Analytical Methods

A novel block copolymer containing gadolinium oxide nanoparticles in ultrasound assisted-dispersive solid phase microextraction of total arsenic in human foodstuffs: A multivariate optimization methodology

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ABSTRACT

A new poly(3-hydroxy butyrate)-*b*-poly(dimethyl amino ethyl methacrylate) amphiphilic block copolymer containing gadolinium oxide nanoparticles (PHB-PDMAEMA-Gd$_2$O$_3$-NPs) were synthesized and used as composite adsorbent for extraction of total arsenic. Characterization of the composite adsorbent material PHB-PDMAEMA-Gd$_2$O$_3$-NP was studied using spectroscopic techniques. Plackett-Burman design and central composite design were employed to screening and optimization of the experimental parameters. This composite adsorbent was utilized in ultrasound assisted-dispersive solid phase microextraction (UA-dSPµE) for the determination of total inorganic arsenic in foodstuffs through hydride generation atomic absorption spectrometry (HG-AAS). It demonstrates a linear relationship across arsenic concentration range of 0.07–1.12 µg/L with a correlation coefficient (0.996). It's showed an enrichment factor of 128 and a limit of detection 0.02 µg/L for total inorganic arsenic determination. Accuracy of the developed method was confirmed through the analysis of certified reference materials with 96.0–98.5% recovery. It proved to be significantly useful UA-dSPµE method for determining total inorganic arsenic in different foodstuffs.

1. Introduction

Arsenic is a naturally occurring element that is widely distributed in the Earth's crust. It can be found in various environmental samples such as air, water, soil, and living organisms. Arsenic can enter the environment through natural processes such as weathering of rocks and minerals containing arsenic, volcanic activity and erosion (Ahmed et al., 2022). Additionally, human activities such as mining, smelting, burning of fossil fuels, and the use of arsenic-containing pesticides and wood preservatives can also contribute to arsenic contamination in the environment. Arsenic can also accumulate in soil, plants and the food chain leading to potential exposure through the consumption of contaminated foodstuffs (Sarker et al., 2022). Arsenic can find its way into foodstuffs through various sources. Arsenic is naturally present in the environment and certain geological formations can contain high levels of total arsenic. Crops grown in regions with naturally occurring arsenic in soil

or water may absorb it through their roots, leading to contamination of the foodstuffs. Arsenic can be present in water sources used for irrigation. If crops are irrigated with water containing elevated levels of arsenic, they can take up the arsenic and accumulate it in their edible parts. Historically, arsenic-containing compounds were used in pesticides and herbicides (Chen et al., 2016). Although their use has been banned in many countries, residual contamination may still be present in soils and can be taken up by crops. Animals raised for food consume various feeds and fodder. If their feed is grown in arsenic-contaminated areas and can be transferred to the animal products such as meat, milk, and eggs. Certain food processing techniques such as washing can remove some arsenic from the outer layers of foodstuffs. However, if water used in cooking is contaminated with arsenic, it can contribute total arsenic levels in the final food product. It occurs naturally in seawater and seafood like fish and shellfish can accumulate arsenic through their diet and the surrounding environment (Shirani et al.,

2020). Marine species, particularly certain types of fish, may have higher levels of inorganic arsenic due to their position in the food chain. It is important to note that the levels of arsenic in foodstuffs can vary depending on geographical location, agricultural practices, food processing methods and individual food items. Arsenic is highly toxic to human beings and can cause a range of adverse health effects. The toxicity of arsenic depends on several factors such as the chemical form of arsenic, duration and level of exposure, individual susceptibility, and route of exposure (Priyadarshanee, Mahto, & Das, 2022; Seyedi et al., 2022). Key points regarding the toxicity of arsenic for human beings. Ingesting high levels of arsenic over a short period can lead to acute poisoning symptoms. Arsenic is classified as a human carcinogen and is associated with an increased risk of developing several types of cancer, including skin, lung, bladder, kidney, and liver cancers (Palma-Lara et al., 2020).

Several analytical techniques have been reported for accurately measuring total inorganic arsenic determination in food samples. Hydride generation atomic absorption spectrometry (HGAAS), Graphite furnace-atomic absorption spectrometry (GF-AAS) are commonly used for inorganic arsenic determination technique involves measuring the absorption of light by arsenic atoms at specific wavelengths (Al-Behadili et al., 2020; Ali et al., 2015). Atomic fluorescence spectrometry (AFS) measures the fluorescence emitted by total arsenic atoms when excited by light at specific wavelengths. Hydride generation AFS is a popular technique for total arsenic determination. Inductively coupled plasma optical emission spectrometry (ICP-OES) uses inductively coupled plasma to atomize and excite the sample (Ziarati et al., 2020). ICP-MS combines inductively coupled plasma with mass spectrometry to measure the elemental composition of a sample. It provides high sensitivity and can detect trace levels of total arsenic concentration. These techniques may require sample preparation steps, such as digestion to extract total arsenic from the food matrix before analysis. The choice of technique depends on factors such as sensitivity requirements, sample matrix complexity and instrument availability in the laboratory (Kara et al., 2021). The above mention analytical spectroscopic techniques have certain disadvantages. The HG-AAS has some advantages such as cheap, easy operation, sensitive and available in every laboratory for the determination of total arsenic at low levels.

Sample preparation for spectroscopic techniques can be time-consuming and require extensive handling and treatment steps. Food samples often contain complex matrices that may interfere with the analysis, necessitating the need for sample digestion, clean-up procedures. Additional steps can increase the overall analysis time and introduce potential sources of error. While spectroscopic techniques can offer excellent sensitivity, they may still have limits when analysing trace levels of total arsenic concentration in complex food matrices. The presence of other matrix interferences can affect the accuracy of the measurements, requiring additional sample treatments. Spectroscopic techniques typically measure total arsenic content without distinguishing between different arsenic species. However, different arsenic species may have varying toxicities and health implications. For a comprehensive assessment of food safety, it may be necessary to determine the total arsenic, which often requires the use of additional separation techniques (Ahmed, et al., 2022). Moreover, the operation and interpretation of spectroscopic data require a certain level of expertise and training. This can limit the accessibility of these techniques to analysis. It is important to consider these limitations and select the most appropriate technique based on the specific requirements of the analysis, available resources, and desired level of accuracy and sensitivity.

Several methods used for the determination of total arsenic concentration in various food samples. Liquid-liquid extraction is a classical extraction method that involves the partitioning of arsenic between two immiscible liquid phases (Ji et al., 2021). Typically, an organic solvent is used to extract total arsenic from the aqueous sample. Organic phase separated, and the total arsenic content is determined using appropriate analytical methods. Solid-phase extraction utilizes a solid-phase sorbent

to selectively retain arsenic from the sample matrix (Dos et al., 2021). Sorbent is packed in a column, and sample is passed through it. Arsenic is retained on the sorbent, while interfering species are washed away. The arsenic is then eluted from the sorbent and analyzed. Cloud point extraction is a surfactant-based extraction method. It involves the addition of a surfactant to the sample, which forms micelles with the analyte (Bunina et al., 2022). Micelles are then separated from the aqueous phase by centrifugation and the analyte is subsequently quantified. The proposed UA-dSPμE method has several advantages such as simple, quick, environmentally friendly, higher enhancement factor, more accurate, sensitive, selective, and higher adsorption capacity than traditional dispersion methods (Altunay et al. 2023). The UA-dSPμE method has been employed with remarkable success, particularly in harnessing the power of ultrasound for enhancing the dispersion of the solid phase extraction. This results in a significantly increased contact area between arsenic contents with novel adsorbent PHB-PDMAEMA-Gd2O3-NPs for extraction. As a consequence, a substantial reduction in the consumption of chemical reagents is evident, aligning well with environmental considerations (Ashouri et al., 2021). It involves the dispersion of an extraction composite adsorbent into the sample containing arsenic in digested foodstuffs. The choice of extraction method depends on factors such as sample matrix, target analytes, required sensitivity and the available equipment and expertise.

Block copolymers are a class of polymers composed of two or more chemically distinct polymer chains linked together. They are known for their unique properties and have various important applications across different fields. The key importance and applications of block copolymers are controlled morphology, nanotechnology, drug delivery, surface modification, separation, photonic devices, coatings, lithography, biomedical applications, storage and conversion, etc. The versatility of block copolymers along with their ability to create well-defined nanostructures makes them invaluable in various scientific and industrial applications, contributing to advancements in materials science, nanotechnology and numerous other fields. In the first step, a block copolymer specifically poly (3-hydroxybutyrate)-*b*-poly (dimethylaminoethylmethacrylate) was synthesized. Poly(3-hydroxyalkanoate) (PHA) is accumulated in some bacterial cells from sugars, carbon dioxide, aliphatic carboxylic acids and various other carbon substrates. Poly(3-hydroxybutyrate) (PHB) is a short-chain-length PHA with a high melting point of approximately 170 °C. It is a hydrophobic, white crystalline polymer (Koray et al., 2010). To ensure improved performance for specific applications, PHB requires chemical modifications. Poly (dimethylaminoethylmethacrylate) is a hydrophilic polymer that exhibits phase separation in response to changes in temperature and pH (Goktaş, 2020; Loh et al., 2013). For the first time, gadolinium oxide nanoparticles (Gd$_2$O$_3$-NPs) were incorporated into the copolymer as an adsorbent for the pre-concentration of total arsenic effectively removing it from matrix components.

The main objective is to develop a new UA-dSPμE method for extraction and determination of total arsenic in various human foodstuffs by using HG-AAS. The UA-dSPμE method underwent a comprehensive exploration of various extraction parameters including pH, adsorbent quantity, mixing duration, sample volume, eluent volume, and temperature. The various optimization parameters that affect total arsenic concentration determination in UA-dSPμE were investigated using multivariate techniques. Furthermore, we validated this developed method for the analysis of diverse foodstuffs, encompassing eggs, fish, red meat, white meat, mushrooms, rice, salami, sausages, black tea, green tea, tomatoes, peppers, flour, cabbage, carrots, parsley and mint. The developed UA-dSPμE method enables the quantification of low levels of total arsenic in human food samples.

2. Methods and materials

2.1. Sampling and samples pretreatment

Real food samples, including natural products, meat products, grains, fruits, and vegetables, were collected from local markets in Tokat city, Turkey. Twenty (20) local markets in were randomly selected for sampling foodstuffs intended for human consumption. A total of 150 samples were collected, with 10 samples taken from each foodstuff, resulting in a total of 15 foodstuff samples. The food items included in the sampling were wheat, honey, egg, fish, red meat, white meat, mushroom, rice, salami, sausage, black tea, green tea, tomato, pepper, flour, cabbage, carrot, parsley and mint. All the food samples were collected and stored in polyethylene plastic bags (Shirani et al., 2023). They were promptly transferred to the laboratory and preserved in dry locations to prevent contamination. This step was crucial to minimize the loss of arsenic concentration prior to initiating the specific digestion procedure for extraction. The microwave-assisted acid digestion procedure for foodstuffs was then employed for further analysis.

2.2. Glassware and chemical reagents

In this research, analytical-grade chemical reagents were utilized. Solutions were prepared by employing high-purity double deionized water (DDW) obtained from an ELGA Laboratory Milli-Q® water system located in Bucks, UK. The required hydrochloric acid with a purity of 37% and nitric acid with a purity of 65% were procured from Merck, a reputable supplier based in Darmstadt, Germany. Additionally, a stock standard solution of inorganic arsenic (1000 mg/L) was acquired from the same source. Working standard solutions were generated by diluting the stock standard solution of arsenic through a series of dilutions using 0.2 mol/L nitric acid. The pH of the solutions was meticulously adjusted within the range of 2.0 to 10 by gradually adding 0.1 mol/L of hydrochloric acid/sodium hydroxide in drop-wise fashion to a phosphate buffer. The pH levels were closely monitored using a pH meter. To create the stock buffer solution required for pH control, a specific quantity of phosphoric acid or acetic acid salt was dissolved in DDW. The accuracy of the proposed UA-dSPµE method was duly validated using CRMs of wheat gluten-8418 (NIST) and clover honey-stalk (IPE-10).

2.3. Instrumentations

The determination of total arsenic was performed using the HG-AAS method with the Perkin Elmer model Analyst 700 instrument obtained from Norwalk, CT, USA. The operational conditions of the HG-AAS for total arsenic determination are described in detail below. To generate and atomize the hydride, a flow rate of 70.0 mL/min of 99.9% pure argon gas was employed, along with D_2 lamp background correction. The generated hydride was then directed into a preheated quartz cell with dimensions of 15.0 cm path length × 8.0 mm inner diameter. The heating of the quartz cell was accomplished using a flame atomizer. In the HG-AAS, an electrode less discharge lamp (EDL) was utilized as the light source for analysis. The recommended conditions for total arsenic determination included a current of 380 mA for the EDL, a wavelength of 193.7 nm, and a spectral bandwidth of 0.7 nm. The carrier/diluents solution utilized had a concentration of 1.50% (v/v) HCl, and the sample flow rate was set at 7.0 mL/min. Sodium tetrahydroborate was prepared at a concentration of 3.0% (w/v) in 1.0% NaOH (w/v) and used with a flow rate of 1.0 mL/min. During the total arsenic determination, the pre-reaction purge time, reaction time, and post-reaction purge time were maintained at 16.0 s, 9.0 s, and 38 s, respectively. The measured values of total arsenic in the standard and real digested foodstuffs solutions were calculated using the WinLab32 software installed in the instrument. The studied foodstuffs underwent centrifugation using an NF-200 centrifugation machine from Turkey, with optimized settings of a speed of 5000 rpm, a time of 60.0 min, and a power supply of 50/60 Hz. The

pH of the solution was adjusted and measured using a pH meter (Sartorius professional, meter pp-15). Characterization techniques such as Fourier Transform Infrared Spectroscopy (FT-IR) and Proton Nuclear Magnetic Resonance Spectroscopy (^{1}H NMR) were employed using the Jasco-430 model from Japan and the Anasazi Instruments, Inc. from the USA, respectively. For the analysis of the synthetic material using Scanning Electron Microscopy (SEM) and SEM-Energy-Dispersive X-ray Spectroscopy (EDX), an FEI Quanta FEG 450 SEM instrument operated at 200 kV was utilized. Finally, the synthetic block copolymer containing Gd_2O_3-NPs underwent analysis using a differential scanning calorimeter (DSC).

2.4. Microwave-assisted acid digestion procedure

To prepare the samples for microwave-assisted digestion, the following steps were followed. Duplicate amounts of 0.50 g of CRMs of wheat gluten-8418 (NIST), clover honey-stalk (IPE-10) and foodstuffs were taken individually in digestion polytetrafluoroethylene (PTFE) flasks. Freshly prepared 10.0 mL of a mixture of nitric acid and hydrogen peroxide in a 1:1 (V/V) ratio was added to each digestion PTFE flask. The flasks were then allowed to cool at room temperature for approximately 20 min. After the cooling period, the PTFE flasks were placed into a covered container in the microwave oven. The microwave conditions for digestion were as follows: 2.0 min at approximately 250 W, 2.0 min at approximately 0 W, 6 min at approximately 250 W, 5.0 min at approximately 400 W, 8 min at approximately 550 W, and a venting period of 8.0 min. After microwave-assisted acid digestion, each PTFE flask was cooled to room temperature. The resulting digested foodstuffs were evaporated to a semi dry solid by removing the excess acid mixture. The semi dry solid was then diluted with 20 mL of DDW in plastic vial. The diluted foodstuffs were used for the determination of total arsenic using the HG-AAS technique. In strong oxidizing media, higher valence arsenic can be present (Bachmann et al. 2023; Aposhian et al. 2023). It is important to note that these steps were specific to the described digestion procedure and the determination of total arsenic in foodstuffs (Ali et al., 2017b). The details may vary for different samples, analytes and analysis techniques. Always refer to established protocols, safety guidelines, and manufacturer's instructions when performing microwave-assisted digestion and subsequent analyses.

2.5. Synthesis of PHB-PDMAEMA block copolymer

The synthesis of a PHB-macro RAFT agent was conducted using the methodology outlined in the referenced publication (Hazer, Eren, Senemoğlu, Modjinou, Renard, & Langlois, 2020). To synthesize the PHB-macro RAFT agent, a blend containing 0.70 g of PHB-macro-RAFT agent, 2.10 g of DM, and 5.0 mg of AIBN was dissolved in toluene. The mixture was polymerized under an argon atmosphere at 80 °C for 5.5 h. After completion, the resulting PHB-PDMAEMA amphiphilic polymer was precipitated in excess diethyl ether. The obtained product was then dried at 40 °C in a vacuum oven for 24 h, resulting in a yield of 1.45 g. The water uptake of the product was measured to be 78%.

2.6. Preparation of PHB-PDMAEMA-Gd$_2$O$_3$ composite material

In a dry tetrahydrofuran solution, 0.46 g of PHB-DM was dissolved in 20 mL. Aqueous solution of $GdCl_3·6H_2O$ (40 wt%, 10 mmol of Gd^{3+}, 0.10 g) was gradually added to the solution with continuous stirring. After one hour, a sodium tetra borate solution in water (25 wt%, 32 mmol, and 0.05 g) was introduced to the mixture and stirred for an additional hour. The addition of aqueous solutions of sodium metaborate (4.0 mol) caused a moderate increase in pH, leading to the conversion of $GdCl_3·6H_2O$ into gadolinium oxide (Gd_2O_3) through the reaction with the reducing agent (Zhou et al., 2012). The obtained mixture was subjected to solvent evaporation, resulting in a residue. This residue was washed three times with 20 mL of distilled water. The

composite material was then dried under vacuum for 24 h. To enhance purification, the product was dissolved in dichloromethane. Subsequently, the solution was filtered to remove any free Gd_2O_3 clusters from the composite material. The resulting solution was then poured into 150 mL of *n*-hexane, leading to the precipitation of the PHB-PDMAEMA-Gd_2O_3 composite material. The composite material was dried under vacuum at room temperature for 24 h, yielding 0.36 g. The chemical structural formula of the PHB-PDMAEMA block copolymer can be observed in Fig. 1a.

2.7. Procedure of the UA-dSPµE method

In this experiment, novel composite adsorbent PHB-PDMAEMA-Gd_2O_3-NPs were utilized for the adsorption and desorption of the total arsenic contents. A solution containing arsenic with a suitable concentration 100 µg/L was adjusted to pH of 6.80 using 0.1 mol/L of HCl/NaOH (Eftekhari et al., 2020). Subsequently, 10 mg of the PHB-PDMAEMA-Gd_2O_3 composite material was added to the solution. The mixture of the tubes was placed in ultrasonic bath for uniform mixing of the total arsenic with composite adsorbent for 6.0 min at 25 °C temperature. Afterward, the sample was subjected to centrifugation to separate the supernatant from the composite material. The total arsenic concentration in the supernatant solution was then determined to investigate the recovery efficiency. For desorption of the absorbed arsenic, an elution step was performed using 2.0 mL of nitric acid (1 mol/L). The total arsenic concentration was subsequently determined using HG-AAS. The percentage recovery of the arsenic was calculated using a specific formula based on the obtained results.

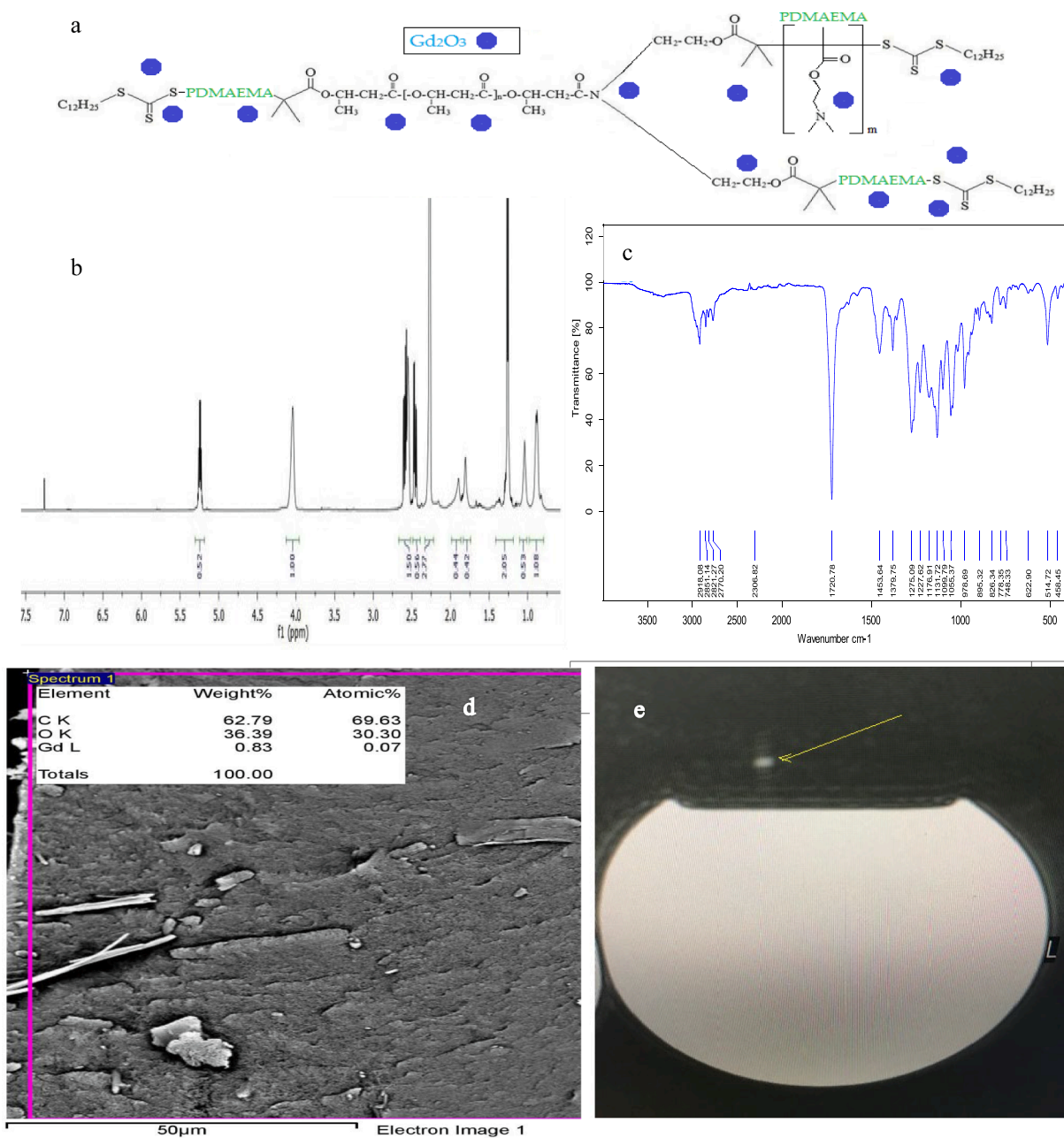$$Recovery\,(\%) = \frac{(Ci - Cf)}{Co} \times 100$$

Fig. 1. Characterization of the synthesized PHB-DMAEMA-Gd_2O_3-NPs; structural formula (a), 1H NMR spectrum (b), FTIR spectrum (c), SEM micrograph with EDX results (d) and MR image (e).

where: Co, Ci, and C_f represent the added, initial and final concentrations of arsenic in μg/L, respectively.

2.8. Multivariate methodology for optimization parameters

Optimization parameters play a crucial role in achieving maximum recovery of total arsenic using UA-dSPμE method. Various parameters, including pH, adsorbent amount, mixing time, temperature, sample volume, and eluent volume were thoroughly studied to determine their impact. The application of multivariate techniques has shown promise in improving the understanding of the synergistic connection between separation and extraction methods, particularly when dealing with extraction and optimization variables. Plackett-Burman design (PBD) is a commonly used statistical technique for screening to identify key factors, while CCD is employed for further data interpretation.

3. Results and discussions

3.1. Structure of the novel composite adsorbent

The PHB-PDMAEMA block copolymer is composed of two monomers, namely poly (3-hydroxybutyrate) and poly (dimethyl amino ethyl methacrylate). The PHB, derived from renewable sources, is a biodegradable polyester containing a hydroxyl group (–OH), a carboxylic group (–COOH), and a repeating methylene group (–CH_2-) three times (Fig. 1a). DM, on the other hand, is synthetic polyester with a repeating methylene group (–CH_2-) four times. The copolymerization of PHB and DM results in a block copolymer with alternating PHB and DM segments. The specific arrangement of these blocks can vary depending on the copolymerization process and the desired properties of the material. Fig. 1a provides the chemical structural formula of the PHB-PDMAEMA block copolymer for reference.

3.2. Characterization of the novel composite adsorbent

Structural characterization of PHB-PDMAEMA block copolymer was carried out using the ^{1}H NMR and FT-IR technique. In the ^{1}H NMR spectrum of the copolymer, you would typically observe peaks corresponding to the different hydrogen (proton) environments in the polymer structure. The PHB segment would typically exhibit signals related to the protons in the hydroxyl groups and the methylene groups. These would appear as broad signals in the region of approximately 1.2 to 2.5 ppm for the methylene protons and around 3.5 to 5.0 ppm for the hydroxyl protons. The specific chemical shifts and splitting patterns of these signals may depend on the polymerization conditions and the presence of any side-chain modifications. The DM segment, being polyester composed of repeating methylene units, would generally exhibit signals in the region of approximately 1.2 to 2.5 ppm for the methylene protons. The specific characteristics of the ^{1}H NMR spectrum of a PHB-PDMAEMA block copolymer can vary depending on the exact composition, the block lengths, and the copolymerization process used. Therefore, it would be best to consult the literature or scientific sources that specifically describe and characterization of the PHB-PDMAEMA block copolymer to obtain the precise spectral data for your particular system. The ^{1}H NMR spectrum of the PHB-PDMAEMA block copolymer was obtained using CDCl$_3$ as the solvent. The spectrum revealed characteristic chemical shifts for the different components of the copolymer. The –CH_3 group of PHB showed a chemical shift at 1.25 ppm, while the –CH_2-COO- group exhibited shifts in the range of 2.4–2.6 ppm. The -N-CH_2- group of PDMAEMA appeared at 4.0 ppm, and the –CHO– group showed shifts between 5.1 and 5.3 ppm. Additionally, the $(CH_3)_2$N– group of DMAEMA was observed at 2.3 ppm. The PDMAEMA segment displayed chemical shifts at 0.9–1.1 ppm for –CH_3 and 1.7–2.0 ppm for –CH_2-C(CH_3)-, as depicted in Fig. 1b.

A novel composite material with enhanced hydrophobicity,

composed of PHB-PDMAEMA block copolymer containing Gd_2O_3-NPs, was synthesized and characterized using the FT-IR and SEM-EDAX technique (Fig. 1c, Fig. 1d). The Gd_2O_3 characterization was identified using MR imaging technique (Fig. 1e). The incorporation of polydimethyl amino groups from PHB-PDMAEMA block copolymer contributed to the increased hydrophilicity and improved adsorption capabilities of the novel multigraft copolymer (Ali et al., 2016). Furthermore, the interaction between arsenic and the adsorbent material, PHB-PDMAEMA block copolymer, was investigated using UA-dSPμE method. In the FT-IR spectra, strong and broad peaks were observed in the range of 2918–2777 per cm, indicating N—H stretching in the amine (–NH) groups of the composite adsorbent. Additionally, a strong and narrow peak appeared at 1720 per cm, corresponding to the C═O stretching of the carboxylic acid in the dimmer of the composite adsorbent. Medium peaks were observed at 1455–1400 cm^{-1}, which can be attributed to C—H and O—H bending of the alkane and carboxylic acid functional groups, respectively. Furthermore, strong peaks at 1379 and 1275 cm^{-1} were observed, representing the S═O stretching of sulphonamide and the C—O stretching of alkyl aryl ether, respectively (Fig. 1c). Based on these spectral results, it can be concluded that the composite material of PHB-PDMAEMA block copolymer containing Gd_2O_3-NPs exhibits potential as an adsorbent for determining total arsenic in digested foodstuffs (Samadifar et al., 2023).

3.3. Characterization of surface morphology

Scanning Electron Microscopy (SEM) is a technique used to obtain high-resolution images of the surface of a sample (Datye & Delariva, 2023). It provides information about the morphology, surface features, and topography of the material. SEM micrographs of the PHB-PDMAEMA block copolymer can reveal details about its surface structure, such as the presence of phase separation or the arrangement of different polymer domains. Energy-Dispersive X-ray Spectroscopy (EDX) is often used in conjunction with SEM to analyze the elemental composition of a material. By detecting characteristic X-rays emitted when a sample is bombarded with an electron beam, EDX can provide qualitative and semi-quantitative information about the elements present in the analyzed area (Shirley & Jarochowska, 2022). In the case of the PHB-PDMAEMA block copolymer, EDX analysis can help identify the distribution of different elements within the material. To obtain SEM micrographs and EDX results of the PHB-PDMAEMA block copolymer, you would need to conduct specific experiments using the appropriate equipment. SEM micrograph of the PHB-PDMAEMA block copolymer was taken to evaluate the Gd_2O_3-NPs content inside. EDX results showed the Gd of 0.83 wt% in the continuous matrix (Fig. 1d). It's best to refer to scientific literature that specifically discuss the synthesis, characterization, and analysis of the PHB-PDMAEMA block copolymer to obtain the precise SEM micrographs and EDX results for this novel composite adsorbent for total arsenic determination.

There can also be a potential use of Gd_2O_3-NPs in conjunction with the PHB-PDMAEMA blocks copolymer for magnetic resonance (MR) imaging. Gadolinium-based contrast agents are commonly used in MR imaging to enhance the contrast and visibility of structures of interest (Blumfield et al., 2019). The Gd_2O_3-NPs due to their unique magnetic and optical properties have been investigated as potential contrast adsorbent in various imaging modalities, including MR imaging. When Gd_2O_3-NPs are incorporated into the PHB-PDMAEMA block copolymer, they can potentially provide enhanced contrast and improve the detection of specific areas of interest during MR imaging. The nanoparticles can be dispersed within the copolymer matrix, allowing them to be delivered to the target site for better visualization. The MR imaging characteristics of the PHB-PDMAEMA block copolymer containing Gd_2O_3-NPs, including the signal intensity, contrast enhancement, and distribution of nanoparticles within the polymer matrix, would depend on factors such as the nanoparticle concentration, size, surface functionalization, and the overall composition of the copolymer. To obtain

MR images of the PHB-PDMAEMA block copolymer containing Gd$_2$O$_3$-NPs, experimental studies would need to be conducted using appropriate MR imaging techniques and equipment. Gadolinium is a MR sensitive metal. MR images were obtained using a Philips Intera 1.5 Tesla Spectrometer. MR image of the PHB-PDMAEMA block copolymer containing Gd$_2$O$_3$-NPs was confirmed with a shiny dot marked with an arrow (Fig. 1e).

3.4. Amount of adsorbent and its capacity

Investigation of optimum adsorbent amount and adsorption capacity in UA-dSPμE method using composite of PHB-PDMAEMA block copolymer with Gd$_2$O$_3$-NPs. The proposed UA-dSPμE method utilizes a composite material of PHB-PDMAEMA block copolymer containing Gd$_2$O$_3$-NPs as a novel adsorbent for arsenic extraction from digested food samples (Al-Kinani et al., 2021). Determining the optimal amount of this

novel adsorbent in the solution mixture is a critical parameter for achieving efficient extraction. This novel composite adsorbent PHB-PDMAEMA-Gd$_2$O$_3$-NPs, is insoluble in aqueous solutions. To assess the impact of adsorbent amount on the maximum extraction of arsenic, a range of 5.0 to 15.0 mg was studied. Results demonstrated that the maximum recovery of total arsenic, exceeding 95%, was achieved when the 10.0 mg adsorbent amount was used. Hence, this specific amount of composite adsorbent was employed in the proposed UA-dSPμE method. Furthermore, it was observed that increasing the adsorbent amount beyond this value did not significantly affect the recovery of total arsenic using the developed UA-dSPμE method. The adsorption capacity of total arsenic for the novel composite adsorbent PHB-PDMAEMA-Gd$_2$O$_3$ can be calculated using the following equation:

$$\text{Adsorption capacity} = \frac{V\{C_i - C_f\}}{M}$$

Here, V represents the volume of the model solution, and M
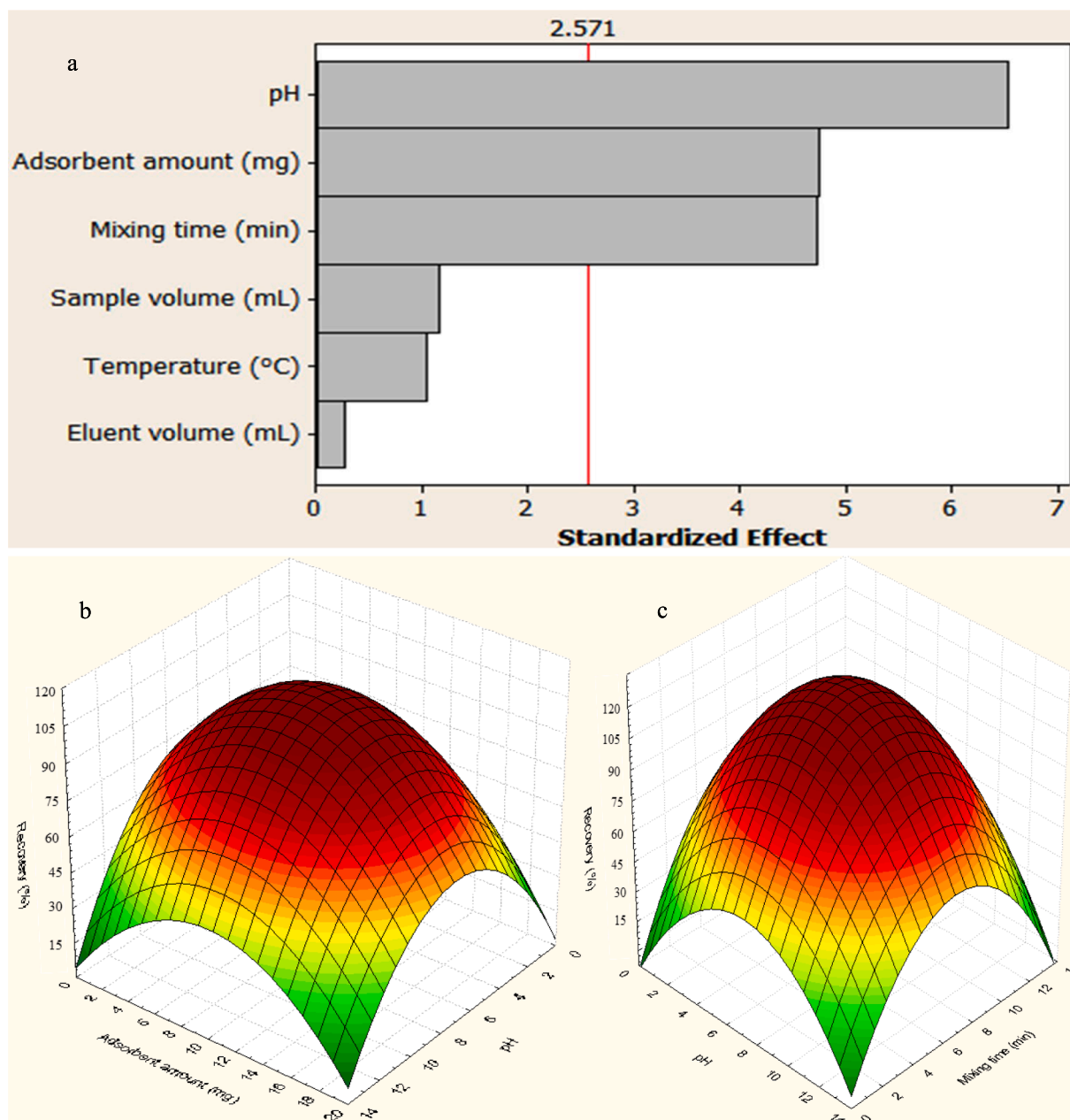

Fig. 2. Optimization by multiviriate techniques: pareto chart of standardized effect in factorial design (a), 3D surface plot interaction between pH and adsorbent amount (b) and 3D surface plot interaction between pH and mixing time (c).

represents the mass of the composite adsorbent. The C_i and C_f refer to the initial and final concentrations of total arsenic, respectively. To evaluate the adsorption capability of the novel adsorbent composite material optimal experimental conditions were employed. A model solution containing 100 mg/L of inorganic arsenic was mixed with 10.0 mg of the PHB-PDMAEMA-Gd$_2$O$_3$ composite adsorbent in a pH 6.80 environment. After thorough mixing, the effluent solution was analyzed using HG-AAS and the remaining concentration of total arsenic was determined to be 35.5 mg/L in the model solution. The adsorption capacity of the novel composite adsorbent PHB-PDMAEMA-Gd$_2$O$_3$ was calculated to be 290 mg/g. This value surpasses the adsorption capacities reported in the literature for arsenic extraction from aqueous solution. Consequently, the composite material developed in this study exhibits a significantly higher adsorption capacity for arsenic compared to previously reported adsorbents (Ali et al., 2016; Shirkhanloo et al., 2017).

3.5. Multivariate optimization methodology

Multivariate techniques refer to a set of statistical methods used to analyze data with multiple variables simultaneously. These techniques take into account the relationships and interactions between variables, allowing for a comprehensive exploration and understanding of complex datasets. The proposed UA-dSPµE method was optimized using multivariate techniques, specifically CCD and factorial design. Minitab-16 statistical software was utilized to create a PBD for screening the most significant extraction parameters. The standardized effects were visualized through a Pareto chart, with an alpha value of 0.05 and a 95% confidence interval for the percentage recovery (Fig. 2a). The screening test of the extraction variables using factorial design yielded observed results at a critical value of 2.571. Factors were considered to have significant effects when their experimental values surpassed this critical value. The optimal levels of the extraction parameters in the developed UA-dSPµE method were employed to generate a two-level PBD, as shown in (Table 1a). The complete factorial design allowed for the illustration of the combined effects of the 12 experimental results, represented by their percentage recovery. The extraction variables, namely pH, adsorbent amount, mixing time, sample volume, temperature, and eluent volume, were examined at both high and low levels. The estimated effects of the extraction factors and their interactions were quantified using the percentage recoveries. By observing the combined percentage recoveries, the effects of varying the extraction parameters from higher to lower values could be analysed (Table 1a).

3.5.1. Factorial design for screening of variables

Factorial design is a popular and efficient approach for experimental parameter screening. It allows researchers to investigate the effects of multiple factors and their interactions on the response variable of interest. In a factorial design, factors are manipulated at different levels, and the response variable is measured under each combination of factor levels. The most significant extraction parameters were observed from the resulting data of PBD, including pH, amount of novel adsorbent, uniform mixing time, sample volume, temperature, and eluent volume with a confidence level of 95%. Therefore, a careful investigation was conducted to determine the impact of these three extraction parameters. Experiment 3 demonstrated that the maximum retrieval of total arsenic

Table 1a
Lower and upper values of the experimental variables in Plackett-Burman Design.

Variables	Units	Lower values	Upper values
pH	–	4.00	10.0
Adsorbent amount	mg	5.00	15.0
Mixing time	min	2.00	10.0
Sample volume	mL	30.0	55.0
Eluent volume	mL	1.00	3.0
Temperature	°C	20.0	35.0

occurred when pH, adsorbent amount, and mixing time were set at higher values, while sample volume, eluent volume, and temperature were set at lower values. Conversely, the lowest recovery of total arsenic, amounting to only 24%, was achieved when all parameters, namely pH, adsorbent amount, mixing time, sample volume, eluent volume, and temperature, were set to lower values, as indicated by rune order 12 shown in Table 1b. The proposed UA-dSPµE method revealed that pH, adsorbent amount, and mixing time exerted significant effects on the recovery of total arsenic. These extraction parameters were found to have considerable impact on the recovery of total arsenic. On the other hand, parameters such as sample volume, eluent volume, and temperature had a lesser influence. In run order 1, a combined effect was observed with higher values of sample volume and pH, and lower values of adsorbent amount, mixing time, temperature, and eluent volume, resulting in a recovery of 44%. In run order 6, a combined effect was observed with higher values of sample volume, adsorbent amount, pH, and mixing time, and a lower value of temperature, leading to a recovery of 89.2% (Table 1b). Hence, it can be concluded that sample volume, temperature, and eluent volume have an insignificant impact on the extraction of total arsenic using the developed UA-dSPµE method. The maximum recovery of total arsenic was observed in run orders 3, 5, 6, and 7, indicating the substantial influence of pH, adsorbent amount, and mixing time, which ensure uniform mixing and extraction of arsenic in digested foodstuffs. By systematically varying the levels of multiple factors and observing their effects on the response variable, factorial designs provide valuable insights into the relationships between factors and the response variable. They are particularly useful for screening a large number of parameters efficiently and identifying significant factors for further investigation.

3.5.2. Central composite design for optimization

A CCD is a commonly used experimental design approach for optimization purposes (Nainggolan et al., 2023). It combines factorial and response surface designs to efficiently explore the response variable space and determine optimal settings for significant parameters. Once the response surface model is fitted, use optimization techniques to identify the significant parameters that maximize or minimize the response variable (Al-Kinan et al., 2023). The optimization of significant variables was carried out using CCD, which primarily involved 2nd order response surface modeling. To further optimize the UA-dSPµE method, a central 2^{3+} star orthogonal composite design was employed, incorporating 5 variables across 20 runs. Among these variables, three crucial extraction parameters, namely pH, adsorbent amount, and mixing time, were identified as significant factors for achieving maximum response in the desired method. Insignificant extraction variables, such as sample volume, eluent volume, and temperature, were set at predetermined suitable values (45 mL, 2.0 mL, and 25 °C, respectively) for all subsequent runs. The influence of the significantly affected experimental parameters, pH, adsorbent amount, and mixing time, on arsenic recoveries was observed. The optimal values for all three parameters, namely pH, adsorbent amount, and mixing time, were determined as 6.80, 10.0 mg, and 5.50 min, respectively. These optimal values were observed in runs 16 and 20, resulting in the highest arsenic recoveries of 98%, as shown in (Table 1c). This finding confirms that the classical method and the central 2^{3+} orthogonal composite design yield similar optimal values for pH and adsorbent amount, as depicted in (Fig. 2b). Run 14 exhibited the highest value of mixing time 12.0 min, while the other two factors had minimal effects on the recovery of arsenic. The pH variable emerged as another significant factor, playing a crucial role to achieve maximum recovery of arsenic in digested foodstuffs. The recoveries of total arsenic ranged from 24 to 43% at the minimum and maximum pH values in runs 1 to 9. In runs 12 and 15, the lowest and highest values of mixing time resulted in arsenic recoveries of 10% and 24%, respectively, while the other two parameters were maintained at their optimal values in both experiments. However, increasing the mixing time to its highest value, while keeping the other

Table 1b
Results of the six experimental variables in Plackett-Burman Design.

Run order	Sample volume (mL)	Adsorbent amount (mg)	pH	Temperature (°C)	Mixing time (min)	Eluent volume (mL)	Recovery (%)
1	55.0	5.00	10.0	20.0	2.00	1.00	44.0
2	55.0	15.0	4.00	35.0	2.00	1.00	42.0
3	30.0	15.0	10.0	20.0	10.0	1.00	90.3
4	55.0	5.00	10.0	35.0	2.00	3.00	62.8
5	55.0	15.0	4.00	35.0	10.0	1.00	72.0
6	55.0	15.0	10.0	20.0	10.0	3.00	89.2
7	30.0	15.0	10.0	35.0	2.00	3.00	72.5
8	30.0	5.00	10.0	35.0	10.0	1.00	64.5
9	30.0	5.00	4.00	35.0	10.0	3.00	39.5
10	55.0	5.00	4.00	20.0	10.0	3.00	44.8
11	30.0	15.0	4.00	20.0	2.00	3.00	34.6
12	30.0	5.00	4.00	20.0	2.00	1.00	24.0

Table 1c
Results of significant variables and percentage recovery in CCD.

Runs	pH	Adsorbent amount (mg)	Mixing time (min)	Recovery (%)
1	4.00	5.00	2.00	24.0
2	10.0	5.00	2.00	25.0
3	4.00	15.0	2.00	32.0
4	10.0	15.0	2.00	38.0
5	4.00	5.00	10.0	35.0
6	10.0	5.00	10.0	24.0
7	4.00	15.0	10.0	32.0
8	10.0	15.0	10.0	32.0
9	4.00	10.0	5.50	43.0
10	10.0	10.0	5.50	23.0
11	6.80	5.00	5.50	55.0
12	6.80	15.0	5.50	10.0
13	6.80	10.0	2.00	17.0
14	6.80	10.0	10.0	32.0
15	6.80	10.0	5.50	24.0
16	6.80	10.0	5.50	98.0
17	6.80	10.0	5.50	76.0
18	6.80	10.0	5.50	87.0
19	6.80	10.0	5.50	90.0
20	6.80	10.0	5.50	98.0

two factors at their optimal values, did not significantly enhance the recovery of total arsenic. The proposed UA-dSPµE method demonstrated the critical role of mixing time at both lower and higher values (Fig. 2c). After identifying the most significant experimental parameters through factorial design, CCD was employed to optimize the significant variables for achieving maximum recovery of total arsenic.

In order to achieve the optimum recovery of total arsenic in digested foodstuffs, a statistical approach known as CCD was employed. The interactions between pH versus adsorbent amount and pH versus mixing time were analyzed through 3D response surface graphs, as depicted in (Fig. 2b, Fig. 2c), to identify the conditions that would result in maximum recovery. A quadratic equation was then used to estimate the expected response surface data, enabling the determination of the optimal values for the significant extraction parameters that would yield maximum recovery. The optimized values were observed to be pH 6.80, adsorbent amount 10.0 mg, and mixing time 5.50 min. remarkably, these theoretical values for achieving maximum recovery were found to be quite similar to the values obtained through CCD in the developed UA-dSPµE method. Subsequent experiments were conducted at these optimized values for the three significant extraction parameters to further validate their effectiveness in maximizing the recovery of total arsenic. Validate the optimized settings by conducting additional experiments to confirm that the predicted optimal values indeed result in improved performance. CCD allows for efficient exploration of the parameter space and helps in identifying the optimal settings for significant parameters. By combining factorial design with response surface modeling, it provides valuable insights into the relationships

between parameters and the response variable, enabling optimization and fine-tuning of the process or system being studied.

3.6. Interfering ions

In food samples, interfering ions can refer to the presence of certain ions that can affect the accuracy and reliability of analytical measurements. These ions can interfere with the analysis of total arsenic in the foodstuffs, leading to erroneous results. The presence of interfering ions can be problematic in various analytical techniques. In order to assess the matrices effect on arsenic enhancement and separation in digested food samples using the present UA-dSPµE method under optimized variables, various foreign ions were individually added to solutions containing 100 µg/L of arsenic. The impact of the foreign ions on arsenic concentration was measured to determine interference. An interfering ion was defined as one that caused a variation in arsenic concentration exceeding 5%. The presence of 1600 mg/L of K^+, HPO_4^{2-}, Ca^{2+}, and Mg^{2+} resulted in arsenic concentration and percentage recovery within the range of 95.6–99.1% (Table 2). This demonstrates the efficient arsenic extraction capability of the developed UA-dSPµE method. Interfering cations and anions such K^+, Ca^{2+}, Mg^{2+}, SO_4^{2-}, and NO_3^- are often found in food samples. The high concentrations of these ions can affect the accuracy of analysis by interfering with the measurement. Even with the

Table 2
Tolerance limits of interfering ions for total arsenic determination using the UA-dSPµE method.

Interfering ions	Tolerance limits[a] (mg/L)	Recovery (%)
Potassium (K^+)	1600	98.6 ± 2.8[b]
Phosphate (PO_4^{3-})	1600	97.8 ± 2.5
Calcium (Ca^{2+})	1600	99.1 ± 1.8
Magnésium Mg^{2+}	1600	96.3 ± 2.1
Thiocynite (SCN^-)	1600	95.6 ± 2.3
Sulfate (SO_4^{2-})	1200	96.4 ± 2.5
Oxalic acid ($C_2O_4^{2-}$)	1200	97.7 ± 2.7
Nitrate (NO_3^-)	1200	98.6 ± 2.0
Fluoride (F^-)	1000	97.5 ± 1.5
Iodide (I^-)	1000	96.5 ± 1.8
Zinc (Zn^{2+})	800	94.5 ± 2.3
Sodium (Na^+)	10,000	95.1 ± 2.9
Chloride (Cl^-)	15,000	96.7 ± 4.5
Manganese (Mn^{2+})	600	97.5 ± 2.2
Copper (Cu^{2+})	600	96.4 ± 2.6
Lead (Pb^{2+})	600	96.8 ± 2.3
Nickel (Ni^{2+})	600	97.6 ± 2.6
Selenium (Se^{4+})	600	95.8 ± 2.5
Cobalt (Co^{2+})	600	98.3 ± 2.5
Aluminum (Al^{3+})	200	98.5 ± 2.2
Iron (Fe^{3+})	200	94.4 ± 2.4
Cadmium (Cd^{2+})	100	96.7 ± 1.9
Chromium (Cr^{3+})	100	97.2 ± 2.1

[a] Total arsenic tested concentration (100 µg/L); [b] Mean ± Standard deviation.

addition of foreign ions at concentrations of 1200 mg/L (SO_4^{2-}, $C_2O_4^{2-}$, NO_3^-), 1000 mg/L (F^- and I^-), 10000 mg/L Na^+, 15000 mg/L Cl^-, 800 mg/L Zn^{2+}, 600 mg/L (Cu^{2+}, Pb^{2+}, Ni^{2+}, Se^{4+} and Co^{2+}), 200 mg/L (Al^{3+} and Fe^{3+}) and 100 mg/L (Cd^{2+} and Cr^{3+}), satisfactory recovery of total arsenic was still achieved. The results indicated that the developed UA-dSPμE method exhibited over 95% recovery of total arsenic for all studied matrix effects (Table 2). Some food samples contain heavy metals (Zn^{2+}, Cd^{2+}, Cu^{2+}, Pb^{2+}, Ni^{2+}, Al^{3+}, Fe^{3+}, Cr^{3+}, etc.) and organic acids, citric acid, maleic acid, acetic acid, etc. These metals can interfere with certain limits and may require sample preparation methods to minimize their effects. These organic acids can affect the pH of the sample and interfere with the performance of developed UA-dSPμE methods that rely on pH sensitive indicators.

Therefore, by controlling the optimal parameters of the present UA-dSPμE method, the interference ions can be minimized. It's important to note that the specific interfering ions in food samples can vary depending on the type of food being analyzed and the analytical method employed. Therefore, it is crucial to consider the specific requirements and limitations of each analytical technique and tailor the sample preparation and analysis accordingly. In conclusion, our present UA-dSPμE method successfully avoids interference from foreign ions, making it a reliable approach for total arsenic determination in food samples.

3.7. Application of UA-dSPμE method

The validity and accuracy of the present UA-dSPμE method for total arsenic determination in digested foodstuffs were assessed using CRMs of wheat gluten-8418 (NIST) and clover honey-stalk (IPE-10), as shown in Table 3a. The measured values were found to be in close agreement with the certified values of the CRMs, with percentage recoveries ranging from (96.0–98.5%). This indicates that the present UA-dSPμE method is highly accurate for total arsenic determination in digested foodstuffs. To further verify the reliability of the present UA-dSPμE method, a standard addition method was employed using spiked standard solutions of arsenic in digested wheat and honey samples at two different increments (5.0 and 10.0 μg/kg). A strong agreement was observed between the added and measured concentrations of total arsenic in both samples. The percentage recoveries obtained by the standard addition method for total arsenic determination in wheat and honey samples ranged from (90.0–100%) shown in Table 3a.

Application of the present UA-dSPμE method by using novel composite adsorbent was used to the assessment of low level of arsenic in various foodstuffs from local markets in Tokat city, Turkey. The resulted data of total arsenic in various food samples such as egg, fish, red meat, white meat, mushroom, rice, salami, sausage, black tea, green tea, tomato, pepper, flour, cabbage, carrot, parsley and mint were reported in Table 3b. The resulted concentration of arsenic in almost all studied food samples was higher than the WHO recommended concentration for total arsenic in human foodstuffs. Arsenic contamination from human foodstuffs such as egg, fish, red meat, white meat, mushroom, rice, salami,

Table 3a
Percentage recoveries of CRMs and standard addition method for total arsenic in foodstuffs.

CRMs	Certified value (μg/kg)	Obtained value (μg/kg)	Recovery (%)
Wheat Gluten-8418 (NIST)	20.0 ± 1.12[a]	19.7 ± 1.15	98.5 ± 3.0
Clover Honey-Stalk (IPE-10)	91.1 ± 22.8	87.4 ± 8.30	95.9 ± 2.0
Standard Addition Method	Added (μg/kg)	Obtained values (μg/kg)	Recovery (%)
Wheat	–	35.5 ± 1.87	–
	5.00	40.3 ± 2.18	96.0 ± 4.0
	10.0	45.2 ± 2.28	97.0 ± 3.0
Honey	–	105 ± 5.22	–
	5.00	110 ± 5.53	100 ± 2.0
	10.0	114 ± 6.05	90.0 ± 3.0

[a] Mean value ± standard deviational.

Table 3b
Results of total arsenic concentration in various human foodstuffs in Tokat city, Turkey.

S. No	Foodstuffs	Arsenic (μg/kg)
1.	Egg	60.0 ± 3.21
2.	Fish	135 ± 5.72
3.	Red meat	50.0 ± 2.51
4.	White meat	94.8 ± 4.81
5.	Mushroom	270 ± 13.3
6.	Rice	110 ± 5.42
7.	Salami	40.0 ± 2.61
8.	Sausage	65.0 ± 3.21
9.	Black tea	75.0 ± 3.73
10.	Green tea	70.6 ± 3.51
11.	Tomato	68.0 ± 3.48
12.	Pepper	55.0 ± 2.71
13.	Flour	35.5 ± 2.62
14.	Cabbage	5.13 ± 0.56
15.	Carrot	3.15 ± 0.27
16.	Parsley	0.64 ± 0.04
17.	Mint	0.53 ± 0.03

sausage, black tea, green tea, tomato, pepper, flour, cabbage, carrot, parsley and mintwere predominant as reported in literatures (Filippini et al., 2019). Concentration of total arsenic measured by present UA-dSPμE method was found higher concentrations as compared to the literature reported, may be due to the different geographical locations. Unpredictably, the arsenic concentrations were obtained higher than the recommended values in foodstuffs collected from different markets of Tokat city, Turkey. The present UA-dSPμE method was also compared with the literature reported methods as shown in Table 4. Highly selective and sensitive present UA-dSPμE method was successfully used for determination of total arsenic concentration in various food samples.

3.8. Analytical performance of UA-dSPμE method

The analytical performance of the present UA-dSPμE method was evaluated for total arsenic determination in foodstuffs. A linear calibration curve ranging 0.07–1.12 μg/L was established for total arsenic determination using the UA-dSPμE method. The LOD of the present UA-dSPμE method was calculated using the following formula:

$$LOD = \frac{3 \times SD}{m}$$

where "SD" represents the standard deviation obtained from the analysis of 10 blank samples and "m" is the slope of the calibration graph after applying UA-dSPμE method. As a result, the achieved LOD and RSD for the present UA-dSPμE method was 0.02 μg/L and 3.80%, which is lower than the reported methods for total arsenic determination in the literature (Table 4). The enrichment factor (EF) was determined by comparing the slopes of the calibration curves obtained with and without pre-concentration using the UA-dSPμE method. For the present UA-dSPμE method, the calculated EF was 128, surpassing the values reported in the literature for arsenic except reported by Ashouri et al. (2022) and Ali et al. (2016). A comprehensive comparison of the analytical performance characteristics of the present UA-dSPμE method for total arsenic determination in foodstuffs, utilizing the novel composite adsorbent PHB-PDMAEMA-G_2O_3, is presented in Table 4. All parameters, including the linear calibration range, LOD, EF, and RSD, obtained with the present UA-dSPμE method, are comparable to those reported in the literature using various adsorbents (Ali et al., 2017; Ali et al., 2016; Altunay et al., 2022; Ashouri et al., 2021; Dos et al., 2021; Elik et al., 2021; Jalilian et al., 2020; Jinadasa et al., 2020; Mustafai et al., 2018; Shirkhanloo et al., 2017). Hence, the present UA-dSPμE method provides a convenient approach for the accurate determination of total arsenic in diverse food samples.

Table 4
Comparative analytical performance of UA-dSPµE versus literature reported methods.

Samples	Methods/ Adsorbents	Techniques	pH	Extraction time (min)	Adsorbent capacity (mg/g)	Linear range (µg/kg)	LOD (µg/ kg)	RSD (%)	EF/ PF	References
Rice	VA-DMSPE/IIP[a]	HPLC-ICP-MS[m]	8.0	15	50.0	1.0–20	0.20	11	10	Jinadasa et al. (2020a)
	SPE/TBAB[b]	FI-HG AAS[n]	1.0	20	N.R[r]	0.12–10	0.04	5.5	17	Dos and Coelho (2021)
	DLLME/TSILs[c]	ET-AAS[o]	3.0	15	30.0	0.2–20	0.04	3.2	200	Ashouri et al. (2021)
Fish	SPE/IIPs[d]	HPLC-ICP-MS[m]	8.5	30	17.7	0.5–20	0.32	12	50	Jinadasa et al. (2020b)
Honey	VA-LPME/EDDS[e]	HG-AAS[p]	6.0	5.0	N.R[r]	0.02–0.60	0.006	4.9	70	Altunay et al. (2022)
Mint/ parsley	US-µSPE/ MIIP[f]		7.2	48	37.0	0.01–85	0.004	3.6	120	Jalilian et al. (2020)
Water and food	MSPME/PSPDMS[h]	ET-AAS[o]	7.0	5.0	11.7	0.02–0.50	6.90	4.1	218	Ali et al. (2016)
	SPE/IIP[d]		6.0	15	106	10.0–100	0.87	4.2	N.R[r]	Mustafai et al. (2018)
	USA-DSL-MPME/[HMIM] PF[i]		3.5	30	119	0.02–1.65	0.01	4.3	100	Shirkhanloo et al. (2017)
	HSL-SDM/MWCNT[j]	HG-AAS[p]	6.0	23	46.1	0.01–0.80	0.003	2.5	83	Ali et al. (2017a)
Food	SPMS/PMaema[k]		4.3	22	75.8	0.01–0.50	0.003	4.3	85	Elik et al. (2021)
	UA-dSPµE /PHB-PDMAEMA-Gd₂O₃-NPs[l]		6.8	5.5	290	0.07–1.12	0.02	3.8	128	This method

[g] magnetic solid phase extraction/soluble eggshell membrane protein-Fe_3O_4NPs.

[q] Inductively couple plasma-optical emission spectrometry.

[a] Vortex-assisted dispersive micro-solid phase extraction/ionic imprinted polymer.

[b] Solid phase extraction/tetra-n-butylammonium bromide.

[c] Dispersive liquid–liquid micro-extraction/task specific ionic liquids.

[d] Solid phase extraction/ionic imprinted polymers.

[e] Vortex-assisted liquid phase microextraction/ethylenediamine-N,N'-disuccinic acid.

[f] Ultra sonic-micro solid phase extraction/magnetic ionic imprinted polymer.

[h] Miniaturized solid phase microextraction/Polystyrene polydimethyl siloxane.

[i] Ultrasound assisted-dispersive solid–liquid multiple phase microextraction/bulky amine-functionalized bimodal mesoporous silica nanoparticles immersed in ionic liquid.

[j] Hydrophobic to hydrophilic switchable liquid–solid dispersive microextraction/multiwall carbon nanotube.

[k] Solid phase microextraction/poly(methylmethacrylate-*co*-2-aminoethyl methacrylate.

[l] Ultrasound assisted-dispersive solid phase micro extraction/poly(3-hydroxy butyrate)-*b*-poly(dimethyl amino ethyl methacrylate) block copolymer containing gadolinium oxide nanoparticles.

[m] High performance liquid chromatography-inductively coupled plasma-mass spectrometry.

[n] Flow injection-hydride generation atomic absorption spectrometry.

[o] Electrothermal-atomic absorption spectrometry.

[p] Hydride generation-atomic absorption spectrometry.

[r] Not reported.

4. Conclusions

In this study, a novel and environmentally friendly UA-dSPµE method was presented as an alternative approach for the determination of total arsenic in various human foodstuffs. A block copolymer, PHB-PDMAEMA containing Gd_2O_3 was used as a novel composite adsorbent. In the present UA-dSPµE method coupled with HG-AAS provided a reliable and efficient total arsenic determination. This composite adsorbent demonstrated high adsorption capacity 290 mg/g and no chemical interference, making it an ideal choice for total arsenic determination in different foodstuffs following acid digestion. The extraction parameters played a crucial role in the extraction efficiency of the present UA-dSPµE method, and therefore, multivariate optimization was performed to achieve optimal extraction conditions. The use of pareto chart and CCD allowed for the screening and optimization of the most influential parameters, significantly improving the extraction productivity of arsenic from real samples. It is expected that this developed technique can be utilized as a portable tool for the separation and determination of total arsenic in various foodstuffs in different sample matrices. The present UA-dSPµE method offers several advantages, including low cost, simplicity, and minimal sample and elution reagent requirements. The method's accuracy and precision were confirmed through the use of CRMs and the standard addition method. The results revealed that the total arsenic concentrations in various foodstuffs exceeded the WHO recommended values for arsenic in human-consumed food samples. In conclusion, the novel UA-dSPµE method presented in this study provides an effective and environmentally friendly approach for total arsenic determination. The results highlight the importance of monitoring arsenic levels in foodstuffs to ensure consumer safety, as the concentrations exceeded the recommended limits. Present UA-dSPµE method has some advantages according to literature values such as low LOD and RSD, short extraction time, high enhancement factor, high adsorption capacity and long linear range (Table 4). The samples can be analyzed at ng/g levels. Tolerance limits of interfering ions for total arsenic determination were found high. So, present method can be easily applied to food samples including highly saline and complex matrices for total arsenic determination by HG-AAS.

CRediT authorship contribution statement

Jamshed Ali: Investigation, Validation, Writing – original draft, Writing – review & editing, Software. **Mustafa Tuzen:** Investigation, Validation, Software, Supervision. **Wahid Jatoi:** Writing – original

draft, Writing – review & editing, Software. **Baki Hazer:** Investigation, Writing – original draft, Writing – review & editing, Software.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

Acknowledgements

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