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# Flame Grilled and Fluorinated - PFAS Analysis in Barbeque Foods Using a Miniaturized QuEChERS Workflow

Margot Lee, Kari Organtini

Waters Corporation, United States

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## Abstract

From burgers and bratwurst to fresh watermelon and tomatoes, barbeques (BBQs) bring together a diverse range of foods that are staples of outdoor dining. While PFAS regulations and monitoring efforts have focused primarily on select food categories such as chicken, pork, and beef, much less is known about PFAS occurrence across the broader assortment of foods commonly found on the BBQ table. To provide a more comprehensive view of potential dietary exposure, this study evaluates PFAS concentrations in EU regulated meats, along with plant-based protein and fruit and vegetables, while demonstrating the robustness and versatility of analytical workflows across diverse food matrices.

An efficient workflow for the analysis of complex meat matrices is presented utilizing a quick, easy, cheap, effective, rugged, and safe (QuEChERS) extraction process to minimize PFAS internal standard consumption, decrease sample preparation time, and lessen matrix load on the analytical system— an important consideration as instrument sensitivity continues to improve.

The extraction workflow incorporated an automated solid-phase extraction (SPE) system capable of processing

up to eight samples simultaneously in under 70 minutes. SPE cleanup is performed using dual-phase Oasis™ GCB/WAX for PFAS Analysis Cartridges, combining graphitized carbon black and weak anion exchange sorbents to effectively remove matrix interference and enable precise, reproducible PFAS quantification across diverse food types. The CEN blend was chosen as it is the official European standard and designed for foods of plant origin, which are included in this study.

## Benefits

- A streamlined PFAS workflow for sample preparation of complex matrices (protein and fat rich meats) with sensitive analysis on the Xevo™ TQ Absolute Mass Spectrometer to quantify at the sub-µg/kg levels required to meet the guidance and regulations from the FDA and EU
- Scaled-down QuEChERS workflow using a 2g sample with proportionally reduced, custom-weighed (miniaturized) QuEChERS salts
- Eliminates evaporation and reconstitution steps between QuEChERS and SPE cleanup, reducing sample preparation time and minimizing the risk of analyte loss while maintaining the sensitivity required for trace-level PFAS analysis
- Use of dual-phase Oasis for PFAS GCB/WAX Cartridges, combining two sorbents in one device, to streamline SPE, ensure cleanliness, and reduce false positives through QC-release testing for low residual PFAS
- The PFAS solution installation kit reduces the risk of system and solvent contamination affecting the analysis and thus providing confidence in the accuracy of results
- Provides a practical workflow for laboratories expanding PFAS testing beyond traditional meat matrices into processed foods, plant-based alternatives, fruits, and vegetables

## Introduction

PFAS are persistent environmental contaminants that can accumulate in a variety of foods commonly consumed by humans, including meats and produce. As PFAS contamination continues to be identified across diverse food matrices, regulatory agencies have increased efforts to better understand dietary exposure and potential human health impacts. The European Union has established maximum levels for four PFAS compounds (PFOS, PFOA, PFNA, and PFHxS) in selected food categories, though allowable concentrations vary by food type.[1] The maximum levels can be seen in Table 1. In contrast, the United States currently has no federally established maximum limits for PFAS in food. The European Food Safety Authority (EFSA) has also established a tolerable weekly intake (TWI) of 4.4 ng/kg body weight for the sum of these four compounds, which are considered major contributors to PFAS levels observed in human serum.[2]

In addition to these regulated compounds, there are currently eight PFAS (PFOA, PFOS, PFNA, PFHxS, HFPO-DA (GenX), PFBS, PFBA, and PFHxA) for which toxicological reference values have been established and are used to evaluate potential health concerns associated with dietary exposure.[3] Although the FDA has not established maximum PFAS limits in food, the agency continues to monitor PFAS occurrence through targeted surveys, public reporting of testing results, and requests for information that may inform future guidance or regulatory actions.[3] Advances in LC-MS/MS technology now enable the detection of a broader range of PFAS at increasingly lower concentrations, supporting more comprehensive characterization of PFAS contamination across complex food matrices and improving our understanding of potential dietary exposure.

To demonstrate the capabilities of the Xevo TQ Absolute Mass Spectrometer and GCB/WAX for PFAS Cartridges for food testing, a workflow was developed for the determination of approximately 46 compounds across a variety of BBQ-related food matrices, including beef, pork, chicken, bratwurst (veal and pork), plant-based burger, watermelon, and tomato. Sample preparation was performed using a reduced-salt weight QuEChERS approach, followed by automated SPE using Oasis GCB/WAX for PFAS Cartridges on the PromoChrom SPE-03 System. Analysis was performed using the Xevo TQ Absolute Mass Spectrometer, enabling quantification at levels relevant to current and emerging regulatory interest. Method performance was evaluated through recovery studies at both 1.0µg/kg and 0.1µg/kg spike levels, demonstrating the ability to detect and quantify PFAS at concentrations relevant to existing European Union regulations. Additionally, the method achieved limits of quantification (LOQs) of 0.001 ug/kg for the EU 4 PFAS (listed in Table 1), meeting the analytical sensitivity recommended for fruits, vegetables, and baby food.

| | µg/kg | PFOS | PFOA | PFNA | PFHxS | Max Sum |
|---|---|---|---|---|---|---|
| Meat of bovine animals, pig, and poultry[1] | Maximum levels[1] | 0.3 | 0.8 | 0.2 | 0.2 | 1.3 |
| | Method LOQs[4] | 0.1 | 0.1 | 0.1 | 0.1 | — |
| Fruit and vegetables[4] | Indicative levels[4] | 0.01 | 0.01 | 0.005 | 0.015 | — |
| | Method LOQs[4] | 0.002 | 0.001 | 0.001 | 0.004 | — |

*Table 1. Maximum levels set in EU Commission Regulation 2022/2388 for food of animal origin[1] and indicative levels proposed in EU Commission Recommendation 2022/1431 for fruits and vegetables[4] with LOQs required by the recommendation for the analytical methods detailed.*

## Experimental

Meat and produce samples were purchased from a local grocery store. All meat samples were purchased fresh, with chicken and beef in ground form, pork and bratwurst as sausage, and the veggie burger as frozen patties. Each meat sample was blended in a food processor with dry ice until a uniform mixture was achieved. Watermelon was purchased pre-cut while tomatoes were purchased whole. Both produce samples were then prepared separately by homogenization in a blender.

All standards were purchased from Wellington Laboratories, Cambridge Isotope Laboratories, and LGC Standards. Table 2 lists the standard mix stock solutions used.

| Name of Commercial Standard | Purpose | Vendor |
|---|---|---|
| MPFAC-HIF-ES | Extracted Internal Standard | Wellington Laboratories |
| MPFAC-HIF-IS | Non-extracted Internal Standard | Wellington Laboratories |
| PFAC-mix | Native Standard Mix | Wellington Laboratories |
| M_2 6:2 FTS | Extracted Internal Standard | Wellington Laboratories |
| 13C3 PFDoDS | Extracted Internal Standard | LGC Standards |
| 13C6 PFTrDA | Extracted Internal Standard | Cambridge Isotope Laboratories |
| 13C3 PFTrDS | Extracted Internal Standard | LGC Standards |
| M_2 Capstone B (M_2 6:2 FTAB) | Extracted Internal Standard | Wellington Laboratories |

*Table 2. Native and isotope labeled standards used for analysis.*

A native PFAS mix stock solution was prepared in methanol and was used for serial dilutions. An extraction internal standard (EIS) solution was prepared in methanol and was used to spike samples prior to extraction. A mixture of EIS and non-extracted internal standards (NIS) was prepared in a solution of ammonium hydroxide, water, acetic acid, and methanol, which also was used as the diluent for the calibration standards. This solvent composition was selected to match the final composition of the SPE eluates, minimizing the solvent mismatch between calibration standards and sample extracts. Following extraction, the NIS solution was added to each sample extract prior to LC-MS/MS analysis.

A ten-point solvent calibration curve was prepared and used for quantification of all food sample extracts. For samples spiked at 1 µg/kg, the calibration range was 10 – 10,000 ng/L (0.01-10 ng/mL; 0.025 µg/kg – 25 µg/kg), while samples spiked at 0.1 µg/kg were quantified using a calibration range of 5 – 5,000 ng/L (0.005-5 ng/mL; 0.0125 – 12.5 µg/kg).

Concentrations were reported in µg/kg. Because there are no representative meat or produce reference samples that could be used as blanks, the blank samples were CEN blend QuEChERS salts that were spiked with EIS. Percent recoveries were calculated by subtracting the concentration in unspiked sample from that measured in the corresponding pre-extraction native-spiked sample, dividing the blank-corrected concentration by the expected spike concentration, and multiplying by 100%.

## Sample Preparation

All native spiked and unspiked samples and blanks were prepared in triplicate. The LC-MS/MS acquisitions were also run in triplicate. Sample preparation was performed using a reduced QuEChERS workflow with custom-weighed CEN Blend Pouches followed by SPE on the PromoChrom SPE-03 Gen 4 Automated SPE System. The sample preparation can be seen in Figure 1, and the SPE program is described in Table 3.

| | |
|---|---|
| 1 | • Meat: Cryo-grind with dry ice, allow to sublimate<br>• Fruit/Veg: Blend to uniform liquid |
| 2 | • Weigh 2 g sample and add to PP tube |
| 3 | • Spike samples with extracted internal standards and allow to sit for 2–3 hours |
| 4 | • Add 10 mL LC-MS grade Acetonitrile and vortex |
| 5 | • Add custom weighed CEN QuEChERS packet, and vortex |
| 6 | • Centrifuge 5 min at 4,000 RPM |
| 7 | • Transfer 10 mL supernatant to new 50 mL PP tube |
| 8 | • Dilute to 50 mL with LC-MS grade water, verify pH ≤ 6, adjust if needed |
| 9 | • Complete SPE with Oasis GCB/WAX dual phase Cartridge on PromoChrom SPE-03 |
| 10 | • Post spike non-extracted internal standards into 5 mL elute and add 25 µL of acetic acid, transfer to injection vial, analyze on Xevo TQ-Absolute System |

*Figure 1. Sample preparation procedure.*

## Automated SPE Method for PFAS in a 2 g Sample Post-QuEChERS Extract

| Action | Inlet 1 | Inlet 2 (ratio) | Flow | Volume |
|---|---|---|---|---|
| Elute W2 | Solvent 5 | — | 8 | 15 |
| Elute W1 | Solvent 3 | — | 8 | 5 |
| Add Sample W1 | Sample | — | 5 | 75 |
| Rinse | Solvent 2 | Air (20%) | 45 | 2.5 |
| Add Sample W1 | Sample | — | 5 | 5 |
| Rinse | Solvent 2 | Air (20%) | 45 | 5 |
| Add Sample W1 | Sample | — | 5 | 5 |
| Rinse | Solvent 2 | Air (20%) | 45 | 5 |
| Add Sample W1 | Sample | — | 5 | 5 |
| Shake | — | Time based | — | 20 s |
| Rinse | Solvent 4 | Air (20%) | 45 | 1.3 |
| Add Sample W1 | Sample | — | 5 | 3 |
| Rinse | Solvent 4 | Air (20%) | 45 | 5 |
| Add Sample W2 | Sample | — | 5 | 5 |
| Shake | — | Time based | — | 20 s |
| Air Purge W2 | Air | — | 5 | 3 |
| Add Sample W2 | Sample | — | 5 | 5 |
| Blow N2 | — | Time based | — | 3 min |
| Rinse | Solvent 5 | Air (20%) | 45 | 1.3 |
| Collect 1 | Sample | — | 1 | 3 |
| Rinse | Solvent 5 | Air (20%) | 45 | 5 |
| Air Purge R | Air | — | 20 | 5 |
| Shake | — | Time based | — | 15 s |
| Clean | Sample | — | 30 | 5 |
| Clean | Sample | — | 30 | 5 |
| Collect 1 | Sample | — | 1 | 15 |

*Table 3. PromoChrom SPE method for extraction of PFAS in meat and produce.*

## LC Conditions

| | |
|---|---|
| UPLC system: | ACQUITY™ UPLC™ I-Class PLUS System with PFAS Analysis Kit |
| Mobile phase A: | 2 mM Ammonium Acetate in Water |
| Mobile phase B: | 2 mM Ammonium Acetate in Acetonitrile |
| Column: | Analytical column: ACQUITY Premier BEH™ $C_{18}$ Column, 2.1 x 50 mm, 1.7 µm (p/n: 186009452)<br>Isolator column: Atlantis™ Premier BEH $C_{18}$ AX Column, 2.1 x 50 mm, 5.0 µm (p/n: 186010926) |
| Vials: | 700 µL Polypropylene Screw Cap Vials 700 µL (p/n: 186005219) |
| Column temperature: | 35 ˚C |
| Sample temperature: | 8 ˚C |
| Injection volume: | 2 µL for 1µg/kg spiked samples, and 10 µL for 0.1µ g/kg spiked samples |

## Gradient Table

| Time (min) | Flow Rate (mL/min) | %A | %B | Curve |
|---|---|---|---|---|
| 0 | 0.3 | 95 | 5 | initial |
| 0.5 | 0.3 | 75 | 25 | 6 |
| 3 | 0.3 | 50 | 50 | 6 |
| 6.5 | 0.3 | 15 | 85 | 6 |
| 7 | 0.3 | 5 | 95 | 6 |
| 8.5 | 0.3 | 5 | 95 | 6 |
| 9 | 0.3 | 95 | 5 | 6 |
| 11 | 0.3 | 95 | 5 | 6 |

## MS Conditions

| | |
|---|---|
| MS system: | Xevo TQ Absolute Mass Spectrometer |
| Ionization mode: | ESI-, (ESI+ for Capstones A and B) |
| Capillary voltage: | 0.5 kV |
| Source temperature: | 100 °C |
| Desolvation temperature: | 350 °C |
| Desolvation flow: | 900 L/hr |
| Cone flow: | 150 L/hr |
| MRM transitions: | See Appendix for full MRM Details |

## Data Management

| | |
|---|---|
| Software: | waters_connect™ for Quantitation Software |

# Results and Discussion

## Linearity and Calibration

Calibration curves were prepared in solvent using ten calibration levels and analyzed throughout each sequence alongside spiked samples. Linear regression with 1/x weighting was used for quantification. Linearity was achieved for all four EU-regulated PFAS analytes, as shown in Figure 2.

The calibration range was selected to support quantification of PFAS at concentrations relevant to current European Union maximum levels for food.[1] The lowest calibration standard (5 ng/L) provided sufficient sensitivity to support quantification of the regulated PFAS compounds in meat and produce following the miniaturized QuEChERS extraction procedure.

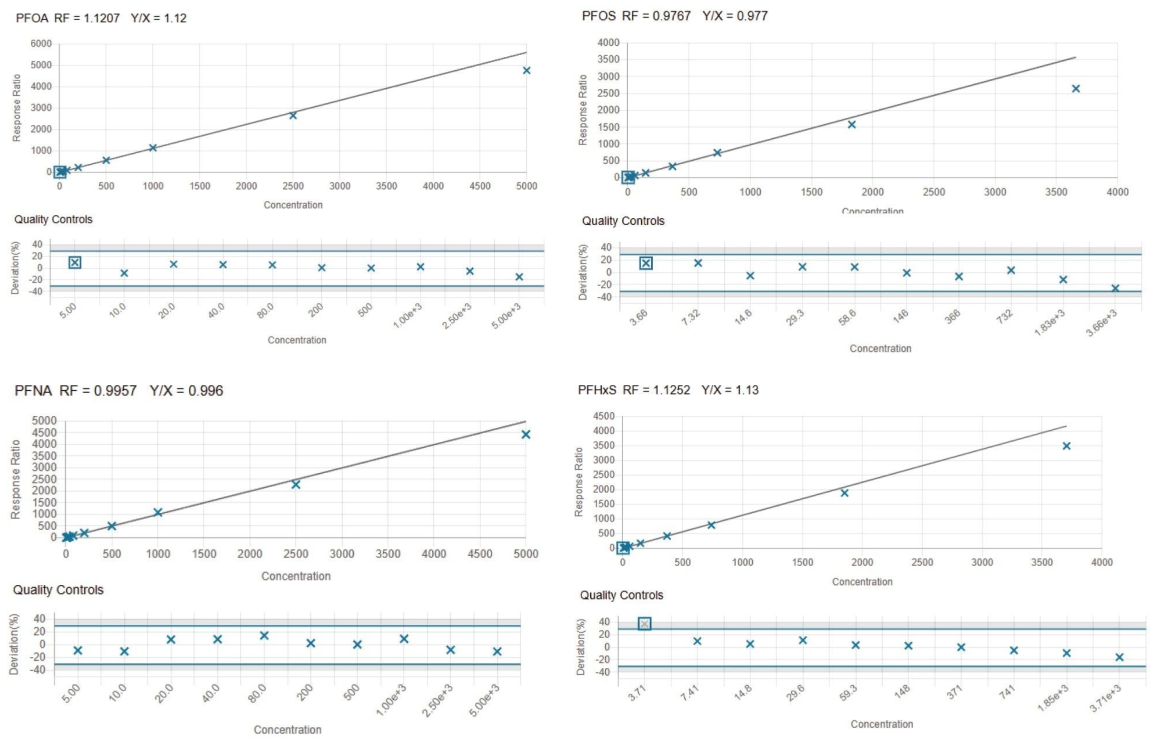


*Figure 2. Calibration curves and residuals plots of the EU mandatory PFAS (PFOS, PFOA, PFNA, and PFHxS).*

## Chromatography

Representative chromatograms of the four EU-regulated PFAS at the lowest calibration level (5 ng/L) are shown in Figure 3. All analytes produced well-defined, symmetrical peaks with consistent retention times and minimal background interference, demonstrating chromatographic performance suitable for quantification across the calibration range.

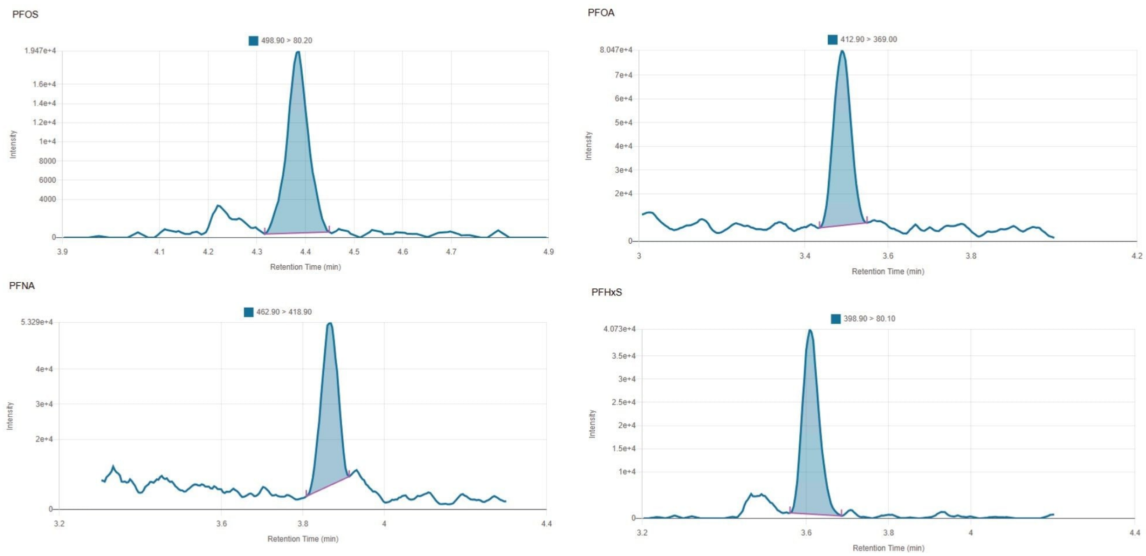


*Figure 3. Representative chromatograms of the EU-regulated PFAS (PFOS, PFOA, PFNA, PFHxS) at the lowest calibration level (Cal 1, 5ng/L).*

Most analytes demonstrated recoveries within the 70–130% range at both the 1 µg/kg and 0.1 µg/kg PFAS fortification levels, as shown in Table 4, highlighting the broad applicability of the method across a diverse range of PFAS analytes and food matrices. Importantly, the four PFAS currently regulated by the European Union (PFOS, PFNA, PFOA, PFHxS) met the EURL POPs recommended recovery criterion of 80-120%[5] at 0.1 µg/kg, supporting the robustness of the method for compounds currently subject to regulatory scrutiny.

While recoveries were generally comparable between the two fortification levels, greater variability was observed for some analytes at 0.1 µg/kg. This increased variability is expected at lower fortification levels; however the method maintained acceptable recovery and demonstrated reliable performance at these trace concentrations. Several fluorotelomer-based compounds exhibited greater concentration-dependent variability, likely reflecting these analytical effects rather than changes in extraction efficiency.

Overall, acceptable recoveries were achieved across the meat and produce samples evaluated, demonstrating the applicability of the extraction and SPE workflow to challenging food samples. The results demonstrate that the method is capable of reliable PFAS quantitation at both µg/kg and sub-µg/kg concentrations, supporting its suitability for trace-level PFAS analysis in foods relevant to current regulatory and monitoring efforts. Previous work demonstrated that Capstone A may be lost during the SPE procedure.[6] Recovery of Capstone A was consistently lower than that of Capstone B, likely because no compound-specific isotopically labeled internal standard was available at the time of experimentation. Instead, the isotopically labeled Capstone B analogue was used as a surrogate internal standard for both analytes, which may not fully compensate for differences in analyte behavior experienced by Capstone A throughout the workflow. Despite this limitation, these results demonstrate that the workflow provides reliable extraction, cleanup, and quantitation for a broad range of PFAS in complex food matrices, including meats and produce commonly associated with barbecue meals, while maintaining performance at concentrations relevant to current regulatory requirements.

| Compound | Spike Concentration | Veggie Burger % Recovery | Bratwurst % Recovery | Beef % Recovery | Chicken % Recovery | Pork % Recovery | Watermelon % Recovery | Tomato % Recovery |
|---|---|---|---|---|---|---|---|---|
| PFBA | 1 ng/g | 92 | 103 | 100 | 98 | 101 | 85 | 89 |
| | 0.1 ng/g | 192 | 156 | 130 | 156 | 157 | 145 | 100 |
| PFPeA | 1 ng/g | 97 | 108 | 104 | 100 | 109 | 92 | 96 |
| | 0.1 ng/g | 125 | 115 | 107 | 119 | 108 | 103 | 103 |
| PFHxA | 1 ng/g | 83 | 105 | 91 | 127 | 101 | 84 | 79 |
| | 0.1 ng/g | 72 | 63 | 63 | 56 | 53 | 55 | 64 |
| PFHpA | 1 ng/g | 93 | 108 | 97 | 102 | 120 | 83 | 86 |
| | 0.1 ng/g | 105 | 109 | 110 | 108 | 93 | 99 | 99 |
| PFOA | 1 ng/g | 99 | 102 | 105 | 100 | 113 | 86 | 100 |
| | 0.1 ng/g | 116 | 119 | 111 | 107 | 87 | 94 | 60 |
| PFNA | 1 ng/g | 104 | 116 | 114 | 101 | 108 | 89 | 90 |
| | 0.1 ng/g | 102 | 123 | 112 | 107 | 92 | 95 | 95 |
| PFDA | 1 ng/g | 109 | 112 | 102 | 95 | 85 | 88 | 87 |
| | 0.1 ng/g | 105 | 113 | 116 | 115 | 94 | 97 | 97 |
| PFUnDA | 1 ng/g | 108 | 125 | 109 | 104 | 104 | 94 | 93 |
| | 0.1 ng/g | 93 | 99 | 104 | 103 | 89 | 90 | 90 |
| PFDoDA | 1 ng/g | 99 | 112 | 99 | 103 | 109 | 88 | 88 |
| | 0.1 ng/g | 87 | 90 | 103 | 104 | 87 | 92 | 92 |
| PFBS | 1 ng/g | 100 | 109 | 102 | 99 | 102 | 87 | 90 |
| | 0.1 ng/g | 103 | 115 | 101 | 105 | 94 | 94 | 85 |
| PFPeS | 1 ng/g | 87 | 98 | 94 | 99 | 104 | 85 | 88 |
| | 0.1 ng/g | 91 | 101 | 104 | 69 | 78 | 98 | 98 |
| PFHxS | 1 ng/g | 90 | 106 | 98 | 91 | 100 | 85 | 87 |
| | 0.1 ng/g | 115 | 102 | 109 | 73 | 88 | 107 | 107 |
| PFHpS | 1 ng/g | 89 | 123 | 112 | 99 | 87 | 92 | 90 |
| | 0.1 ng/g | 77 | 146 | 96 | 95 | 85 | 90 | 90 |
| PFOS | 1 ng/g | 95 | 104 | 109 | 96 | 97 | 91 | 90 |
| | 0.1 ng/g | 82 | 77 | 110 | 88 | 63 | 89 | 89 |
| PFNS | 1 ng/g | 99 | 97 | 111 | 99 | 108 | 95 | 96 |
| | 0.1 ng/g | 90 | 129 | 98 | 92 | 87 | 83 | 83 |
| PFDS | 1 ng/g | 100 | 78 | 100 | 102 | 103 | 88 | 87 |
| | 0.1 ng/g | 94 | 129 | 97 | 107 | 97 | 89 | 89 |
| PFDoDS | 1 ng/g | 83 | 89 | 79 | 77 | 79 | 73 | 67 |
| | 0.1 ng/g | 92 | 90 | 103 | 98 | 95 | 98 | 98 |
| PFEESA | 1 ng/g | 95 | 116 | 106 | 104 | 108 | 92 | 93 |
| | 0.1 ng/g | 85 | 95 | 102 | 99 | 95 | 88 | 88 |
| PFMPA | 1 ng/g | 105 | 114 | 104 | 103 | 112 | 87 | 93 |
| | 0.1 ng/g | 93 | 90 | 99 | 97 | 93 | 98 | 98 |
| PFMBA | 1 ng/g | 97 | 110 | 106 | 103 | 104 | 88 | 95 |
| | 0.1 ng/g | 92 | 88 | 97 | 94 | 83 | 93 | 93 |
| GenX | 1 ng/g | 97 | 108 | 108 | 101 | 102 | 88 | 91 |
| | 0.1 ng/g | 105 | 106 | 113 | 107 | 83 | 105 | 105 |
| ADONA | 1 ng/g | 99 | 109 | 101 | 100 | 95 | 87 | 91 |
| | 0.1 ng/g | 98 | 99 | 107 | 97 | 76 | 92 | 92 |

| Compound | Spike Concentration | Veggie Burger % Recovery | Bratwurst % Recovery | Beef % Recovery | Chicken % Recovery | Pork % Recovery | Watermelon % Recovery | Tomato % Recovery |
|---|---|---|---|---|---|---|---|---|
| FOSA | 1 ng/g | 97 | 108 | 100 | 98 | 96 | 86 | 88 |
| | 0.1 ng/g | 93 | 97 | 101 | 102 | 92 | 95 | 93 |
| NMeFOSA | 1 ng/g | 98 | 107 | 111 | 110 | 110 | 97 | 94 |
| | 0.1 ng/g | 104 | 110 | 100 | 119 | 105 | 114 | 114 |
| NEtFOSA | 1 ng/g | 123 | 105 | 94 | 111 | 110 | 94 | 98 |
| | 0.1 ng/g | 92 | 93 | 103 | 103 | 101 | 97 | 97 |
| N-MeFOSAA | 1 ng/g | 95 | 109 | 105 | 93 | 105 | 102 | 95 |
| | 0.1 ng/g | 96 | 101 | 109 | 106 | 104 | 101 | 101 |
| N-EtFOSAA | 1 ng/g | 96 | 109 | 94 | 101 | 99 | 84 | 84 |
| | 0.1 ng/g | 85 | 92 | 95 | 95 | 74 | 103 | 103 |
| NMeFOSE | 1 ng/g | 131 | 114 | 113 | 114 | 107 | 93 | 98 |
| | 0.1 ng/g | 90 | 93 | 92 | 100 | 100 | 97 | 97 |
| NEtFOSE | 1 ng/g | 88 | 173 | 107 | 98 | 103 | 88 | 88 |
| | 0.1 ng/g | 80 | 93 | 100 | 98 | 98 | 94 | 94 |
| NFDHA | 1 ng/g | 100 | 109 | 102 | 104 | 106 | 91 | 93 |
| | 0.1 ng/g | 91 | 94 | 99 | 92 | 86 | 89 | 89 |
| 9Cl-PF3ONS | 1 ng/g | 93 | 111 | 104 | 101 | 100 | 92 | 90 |
| | 0.1 ng/g | 78 | 109 | 90 | 89 | 82 | 78 | 78 |
| 11Cl-PF3OUdS | 1 ng/g | 90 | 120 | 94 | 92 | 92 | 88 | 87 |
| | 0.1 ng/g | 91 | 133 | 104 | 97 | 95 | 93 | 93 |
| 4:2 FTS | 1 ng/g | 118 | 122 | 108 | 109 | 101 | 57 | 76 |
| | 0.1 ng/g | 22 | 71 | 100 | 80 | 78 | 50 | 50 |
| 6:2 FTS | 1 ng/g | 89 | 98 | 96 | 99 | 98 | 83 | 88 |
| | 0.1 ng/g | 132 | 130 | 128 | 131 | 171 | 122 | 101 |
| 8:2 FTS | 1 ng/g | 97 | 105 | 106 | 98 | 101 | 87 | 85 |
| | 0.1 ng/g | 106 | 94 | 110 | 105 | 85 | 101 | 92 |
| 3:3 FTCA | 1 ng/g | 91 | 97 | 94 | 100 | 92 | 77 | 76 |
| | 0.1 ng/g | 78 | 85 | 87 | 87 | 44 | 78 | 78 |
| 5:3 FTCA | 1 ng/g | 96 | 101 | 100 | 100 | 98 | 83 | 78 |
| | 0.1 ng/g | 80 | 90 | 91 | 76 | 103 | 71 | 63 |
| 7:3 FTCA | 1 ng/g | 102 | 112 | 98 | 97 | 109 | 87 | 82 |
| | 0.1 ng/g | 97 | 103 | 113 | 90 | 160 | 78 | 78 |
| PFTrDS | 1 ng/g | 70 | 88 | 83 | 76 | 80 | 74 | 66 |
| | 0.1 ng/g | 101 | 106 | 109 | 109 | 105 | 108 | 108 |
| PFTreDA | 1 ng/g | 100 | 112 | 106 | 104 | 107 | 93 | 97 |
| | 0.1 ng/g | 80 | 89 | 104 | 105 | 97 | 92 | 92 |
| PFTriDA | 1 ng/g | 93 | 102 | 82 | 85 | 80 | 73 | 72 |
| | 0.1 ng/g | 209 | 121 | 124 | 89 | 51 | 103 | 103 |
| PFUnDA | 1 ng/g | 108 | 129 | 109 | 104 | 104 | 94 | 93 |
| | 0.1 ng/g | 93 | 99 | 104 | 103 | 89 | 90 | 90 |
| PFUnDS | 1 ng/g | 60 | 128 | 79 | 91 | 101 | 72 | 78 |
| | 0.1 ng/g | 24 | 58 | 90 | 80 | 82 | 92 | 92 |
| Capstone A | 1 ng/g | 36 | 53 | 14 | 23 | 65 | 33 | 51 |
| | 0.1 ng/g | 27 | 13 | 30 | 19 | 12 | 33 | 35 |
| Capstone B | 1 ng/g | 159 | 132 | 89 | 108 | 121 | 95 | 75 |
| | 0.1 ng/g | 119 | 100 | 105 | 71 | 60 | 107 | 107 |

*Table 4. Percent recovery of each PFAS spiked into meats, with recoveries calculated at 1n ng/g and 0.1 µg/kg spike level.*

Table 5 summarizes the PFAS detected in each sample. Among the four PFAS currently regulated by the European Union (PFOS, PFOA, PFNA, and PFHxS), detections were infrequent and all measured concentrations remained well below the current EU maximum levels for meat and produce. PFOA and PFNA were detected sporadically across several matrices at low concentrations, while PFHxS was detected only in bratwurst and chicken, and PFOS was detected only in beef. The combined concentration of the four regulated PFAS remained low across all samples, with no matrix approaching the current European regulatory limits.

Several non-regulated short-chain PFAS and fluorotelomer compounds were also detected. PFBS was observed primarily in the veggie burger and bratwurst, while 4:2 FTS was detected in the veggie burger, watermelon, and tomato. Watermelon exhibited the highest total PFAS concentration (0.213 µg/kg), driven predominantly by 4:2 FTS rather than the regulated PFAS. Although this study was not designed to identify contamination sources, fluorotelomer compounds such as 4:2 FTS have been associated with environmental contamination and may reflect exposure through agricultural inputs or other environmental pathways.

Overall, these findings demonstrate that commercially available meat and produce samples contained relatively low PFAS concentrations, with regulated PFAS detected only sporadically and at trace levels. At the same time, the broader analyte panel provided additional insight into the occurrence of short-chain and emerging PFAS beyond those currently regulated, highlighting the value of comprehensive PFAS monitoring in food.

| Compound | Veggie Burger (µg/kg) | Bratwurst (µg/kg) | Beef (µg/kg) | Chicken (µg/kg) | Pork (µg/kg) | Watermelon (µg/kg) | Tomato (µg/kg) |
|---|---|---|---|---|---|---|---|
| PFPeA | ND | ND | ND | 0.037 | 0.037 | 0.029 | 0.038 |
| PFHpA | <LOQ | <LOQ | <LOQ | <LOQ | 0.052 | ND | ND |
| PFOA | 0.014 | <LOQ | <LOQ | <LOQ | ND | ND | ND |
| PFNA | <LOQ | <LOQ | <LOQ | <LOQ | ND | ND | <LOQ |
| PFDA | ND | <LOQ | <LOQ | <LOQ | ND | ND | ND |
| PFUnDA | <LOQ | <LOQ | <LOQ | <LOQ | ND | ND | ND |
| PFTriDA | ND | ND | <LOQ | <LOQ | ND | ND | ND |
| PFTreDA | <LOQ | <LOQ | <LOQ | <LOQ | ND | ND | ND |
| PFBS | 0.047 | 0.024 | ND | <LOQ | ND | ND | ND |
| PFHxS | ND | 0.013 | ND | <LOQ | ND | ND | ND |
| PFOS | ND | ND | <LOQ | ND | ND | ND | ND |
| NMeFOSA | ND | <LOQ | ND | <LOQ | ND | 0.019 | ND |
| 4:2 FTS | 0.042 | ND | ND | ND | ND | 0.164 | 0.021 |
| Total combined | **0.111** | **0.052** | **0.008** | **0.047** | **0.089** | **0.212** | **0.059** |
| Sum 4 regulated | **0.019** | **0.022** | **0.005** | **0.006** | **0.00** | **0.00** | **0.00** |

*Table 5. Concentrations in µg/kg of PFAS detected in meats and produce following blank correction.*

Figures 4 and 5 demonstrate the presence of the four compounds regulated by the EU and Figures 6 and 7 demonstrate the eight compounds that have been evaluated in food by the FDA in the meat and produce evaluated. While the U.S. doesn't currently have regulatory limits for these in food, the FDA uses these compounds for risk assessment and monitoring. This broader panel reinforces the same overall trends, while capturing additional short-chain and emerging PFAS. Trace levels of PFOA and PFNA were detected in the veggie burger and tomato samples. Although these concentrations were well below current EU maximum limits, they exceeded the EU Recommendation (EU) 2022/1431[4] monitoring guidance level of 0.001 µg/kg, highlighting the capability of the method to detect PFAS at concentrations relevant to ongoing European monitoring efforts.

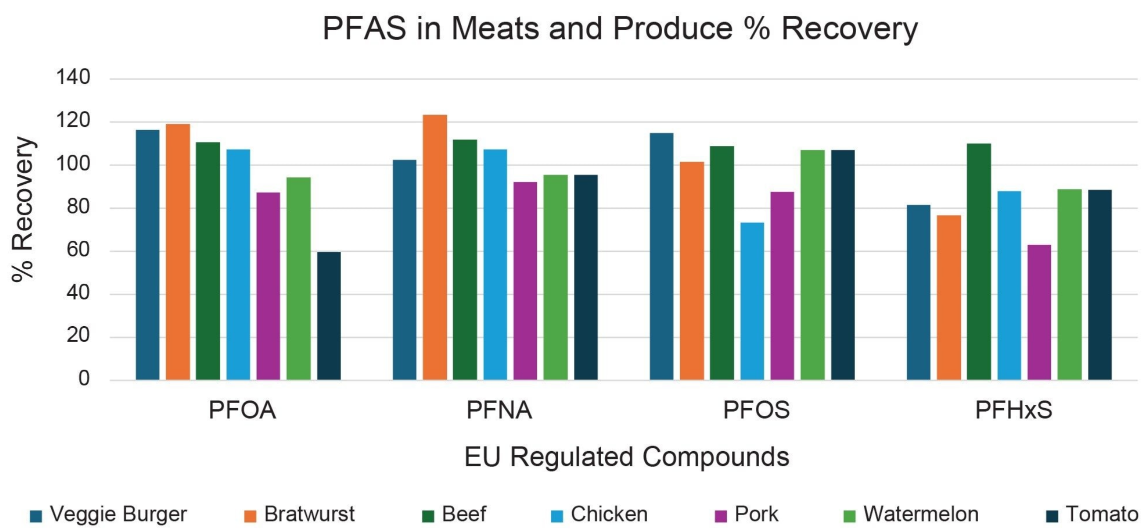


*Figure 4. Percent recovery for the four PFAS compounds regulated in food by the EU.*

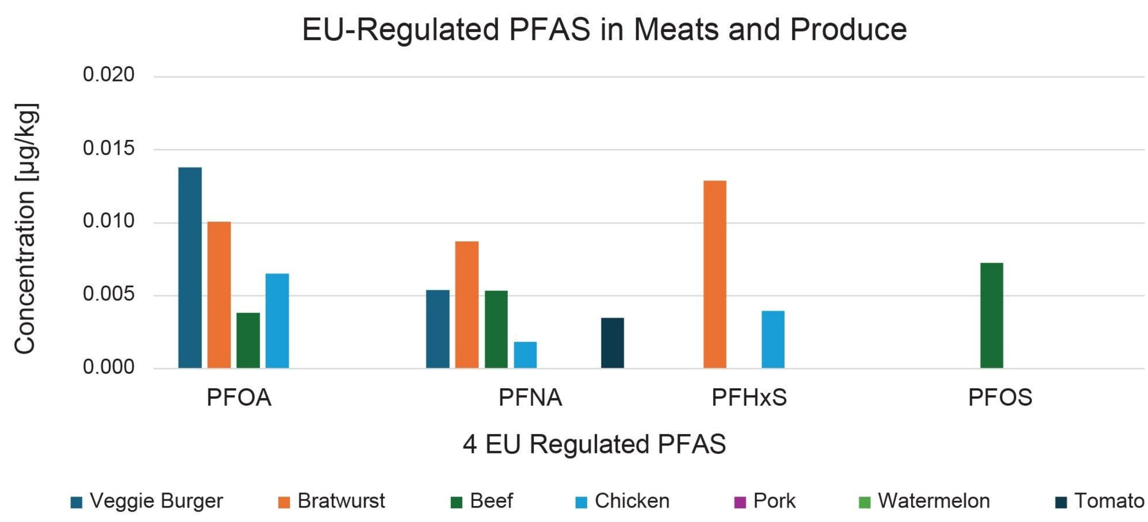


*Figure 5. Calculated concentration in µg/kg for the four PFAS compounds regulated in food by the EU.*

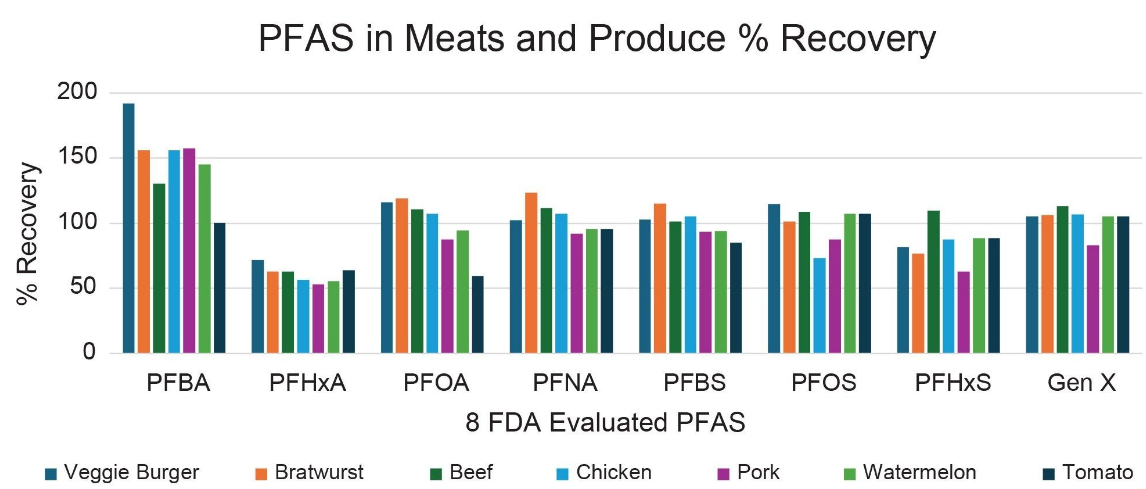


*Figure 6. Percent recovery for the eight PFAS compounds evaluated in food by the FDA, including the four EU regulated PFAS. The elevated PFBA recoveries observed may reflect contributions from background contamination, as PFBA is a ubiquitous environmental and laboratory contaminant.*

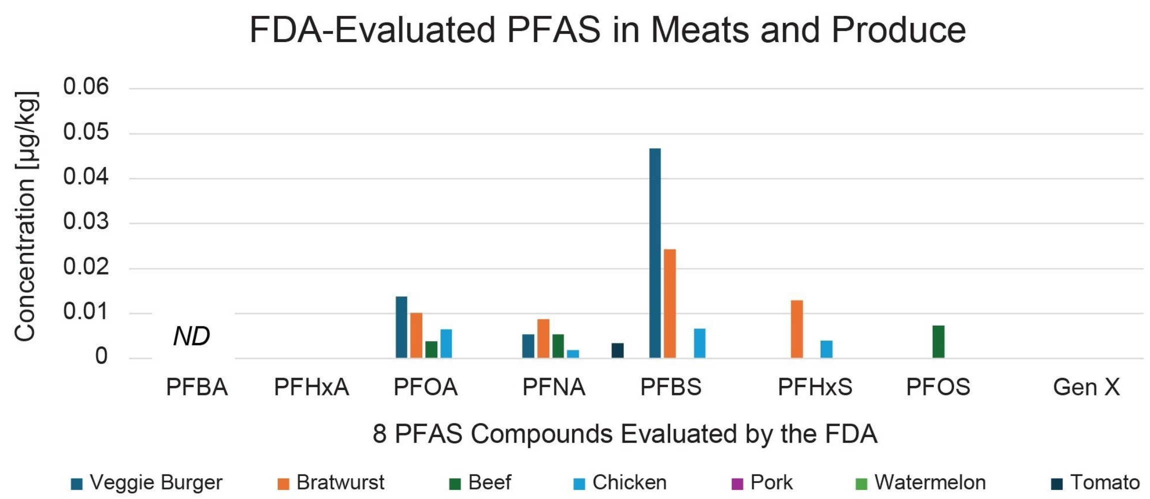


*Figure 7. Eight PFAS compounds evaluated in food by the FDA, including the four EU regulated PFAS. No US regulatory limits have been set as of the time of this publication (July 2026).*

## Conclusion

A reduced-volume QuEChERS workflow provided a simple and efficient sample preparation approach while minimizing sample requirements, reducing consumption of costly PFAS standards (as less volume of standards are needed for smaller sample sizes), and decreasing overall preparation time. Coupled with the enhanced sensitivity of the Xevo TQ Absolute Mass Spectrometer, the method enabled reliable analysis at concentrations as low as the 0.1µg/kg level regulated by the European Union without requiring larger sample masses.

For more complex matrices, automated SPE using the PromoChrom SPE-03 System in combination with the Oasis GCB/WAX for PFAS Cartridges provided efficient and reproducible extraction of PFAS from higher fat and protein foods. Automation of the SPE workflow also reduces hands-on time and increases laboratory throughput.

The method supports the analysis of PFAS currently regulated by the EU, compounds under evaluation by the FDA, and additional PFAS of emerging interest, including Capstone A and Capstone B. Recovery of Capstone A was consistently lower than that of Capstone B, likely attributable to the absence of an isotopically labeled internal standard specific to Capstone A. Quantitation of both analytes was performed using the Capstone B mass-labeled internal standard, which may not fully compensate for differences in extraction efficiency and matrix effects experienced by Capstone A.

Acceptable method performance was demonstrated at both 1 µg/kg and the more challenging 0.1 µg/kg fortification levels, supporting reliable quantification at concentrations relevant to current regulatory guidance. Across the food samples analyzed, PFAS occurrence was generally low, with detections consisting of mostly short-chain PFAS and only limited detections of regulated compounds at trace concentrations. These findings further demonstrate that PFAS monitoring should encompass a broad range of food matrices including meats, processed foods, plant-based alternatives, and produce.

As PFAS surveillance continues to expand, the reduced-volume QuEChERS workflow combined with automated SPE using Oasis GCB/WAX for PFAS Cartridges provides a robust, high-confidence solution for laboratories implementing or expanding PFAS testing. By reducing sample preparation time, minimizing solvent and PFAS standard consumption, and supporting reliable analysis across diverse food matrices, the workflow offers an efficient approach to high-confidence PFAS monitoring for routine laboratory food testing. Ultimately, this work demonstrates that even complex food matrices, including foods commonly seen in BBQs, can be analyzed using streamlined sample preparation and enhanced sensitivity of the Xevo TQ Absolute Mass Spectrometer.

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| Compound | CAS Number | Internal Standard | CV | CE | Expected RT | Precursor Mass (*m/z*) | Product Mass (*m/z*) | Product Mass 2 (*m/z*) |
|---|---|---|---|---|---|---|---|---|
| 11Cl-PF3OUdS | 763-051-92-9 | M8 PFOS | 30 | 30 | 5.35 | 630.9 | 450.80 (Quan) | 83 |
| 3:3 FTCA | 356-02-5 | None | 5 | 40 | 2.1 | 241 | 176.90 (Quan) | 116.9 |
| 4:2 FTS | 757124-72-4 | M2 4:2 FTS | 15 | 35 | 2.7 | 326.9 | 307.00 (Quan) | 81.1 |
| 5:3 FTCA | 914637-49-3 | M5 PFHxA | 5 | 25 | 3.8 | 340.9 | 237 | 216.90 (Quan) |
| 6:2 FTS | 27619-97-2 | M2 6:2 FTS | 15 | 30 | 3.3 | 426.9 | 407 | 80.80 (Quan) |
| 7:3 FTCA | 812-70-4 | M5 PFHxA | 10 | 22 | 5 | 440.9 | 337 | 316.90 (Quan) |
| 8:2 FTS | 39108-34-4 | M2 8:2 FTS | 15 | 35 | 4 | 526.9 | 506.8 | 80.80 (Quan) |
| 9Cl-PF3ONS | 756426-58-1 | M8 PFOS | 15 | 25 | 4.6 | 530.9 | 350.90 (Quan) | 83 |
| ADONA | 919005-14-4 | M3 GenX | 10 | 25 | 3.2 | 376.9 | 85 | 251.00 (Quan) |
| FHxSA | 41997-13-1 | M8 FOSA | 30 | 25 | 5.96 | 398 | 169 | 78.10 (Quan) |
| FOSA | 754-91-6 | M8 FOSA | 40 | 30 | 5.9 | 497.9 | 78.20 (Quan) | |
| GenX (HFPO-DA) | 13252-13-6 | M3 GenX | 5 | 35 | 2.3 | 285 | 169.00 (Quan) | 119 |
| N-EtFOSAA | 2991-50-6 | D5 N-EtFOSAA | 15 | 20 | 5 | 584 | 525.9 | 418.80 (Quan) |
| N-MeFOSAA | 2355-31-9 | D3 N-MeFOSAA | 35 | 25 | 4.5 | 569.9 | 418.90 (Quan) | 219.1 |
| NEtFOSA | 4151-50-2 | dNEtFOSA | 5 | 25 | 7.04 | 525.9 | 168.90 (Quan) | 218.9 |
| NEtFOSE | 1691-99-2 | d9 NEtFOSE | 15 | 15 | 6.91 | 630 | 59.00 (Quan) | |
| NFDHA | 151772-58-6 | M5 PFHxA | 5 | 10 | 2.8 | 295 | 200.90 (Quan) | 84.9 |
| NMeFOSA | 31506-32-8 | dNMeFOSA | 40 | 30 | 6.75 | 511.9 | 218.9 | 168.90 (Quan) |
| NMeFOSE | 24448-09-7 | d7 NMeFOSE | 15 | 15 | 6.6 | 616 | 59.00 (Quan) | |
| PFBA | 375-22-4 | M4 PFBA | 10 | 20 | 2.05 | 212.9 | 169.00 (Quan) | 19 |
| PFBS | 375-73-5 | M3 PFBS | 15 | 30 | 2.7 | 298.9 | 80.10 (Quan) | 99.1 |
| PFDA | 335-76-2 | M6 PFDA | 14 | 15 | 4.2 | 512.9 | 468.90 (Quan) | 219 |
| PFDoDA (PFDoA) | 307-55-1 | M PFDoDA | 30 | 25 | 4.9 | 612.9 | 568.90 (Quan) | 169 |
| PFDoDS (PFDoS) | 79780-39-5 | $^{13}C_3$ PFDoDS | 40 | 55 | 5.8 | 699.1 | 80.00 (Quan) | 99 |
| PFDS | 335-77-3 | M8 PFOS | 25 | 40 | 5.1 | 598.9 | 80.20 (Quan) | 99.1 |
| PFEESA | 113507-82-7 | M5 PFHxA | 15 | 20 | 2.9 | 314.9 | 134.90 (Quan) | 82.9 |
| PFHpA | 375-85-9 | M4 PFHpA | 15 | 15 | 3.1 | 362.9 | 319.00 (Quan) | 169 |
| PFHpS | 375-92-8 | M8 PFOS | 15 | 35 | 4.1 | 448.9 | 80.20 (Quan) | 99.1 |
| PFHxA | 307-24-4 | M5 PFHxA | 5 | 20 | 2.6 | 312.9 | 269.0 (Quan) | |
| PFHxS | 355-46-4 | M3 PFHxS | 10 | 35 | 3.7 | 398.9 | 80.10 (Quan) | 99.1 |
| PFMBA | 863090-89-5 | M5 PFPeA | 10 | 10 | 2.54 | 278.9 | 84.90 (Quan) | |
| PFMPA | 377-73-1 | M5 PFPeA | 23 | 10 | 2.15 | 228.9 | 84.90 (Quan) | |
| PFNA | 375-95-1 | M9 PFNA | 10 | 15 | 3.8 | 462.9 | 418.90 (Quan) | 219 |
| PFNS | 68259-12-1 | M8 PFOS | 20 | 40 | 4.8 | 548.9 | 80.20 (Quan) | 99.2 |
| PFOA | 335-67-1 | M8 PFOA | 10 | 15 | 3.5 | 412.9 | 369.00 (Quan) | 169 |
| PFOS | 1763-23-1 | M8 PFOS | 15 | 40 | 4.4 | 498.9 | 80.20 (Quan) | 99.1 |
| PFPeA | 2706-90-3 | M5 PFPeA | 10 | 20 | 2.4 | 262.9 | 219.00 (Quan) | 19 |
| PFPeS | 2706-91-4 | M3 PFHxS | 10 | 30 | 3.45 | 348.9 | 80.10 (Quan) | 99.1 |
| PFTreDA (PFTeDA) | 376-06-7 | M2 PFTreDA | 10 | 25 | 5.6 | 712.9 | 668.90 (Quan) | 169 |
| PFTriDA (PFTrDA) | 72629-94-8 | $^{13}C_6$ PFTrDA | 5 | 30 | 5.3 | 662.9 | 618.90 (Quan) | 169 |
| PFUnDA (PFUnA) | 2058-94-8 | M7 PFUnDA | 25 | 20 | 4.6 | 562.9 | 518.90 (Quan) | 269 |
| Capstone A | 80475-32-7 | M2 Capstone B | 44 | 34 | 4.4 | 529.1 | 58.00 (Quan) | 440 |
| Capstone B (6:2 FTAB) | 34455-29-3 | M2 Capstone B | 92 | 32 | 3.96 | 571.1 | 103.95 (Quan) | 439.97 |
| PFTrDS | 72629-96-0 | $^{13}C_3$PFTrDS | 40 | 54 | 6.1 | 749.1 | 80.00 (Quan) | 99 |
| PFUnDS | 749786-16-1 | M2 10:2 FTS | 40 | 52 | 5.45 | 649.1 | 80.00 (Quan) | 99 |
| PFHxA | 307-24-4 | M5 PFHxA | 5 | 10 | 3.7 | 312.9 | 269.00 (Quan) | |

*Appendix Table 1. MS method conditions for PFAS included in method. "(Quan)" indicates MRM used as quan* *ion.*

## Featured Products

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https://www.waters.com/nextgen/global/products/chromatography/chromatography-systems/acquity-uplc-i-class-plus-system.html>

MassTrak ACQUITY UPLC I-Class PLUS/Xevo TQ Absolute XR IVD System <
https://www.waters.com/nextgen/global/products/in-vitro-diagnostics-solutions/lc-ms-ms-ivd-systems-portfolio/masstrak-acquity-uplc-i-class-plus-xevo-tq-absolute-xr-ivd-system.html>

waters_connect for Quantitation <https://www.waters.com/nextgen/global/products/informatics-and-software/waters_connect-for-quantitation.html>

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