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# 3D-printed device for improved membrane-based extraction procedure of xenobiotics in complex matrices

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ABSTRACT

To minimize the environmental and human health impacts of chemical processes, there is growing interest in eco-friendly methods aligned with the principles of Green Analytical Chemistry (GAC). A successful chemical analysis typically involves sample preparation, sampling, separation and analysis, quantification, and data interpretation. Among these, sample preparation plays a crucial role in isolating and preconcentrating target analytes from complex matrices.

In 2014, fabric phase sorptive extraction (FPSE) was introduced as a simplified and greener sample pre-treatment method. Building on this advancement and a recent patent, the present study introduces an innovative 3D-printed device designed for use with a range of target analytes and complex sample matrices. Constructed from inert materials, the device features a rigid, modular structure with multiple windows that securely hold various membrane-based extraction materials. These include FPSE membranes, electrospun membranes, and materials derived from adsorbent systems recovered from production or usage waste, as well as permeable molecularly imprinted polymers (MIPs).

The device offers several advantages, including enhanced enrichment factors, compatibility with diverse planar membrane types, and highly customizable selectivity based on membrane configuration and chemistry. Its design also incorporates a built-in slot for a magnetic stirrer, enabling precise control of rotation speed during extraction-even *in field* conditions using a portable, battery-powered stirrer.

Experimental results unequivocally demonstrate that the new device achieves superior enrichment factors compared to previously validated methods for the same analytes, confirming its effectiveness and potential for broader analytical applications.

## 1. Introduction

Environmental pollution is a pressing global issue, strongly tied to the interaction between human activity and the environment. In recent years, this concern has driven a growing focus on environmentally friendly chemical practices. A key goal of modern analytical technologies is to ensure high quality results while minimizing the environmental impact of chemical analyses—an objective supported by the principles of Green Chemistry (GC), Green Analytical Chemistry (GAC), and Green Sample Preparation (GSP) [1–4].

Conventional analytical methods often generate substantial chemical waste, posing risks to both human health and the environment [1–5]. A typical chemical analysis involves several essential steps: sampling, sample preparation, separation and detection, quantification, and data

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interpretation. Among these, sample preparation is especially critical, as it involves isolating and preconcentrating target analytes—often present at trace or ultra-trace levels—from complex sample matrices laden with potential interferences [6]. However traditional sample preparation techniques (e.g., liquid-liquid extraction, protein precipitation) cause loss of analytes, and in complex matrix with low presence of analytes it could be a problem. In fact, the step in which there are major issues (and consequently reduction of efficiency) is sample preparation and many scientists are focusing their research to overcome this problem, simplifying sample preparation procedure, and maximizing automation, feasibility and portability, as required also by White Analytical Chemistry (WAC), an extension of GC [7].

To streamline this challenging step, several techniques have been developed. One such method is Fabric Phase Sorptive Extraction (FPSE), introduced and patented in 2014 [8]. FPSE employs natural or synthetic fabric substrates coated with sol-gel-derived hybrid sorbents to create an efficient, low-waste extraction membrane [9]. However, since GAC encourages the development of multi-analyte methods, FPSE often requires a compromise: selecting a single extraction chemistry that may not be optimal for every analyte. FPSE overcomes problem related to interferences, because it could be used directly also in viscous and complex matrices, without additional treatment. The ease to use and the wide range of coating and applicability have permitted to increase its attention to scientist world [10–13].

To address the limitation related to the choice of one surface chemistry, a new 3D-printed microextraction device was patented in 2025 by Kabir and colleagues [14]. As previously reported [9], to reduce extraction time required to obtain a good efficiency in extraction, various method could be applied, for example: reducing the coating thickness, increasing primary contact surface area and increasing the analyte diffusion in the sample matrix by applying external stirring. All of these parameters are respected with this device (plus for the cavity at the base of the device to put a magnet for stirring), and additionally, each FPSE works based on their characteristics, improving extraction efficiency and obtaining better results.

This device allows for the simultaneous use of multiple membrane types, improving analyte recoveries, sensitivity, and extraction efficiencies. Its versatility makes it suitable for diverse applications, including biological, pharmacotoxicological, clinical, environmental, pharmaceutical, food, cosmetic, and quality control analyses. It supports the extraction of a wide range of chemical compounds, including organic molecules and inorganic species like heavy metals.

Recently, interesting in 3D printing device has grown, especially in analytical chemistry, in which this approach could be useful in extraction and/or sample preparation step. For example, Carrasco-Correa et al. developed a device with a cup shape based on immunoaffinity working as stirring sorptive micro extraction. They used antibody (Ab) against Diclofenac (which was their target analyte) to extract the drug from wastewater using HPLC-UV to ensure the correct workflow of the device [15]. Instead, Ceballos and colleagues developed the first 3D printed device for uranium extraction through a flow-through magnetic-stirring assisted system. They overcome issues related to various sample preparation processes such as centrifugation or long filtration procedure through this 3D printed container [16]. Other interesting use of 3D printing in analytical chemistry are used mainly for environmental samples [17], but also for some little application in biological field [18, 19]. However, many 3D printed device for (micro) extraction techniques are focusing/works selectively, which means that they were developed for one/one type/one class of analyte(s). Additionally, Rolan-Pijuan and colleagues reported how stirring can influence extraction through FPSE [20].

The major advantage of FPSE is the wide range of applicability and all of these theories have led to the development of this device permitting the possibility of using more (substrates) than one simultaneously. Consequently, result manifests itself in improvements of micro extractions from both quali- and quantitative point of view.

The main aim of this manuscript is to present some applications of the patented device across different use cases, including examples drawn from existing literature. It demonstrates enhanced extraction efficiency and highlights the device's broad applicability across various complex matrices [21–25]. Already validated methods were used to demonstrate the possibility to improve sample preparation and, consequently, obtain higher results with the new device.

## 2. Materials and methods

### 2.1. Materials

All chemicals were of analytical grade or higher. Methanol (MeOH) and acetonitrile (AcN) were obtained from Honeywell (New Jersey, USA). Sodium phosphate monobasic and dibasic (purity >99 %), *o*-phosphoric acid, ethanol (EtOH), and a selection of phenolic compounds-including gallic acid, vanillic acid, caffeic acid, syringic acid, (-)-epicatechin, *p*-coumaric acid, and resveratrol-were sourced from Sigma-Aldrich (Milan, Italy).

A range of drugs used in the treatment of inflammatory bowel disease (IBD), including ciprofloxacin, sulfasalazine (Azulfidine), cortisone, and several NSAIDs (flurbiprofen, indoprofen, ketoprofen, fenbufen, ibuprofen), were also acquired from Sigma-Aldrich.

Ultrapure water (18.2 MΩ·cm at 25 °C) was generated using a Milli-Q Plus purification system (Millipore, Bedford, MA, USA).

Parabens (methyl paraben MPB, ethyl paraben EPB, propyl paraben PPB, isopropyl paraben iPPB, butyl paraben BPB, isobutyl paraben iBPB, benzyl paraben BzPB) and UV filters (BP-1, BP-2, BP-4, 4-DHB, DHMB, BZ) were provided by the Global Forensic and Justice Center (GFJC), Department of Chemistry and Biochemistry, Florida International University (Miami, FL, USA).

The FPSE membranes used included:

- Sol-gel Carbowax 20 M (Sol-gel CW 20 M, sorbent loading 8.63 mg/cm$^2$);
- Sol-gel Polyethylene Glycol-Polypropylene Glycol-Polyethylene Glycol (Sol-gel PEG-PPG-PEG, sorbent loading, 5.68 mg/cm$^2$);
- Sol-gel Octadecyl silane (Sol-gel C18, sorbent loading, 4.88 mg/cm$^2$);
- Sol-gel Polycaprolactone-Polydimethylsiloxane-Polycaprolactone (Sol-gel PCAP-PDMS-PCAP, sorbent loading 6.14 mg/cm$^2$);
- Sol-gel Polypropylene Glycol-Polyethylene Glycol-Polypropylene Glycol (Sol-gel PPG-PEG-PPG;
- Sol-gel Sucrose (Sol-gel SCS, sorbent loading 4.31 mg/cm$^2$);
- Sol-gel Polytetrahydrofuran (sol-gel PTHF, sorbent loading 3.96 mg/cm$^2$);
- Sol-gel Polycaprolactone (Sol-gel PCL).

All membranes were also provided by the Global Forensic and Justice Center (GFJC) at Florida International University, Miami, Florida, USA.

### 2.2. HPLC conditions

Chromatographic analyses were conducted using a Thermo Fisher Scientific HPLC system (Spectra System P2000) with a photodiode array detector (Spectra System UV6000LP). Detailed chromatographic conditions are provided in **Table S1** (Supplementary Materials).

### 2.3. Preparation of standard solutions

Stock solutions (1 mg/mL) of all analytes were prepared in appropriate solvents and stored under suitable conditions:

- UV filters: Prepared in MeOH and stored in amber vials at −20 °C; working solutions diluted in MeOH: HPW (50:50, *v:v*), stored at 4 °C, protected from light.

- Phenolic compounds: Stock solutions in EtOH; working solutions prepared in MeOH.
- IBD drugs: Stock solutions in mobile phase; working solutions obtained by dilution with the same.
- NSAIDs: Prepared in MeOH; working solutions diluted with phosphate buffer (pH 2.5, 30 mM): AcN (50:50, *v:v*).
- Parabens: Stock solutions in MeOH; diluted with water to prepare working solutions.

### 2.4. Sample preparation

Biological samples (whole blood, plasma, urine, and saliva) were collected from healthy volunteers with informed consent. According to international guidelines, fortified matrices were prepared with no >15 % alteration, specifically, 10 % of each matrix was spiked with analytes. Details are available in **Table S2** about each method used and previously validated.

### 2.5. FPSE procedure

The FPSE protocol followed these optimized steps:

1. Membrane cleaning: FPSE disk washed with 2 mL of AcN: MeOH (50:50, *v:v*) for 5 min.
2. Rinsing: Washed membrane submerged in HPW and handled with tweezers.
3. Extraction: Hydrated membrane placed in the sample and agitated on a TAAB rotator (500 rpm at room temperature) for 60 min (we have chosen the maximum time possible just to ensure the correct work without considering maximum absorbance or competition for each sorbent).
4. Back-extraction: Solvent volume and composition adjusted per analyte class; 150 μL of MeOH or mobile phases.
5. Centrifugation: 12,000 × *g* for 10 min.
6. Analysis: Supernatant injected into the HPLC-PDA system.

## 3. Results and discussion

Building upon previous research [21–25], this study evaluated the enhancement of analyte recovery using a novel 3D-printed FPSE device across biological and environmental matrices. The aim of using various and previously validated method was to evaluate the response of the device in front of different matrices and various analytes. There was the necessity of using high concentration just to better understand the results. In future we will perform calibration curves and real samples analysis directly using this device. In this manuscript, we will show only results relative to enrichment factors obtained using the new device. In Figs. 1 and 2 the device was presented and described in its dimensions and configuration tested in the present study.

The device could be constructed by inert and often recycled materials (e.g., polymer resins, plastics), features a rigid, windowed structure designed to support membrane-based extraction media. A key advantage is its high primary contact surface area (PCSA), which improves analyte interaction and diffusion.

Its modular design comprises two interlocking parts (male-female mechanism), allowing easy assembly and secure fixation of up to six FPSE membranes with distinct chemistries. A cavity in the base houses a magnetic stirrer, which promotes analyte diffusion-even in viscous matrices like whole blood-thereby enhancing extraction efficiency. The device has a height of 3.4 cm, width of 1.5 cm and a thickness of 0.4 cm. The hollow base is 1.8 cm wide and 1 cm thick to allow the insertion of the magnet, as shown in Fig. 1–3. The idea project was designed using CAD software, meanwhile the 3D stamp was obtained using Stereolithography (SLA) method and resin as material. Moreover, being the device useful for diverse applications, it may be subject to various modifications, increasing or decreasing the number of windows present according to the use and application at the time requested. As we previously reported, number of windows can be increased, but consequently there is the necessity of rising the sample volume or decreased by reducing sample volume. The choice of 6 windows is based on the possibility of testing the same device on environmental and biological matrices, without necessity of stamping other devices. For example, with environmental matrix based on the size of this device only 4 mL of sample was required. For biological matrices, using directly whole blood without any sample treatment to reduce both viscosity and sample amount we have diluted sample in order to arrive at 4 mL and cover the device/the FPSE.

This flexible design ensures compatibility with multiple membrane chemistries simultaneously, significantly improving the recovery of diverse analytes. Results (see Tables 1–5) confirm increased enrichment factors across a variety of sample types, demonstrating the effectiveness of combining different sorbent types in a single analysis.

First, an "extraction" of the empty device was conducted, in order to ensure the absence of interference (due to release of materials/

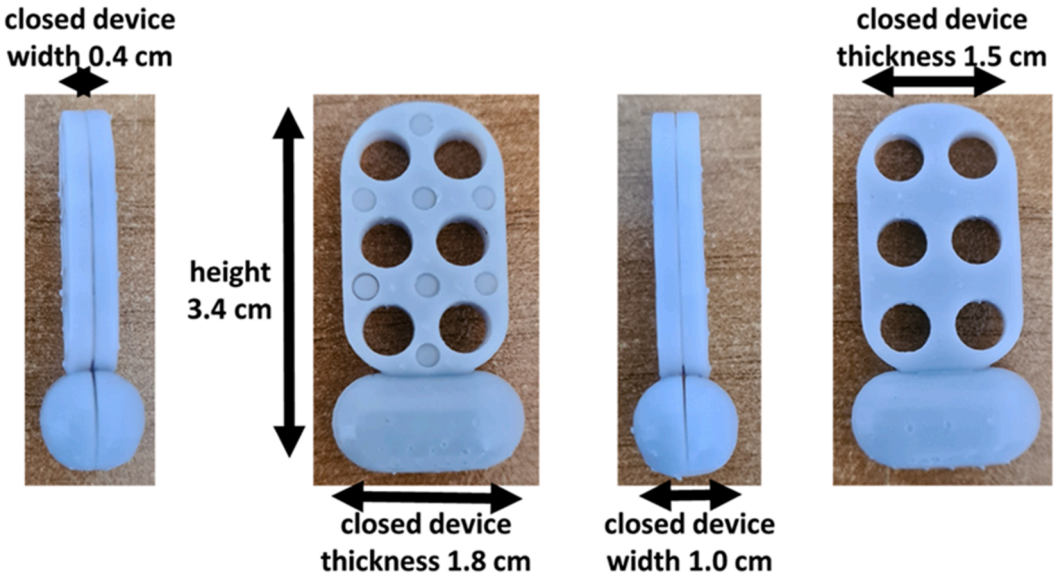


**Fig. 1.** Measurements expressed in cm of the device.

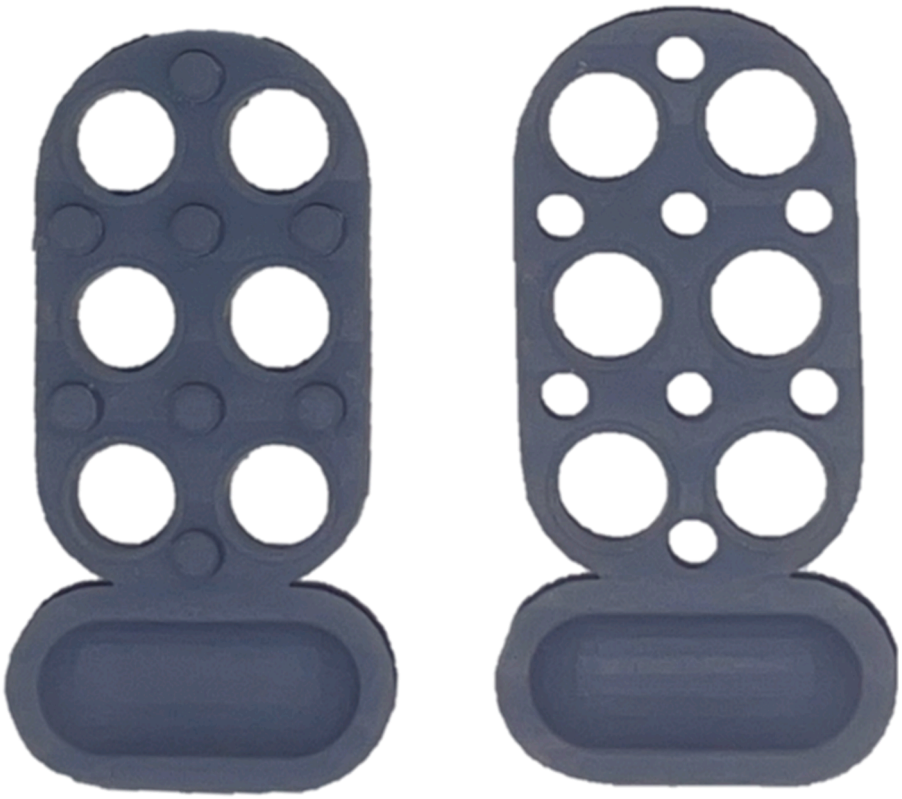

**Fig. 2.** Portions of the device.

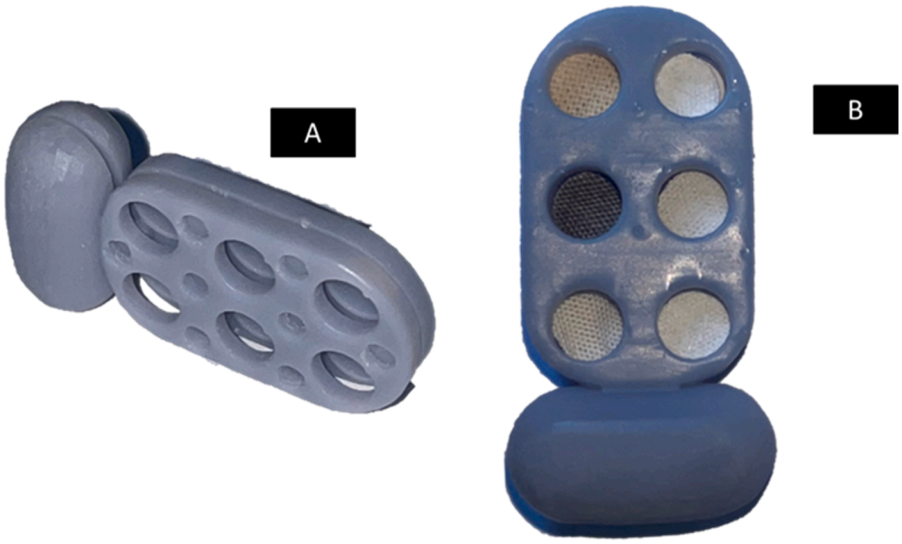


**Fig. 3.** Closed device without (A) and without FPSE membranes (B).

**Table 1**
Enrichment factors calculated for parabens.

| | | | MPB | EPB | PPB | Iso-PPB | BPB | Iso-BPB | BzPB |
|---|---|---|---|---|---|---|---|---|---|
| Biological matrices | *Classic FPSE protocol* | Whole blood[a] | 216 | 310 | 552 | 542 | 548 | 563 | 475 |
| | | Plasma[a] | 84 | 162 | 419 | 363 | 441 | 432 | 144 |
| | | Urine | 30 | 501 | 738 | 804 | 1092 | 1165 | 1487 |
| | *New Device* | Whole blood[a] | 178 | 275 | 614 | 753 | 1311 | 1612 | 1564 |
| | | Plasma[a] | 119 | 180 | 415 | 419 | 608 | 684 | 285 |
| | | Urine | 307 | 561 | 847 | 926 | 1152 | 1227 | 911 |
| Environmental | *New Device* | Tap water | 331 | 5890 | 93 | 1053 | 1668 | 1833 | 2056 |

[a] whole blood and plasma were diluted 1:5 v:v before extraction process. These samples were compared with a reference standard solution diluted 1:5 v:v too.

**Table 2**
Enrichment factors based on UVFs.

| | | | BP-4 | 4-DHB | BP-2 | BP-1 | DHMB | BZ |
|---|---|---|---|---|---|---|---|---|
| Biological matrices | *Classic FPSE protocol* | Whole blood[a] | 8 | 63 | 53 | 79 | 259 | 399 |
| | | Plasma[a] | 5 | 51 | 42 | 35 | 219 | 413 |
| | | Urine | 95 | 183 | 196 | 315 | 359 | 387 |
| | *New Device* | Whole blood[a] | 7 | 45 | 46 | 94 | 232 | 389 |
| | | Plasma[a] | 8 | 14 | 15 | 16 | 89 | 312 |
| | | Urine | 18 | 31 | 38 | 122 | 261 | 467 |
| Environmental | *New Device* | Tap water | 24 | 112 | 130 | 297 | 544 | 577 |

[a] whole blood and plasma were diluted 1:5 v:v before extraction process. These samples were compared with a reference standard solution diluted 1:5 v:v too.

**Table 3**
Enrichment factors of phenolic compounds.

| | | | Gallic acid | Vanillic acid | Caffeic acid | Syringic acid | (-)-epicatechin | *p*-coumaric acid | Resveratrol |
|---|---|---|---|---|---|---|---|---|---|
| Biological matrices | *Classic FPSE protocol* | Whole blood[a] | – | – | – | – | – | 2 | 20 |
| | | Plasma[a] | 1 | 1 | 2 | – | 10 | 3 | 59 |
| | | Urine | 3 | 5 | 10 | 5 | 36 | 11 | 126 |
| | | Saliva | 3 | 6 | 7 | 3 | 49 | 9 | 107 |
| | *New Device* | Whole blood[a] | – | – | – | – | – | 2 | 9 |
| | | Plasma[a] | 1 | 1 | 1 | – | 4 | 3 | 25 |
| | | Urine | 5 | 8 | 10 | 8 | 19 | 12 | 71 |
| | | Saliva | 5 | 9 | 10 | 7 | 24 | 11 | 70 |
| Environmental | *New Device* | Tap water | 3 | 6 | 6 | 4 | 19 | 8 | 87 |

[a] whole blood and plasma were diluted 1:5 v:v before extraction process. These samples were compared with a reference standard solution diluted 1:5 v:v too.

**Table 4**
Enrichment factors for IBD drugs.

| | | | Ciprofloxacin | sulfasalazine (Azulfidine) | Cortisone |
|---|---|---|---|---|---|
| Biological matrices | *Classic FPSE protocol* | Whole blood[a] | 17 | 5 | 144 |
| | | Plasma[a] | 29 | 5 | 289 |
| | | Urine | 5 | 66 | 219 |
| | *New Device* | Whole blood[a] | 13 | 6 | 29 |
| | | Plasma[a] | 14 | 9 | 43 |
| | | Urine | 23 | 122 | 39 |
| Environmental | *New Device* | Tap water | 47 | 145 | 23 |

[a] whole blood and plasma were diluted 1:5 v:v before extraction process. These samples were compared with a reference standard solution diluted 1:5 v:v too.

**Table 5**
Enrichment factors reported for NSAIDs.

| | | | Furprofen | Indoprofen | Ketoprofen | Fenbufen | Flurbiprofen | Ibuprofen |
|---|---|---|---|---|---|---|---|---|
| Biological matrices | *Classic FPSE protocol* | Whole blood[a] | 41 | 67 | 71 | 69 | 67 | – |
| | | Plasma[a] | 39 | 53 | 96 | 98 | 93 | 45 |
| | | Urine | 18 | 51 | 85 | 143 | 191 | 204 |
| | | Saliva[a] | 141 | 419 | 646 | 1240 | 1529 | 1598 |
| | | Saliva (unaltered) | 15 | 31 | 45 | 79 | 97 | 98 |
| | New device | Whole blood [a] | 60 | 92 | 61 | 53 | 67 | – |
| | | Plasma [a] | 66 | 88 | 82 | 69 | 95 | 46 |
| | | Urine | 9 | 15 | 20 | 51 | 81 | 105 |
| | | Saliva [a] | 86 | 138 | 135 | 277 | 412 | 531 |
| | | Saliva (unaltered) | 23 | 40 | 49 | 84 | 107 | 113 |
| Environmental | New device | Tap water | 10 | 14 | 18 | 40 | 56 | 73 |

[a] whole blood and plasma were diluted 1:5 v:v before extraction process. These samples were compared with a reference standard solution diluted 1:5 v:v too.

absorbance of it), establishing the possibility of using it in all of the matrices tested. In this way, the absence of interference and a sort of stability of the device based on our types of common solvents/matrices (MeOH, EtOH, $H_2O$, whole blood, urine, saliva, plasma) used was ensured.

This approach aligns with GC, GAC, and GSP principles by reducing time, solvent use, and material waste. The selected matrices-plasma, urine, whole blood-were chosen to showcase the device's adaptability to complex, real-world analytical scenarios.

Enrichment factors, expressed as percentage increases in chromatographic peak areas relative to standard solutions, are reported in the accompanying tables. As reported in 2.1 (materials), for each experiment six membranes were used in the device. In **table S3** are reported the chemistry used for each class of compounds, based on the previously studies in which they have been tested, being sure of their usefulness.

About back extraction of each FPSE for various experiments, they were taken out from the device, put in a new Eppendorf containing extraction solvent (MeOH, EtOH, mobile phases based on previously validated method), and simultaneously extracted. In this way there is not an excessive time consuming due to, for example, more consequential draws for each individual FPSE, following GAC principles.

In most of the analysis carried out, enrichment factor results better

than when used singularly. When results are lower, it is important to highlight that the membrane used had an inferior diameter, to ensure that they were all soaked in the matrix, as visible in Tables 1-5. One of the first points to consider in order obtaining suitable biological samples for instrumental analysis is biocompatibility. Biocompatibility is generally understood as protein adsorption and platelet adhesion when exposed to physiological fluids, for this reason it is often required protein precipitation to avoid irreversible conditions (for example clogging). FPSE (except C18) used for this manuscript are all biocompatible and their extraction performance is not influenced by the presence of protein or others external influences [26,27].

About parabens (Table 1), all enrichment factors have resulted higher than in past experiments, reaching a value up to five times higher, except for some values in plasma matrix [21]. About them affinity for FPSE a previous study was established that the best FPSE was CW20 M, but all others FPSE testes (the same that we used in this manuscript with the device shown in table S3) were good in enrichment factors, well explained by them polarity for CW 20 M and PEG300, others are medium polar [21].

To confirm previously reported problems in use one single type of FPSE, UV filters is the best option, because the higher value in enrichment factor is obtained using different coating based on chemistry of UV filter. To facilitate the extraction process from whole blood and plasma, in this case, after fortification, samples were diluted 1:5 *v:v*, obtaining enrichment factors higher than for past experiments [22]. Best affinity about FPSE for UV filters were less linear then for parabens, because BP-4, 4-DHB and BP-2 obtained their major enrichment factors with CW 20 M, instead for PPB, BP-1, DHMB and BZ best value were with SCS FPSE. However, they have chosen CW 20 M as best FPSE, because it was the only one to extract also the most polar compound (BP- 4) with good yields.

As reported in a past research [23], the choice of solvent used for back extraction is fundamental and based on chemical affinity of each compound enrichment factors could change. But the possibility to use more coating in a single extraction increases the enrichment factors and extraction yields in one extraction, matching perfectly with GAC requests.

Another interesting point to underline is that each coating presents different maximum values for adsorbing analytes and this characteristic is fully explained by Kabir and colleagues [24]. Instead, using this device percentage are more linear in all the concentrations used, avoiding to waste materials for the same experiment, because, as we know, biological sample are the lower sample in quantities, specially for clinical studies.

Tartaglia and colleagues compared two different dimensions of FPSE for their experiments, showing of course an increase in enrichment factors related to increase of diameters of the membrane in solvent solutions [25]. Using biological and environmental matrices, sometimes enrichment factors are lower than the higher FPSE diameter, but higher than the little ones, this could be a new point of view, but an increase in dimensions of the FPSE diameter will also increase the device and consequently, to be all membranes wet, also sample volume will be higher. However, for some analytes of interest enrichment factor is twice the previous.

## 4. Greenness of the device

In Fig. 4 are reported some examples highlighting the greenness of the patented device. First, the most common AGREE was tested. As shown in panel A, we obtained a good score [28]. About the first

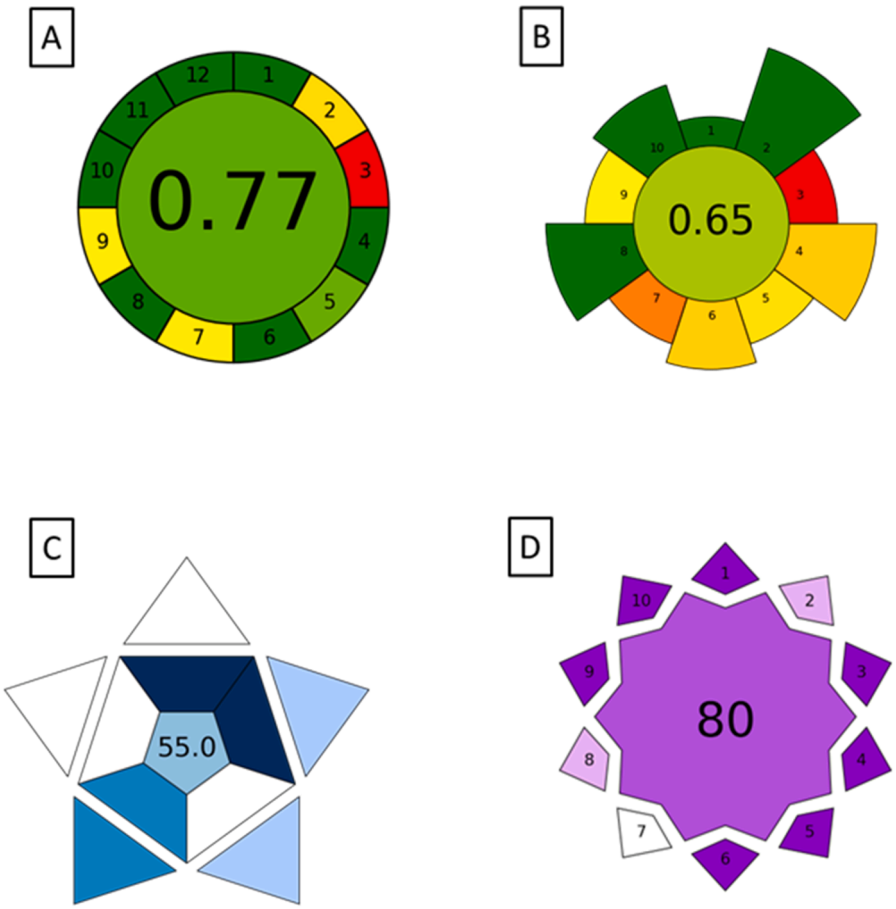


**Fig. 4.** Main used tools to ensure greenness and novelty of the device.

parameter, sampling could be performed in situ (for example for environmental samples), using with this specific device 4 mL of sample volume. As previously reported, sample volume and device's size could be reduced, decreasing number of windows for FPSE. In our experiments, we performed analysis in laboratory (not *in situ*) using a common and ease available instrumentation. In addition, AGREEprep was performed, panel B Fig. 4.

The worst parameter was the third, because renewable materials were not used, but this type of device could be also done using waste materials, as circular bioeconomy suggest [29,30].

About BAGI (Blue Applicability Grade Index), better part are regarding the absence of hazardous reagents, using only common solvents, the absence of preconcentration using instrument with high costs and energy consumption [31].

The violet tools, called Violet Innovation Grade Index (VIGI), panel D, perfectly match with this device, because it simplifies sample preparation, it is a miniaturized device, it is in center of various disciplines, improves sensitivity and it is a new approach for sampling/sample preparation [32].

## Conclusions

FPSE, first introduced in 2014, has revolutionized sample pretreatment by significantly simplifying and reducing the steps involved in chemical analysis. Building upon this foundation, the present work led to the development of a novel extraction device capable of hosting a variety of planar sorptive materials for the effective extraction of diverse analytes from different environmental, pharmaceutical, biological sample matrices.

The key advantages of the proposed device include the increase in enrichment factor from complex matrices, the possibility to use more than one FPSE, based on chemical characteristics of analytes to extract (with this device maximum 6) and the possibility to stir the device during extraction time, increasing permeability of FPSE. Being so little and portable, this system is suitable for small volume, but the mainly advantage is the possibility of in situ sampling. Based on the specific application, size of the device could be changed/adjusted based on the application. Being ease to use and having a specific diameter, this device could be useful for other planar extraction membranes.

The device's modularity, compactness, and field-deployable features make it an adaptable tool for modern analytical applications. Results from Experiments 1 through 5 confirm its robust performance across various sample matrices, including potentially unconventional ones-highlighting its versatility and analytical effectiveness. Notably, the improvements observed in enrichment factors underscore the potential of this device for high-efficiency extraction in complex analytical scenarios.

## CRediT authorship contribution statement

**Miryam Perrucci:** Methodology, Formal analysis, Investigation, Validation, Data curation, Writing – original draft, Writing – review & editing. **Erika Maria Ricci:** Methodology, Formal analysis, Investigation, Validation, Data curation, Writing – original draft, Writing – review & editing. **Abuzar Kabir:** Conceptualization, Supervision, Methodology, Writing – original draft. **Kenneth G. Furton:** Conceptualization, Supervision, Methodology, Writing – original draft. **Marcello Locatelli:** Conceptualization, Supervision, Methodology, Writing – original draft.

## Declaration of competing interest

This article is a direct result of a patent registered by the authors that declare the existence of a potential conflict of interest, as intellectual property protection implies an economic interest in the device.

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This research received no external funding.

*Data availability statement*

All relevant data are provided within the manuscript.

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## Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.sampre.2025.100205.

## Data availability

Data will be made available on request.

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