.8 ng/100 cm^2). Meanwhile, the packaging with the highest sum of PFAS compounds are P1 (97.7 ng PFAS/100 cm^2), P4 (77.3 ng PFAS/100 cm2), and P6 (20.3 ng PFAS/100 cm^2).

Discussion

Optimization and Verification

While optimization and method verification produced values that were within the acceptance criteria set for linear regression and repeatability, other performance characteristics could be employed to further establish the accuracy of the procedure and the reliability of results. These may include residual analysis, intermediate precision, trueness, robustness, and uncertainty estimation, among others. Since the ITDI-DOST requested Shimadzu (Asia-Pacific) Pte. Ltd. to conduct instrumental analysis only for selected packaging, these aforementioned performance parameters will have to be conducted in the next phase of the project which involves capability enhancement and method validation in the Philippine setting.

Sample Testing

The results of the preliminary screening revealed the presence of PFAS compounds in selected paper-based packaging manufactured locally and used by popular QSRs in Metro Manila. Some restricted fluorinated compounds such as PFOA and PFBS were detected but below regulatory levels. These substances must be controlled, if not completely eliminated, in local paper packaging to prevent aggregate and cumulative exposures. In addition, brand owners planning to use these contact materials for food products abroad may have to conduct regular evaluations to ensure that the packaging of their commodities continues to comply with international regulations and does not compromise public health and safety. Failure to do so may result in product recalls, reputational damage, and business loss. In contrast, less common compounds such as PF-3,7-DMOA, PFHxA, and PFBA were quantified in remarkably larger amounts compared to others. While currently permitted by foreign legislation, occasional monitoring should still be performed on these compounds should future scientific studies uncover accompanying health hazards.

The packaging with the highest PFAS concentration was P1 with 97.7 ng PFAS/100 cm^2. This translates to approximately 65.1 ng total organic fluorine/100 cm^2 which is approximately 153 times lower than the permissible value set by the Ministry of Environment and Food of Denmark in 2015. Denmark is currently the only country that regulates PFAS (in terms of total organic fluorine) in packaging. Using 10,000 ng/100 cm^2 as the indicator value[46] and comparing the highest attained total PFAS concentration from the study, none of the local samples tested exceeded the limit. However, it should be emphasized that since only targeted analysis through LC-MS was performed, other ionic PFAS compounds were not quantified and the experimental sum may be lower than the actual. In addition, the analysis did not account for volatile PFAS which can be quantified using Gas Chromatography-Mass Spectrometry (GC-MS), and precursors that form perfluoroalkyl carboxylates which can be identified through Total Oxidizable Precursor (TOP) Assay. Thus, the total organic fluorine had been underestimated. A previous study by Robel *et al*. closed the mass balance on fluorine in paper packaging before and after the extraction process.[47] Their research summed all migrated PFAS obtained from LC-MS, GC-MS, and TOP Assay and found it comparable (i.e. within analytical error) with the PFAS from pre-extracted packaging determined through Particle-Induced Gamma-ray Emission (PIGE) Spectroscopy—proving the presence of other fluorinated substances.

The results of this study and those obtained from previously published research outside Southeast Asia are summarized in Table 5 to obtain a more global perspective of PFAS levels in food packaging. Since the values were originally reported in different units, conversion (to ng F/100 cm^2) and estimation were performed using the information provided in the journals. Earlier studies[34,48,49] obtained figures that are above the indicator value for PFAS in packaging while recent determinations[50] yielded lower concentrations and detection frequencies for a majority of PFAS compounds. The most feasible reason for the difference is underestimation since both Dueñas-Mas *et al*. and this study used only one instrument to quantify selected PFAS compounds. However, other factors such as reduced background corrections leading to ease in integration[35] and increased awareness resulting in modifications of raw materials may have contributed.

Table 5: Comparison of Total Organic Fluorine in Packaging Determined by Various Studies

Year	Proponents	Study Site	Reported Values	Converted Values, ng F/100 cm^2
2017	Schaider *et al*.[34]	U.S.	16 - 800 nmol F/ cm^2	3.04 x 10^4 -1.52 x 10^6
2019	Li *et al*.[48]	China	0.01 - 0.08 mg F/ kg	1667 – 1.33 x 10^4
2023	Schwartz-Nabonne *et al*.[49]	Canada	3580 - 1.30 x 10^6 µg F/ m^2	3.58 x 10^4 – 1.30 x 10^7
2023	Dueñas-Mas *et al*.[50]	France	22.7* ng PFAS/ g	116
This Study	Encarnacion *et al*.	Philippines	8.20 - 97.7 ng PFAS/ g	5.38 – 65.1

*Sum of Average Values of PFAS Compounds Determined

While local samples tested in this study have lower concentration levels than Danish standards, there are several specific circumstances when problems may arise. First, QSRs offer “set meals” which are considered more economical. Hence, consumers purchase two or more food items in contact with two or more types of packaging. This practice leads to a compounded exposure to PFAS, if present. Second, QSRs tend to overpackage as a means of protecting their commodities. For example, a cup of rice is wrapped in either P1 or P2, and is commonly placed alongside a serving of viand inside P4, P5 or P6. This implies that the PFAS exposure from multiple-packaged food items is the sum of occurring migrations from all contact sources and is likely higher than single-packaged food products. Lastly, different factors affect the migration behavior of contaminants.[51] The physicochemical properties of the packaging material and food product contained, the surface area of exposure, time of contact, and ambient and food temperatures play significant roles and regulate the transfer of PFAS compounds. While it is extremely unlikely that 100% of PFAS compounds are extracted, follow-up migration studies considering the aforementioned contributors are essential to determine transfer kinetics and effects on the analyte concentration.

Follow-Through Studies

While the laboratory has implemented available controls to ensure the quality of test results, additional recommendations, apart from those stated in the earlier parts of the discussion, have been identified for improvement and incorporation in the succeeding phases of the project. First, there is a need to utilize a delay column and a PEEK (poly-ether-ether-ketone) tubing. These tools help reduce background concentrations of PFAS compounds for more accurate quantitation. The same advantage is obtained in using method blanks and spiked samples. None of these accessories and quality control checks were used in this preliminary screening. Second, it is essential to confirm the absence of potential interferences for PFAS compounds with only one transition. Multiple interferents have been found in a variety of matrices for these PFAS containing carboxylic acids with short carbon chains such as PFBA and PFPeA.[52] Depending on the instrument to be used, several adjustments including modification of LC-MS conditions and matching of internal standards should be employed to properly investigate and confirm detections for this specific group. Third, instead of external calibration, isotope dilution mass spectrometry (IDMS) may be validated as a technique for measurement. This high-order

method is a more accurate way to account for both matrix and sample preparation effects compared to conventional practice. Capability enhancement on this advanced approach is on-going to provide a better baseline for assessing PFAS in contact materials in the Philippines. Next, variations in the method of laboratory sampling and analysis may be explored. Modifications in sampling can address questions on possible inhomogeneity of PFAS contamination across the whole sample. Meanwhile, separate analysis of raw materials (e.g. paper, ink, coating etc.) can identify percent contribution to the total PFAS in the final form of the packaging. However, a major advantage would be that PFAS by-products arising from the manufacturing process are likely to be unaccounted. Lastly, in order to generate better conclusions and instigate acceptable legislations, the number of samples screened must be increased. Considering the significant contribution of the manufacturing industry to the annual gross domestic product (GDP) of the Philippines,[53] there is a need to involve micro-, small and medium-sized enterprises (MSMEs), and large corporations to accurately profile locally-available packaging and map PFAS detections within a certain region or across the entire country.

Conclusion

Studies on PFAS are continuously progressing worldwide with most research originating from North America and Europe. This collaborative study between the Philippines and Singapore establishes a baseline for PFAS levels in local packaging, and aspires to further increase awareness on PFAS in Southeast Asia, to stimulate follow-through research projects on these contaminants, and to commence the setting up of guidelines and limits concerning these substances in the Philippines. With diseases such as hypertension (a major outcome of obesity), genitourinary cancers, and COVID-19 being the leading causes of death in the Philippines in 2022.[54] this study is timely and relevant as all of which were established to be connected to PFAS.

In this preliminary study, PFAS were detected in selected local fast food packaging. Among those regulated in Europe, PFHpA, PFOA, PFNA and PFDA were present but at trace levels. PFBS, a substance of very high concern, was also measured but only in clamshells. Paperboard clamshells for large burgers were found to contain the second highest amount of total PFAS with 77.3 ng PFAS/100 cm^2 next to paper wrappers for rice and small burgers with 97.7 ng PFAS/100 cm^2.

Despite the presence of PFAS in all packaging, not one sample was above the Danish limit for PFAS in packaging of 10,000 ng F/100 cm^2. However, this study does not disregard cumulative effects that may arise from use of multiple packaging, and high frequency and long-term exposures, which remains to be explored.

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Conflict of Interest

The authors declare no conflict of interest.

Data Availability

The manuscript incorporates all relevant datasets produced or examined throughout this study.

Ethics Statement

Not Applicable

Authors' Contributions

The following are the authors and their respective contributions to the study: Elyson Keith Ponce Encarnacion (Concept and Design, Leadership and Supervision, Interpretation, and Writing of Manuscript); Anne Cardoza Alcantara (Literature Search, Procurement of Resources, and Critical Review); Harold Esplana Armario (Literature Search, Data Collection and Processing, and Critical Review); Winnie Pagaduan Alejandro (Data Collection and Processing, and Critical Review); Zhaoqi Zhan

(Analysis, and Writing of Manuscript); Zhe Sun (Analysis, and Writing of Manuscript); and Ng Lin (Analysis). All authors have given their approval for its publication.

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