Ultrasonics - Sonochemistry 47 (2018) 57–67

Contents lists available at ScienceDirect

Ultrasonics - Sonochemistry

journal homepage: www.elsevier.com/locate/ultson

A novel naphthalene carboxylic acid-based ionic liquid mixed disperser combined with ultrasonic-enhanced *in-situ* metathesis reaction for preconcentration of triclosan and methyltriclosan in milk and eggs

Xuedong Wang[a], Mei Wang[b], Xuran Wang[c], Liyang Du[a], Fangyu Chu[a], Weinan Ding[a], Haidong Gu[a,*], Huili Wang[a,*]

[a] School of Environmental Science and Engineering, Suzhou University of Science and Technology, Suzhou 215009, China
[b] Key Laboratory of Watershed Sciences and Health of Zhejiang Province, Wenzhou Medical University, Wenzhou 325035, China
[c] School of Materials Science & Engineering, University of Science & Technology Beijing, Beijing 100083, China

ARTICLE INFO

Keywords:
Ionic liquid [C_4MIM][NCA]
In-situ metathesis reaction
Microextraction with ionic liquids as both extractor and disperser
Triclosan
Methyltriclosan
Central composite design

ABSTRACT

A microextraction method was developed based on utilization of a novel ionic liquid (IL) [C_4MIM][NCA] as disperser and conventional ILs as extractor (IL-IL-DLLME). This method was integrated with an *in-situ* metathesis reaction to achieve high extraction efficiency by eliminating the loss of analytes in the discarded disperser after microextraction. Ultrasonic energy was compared to traditional mechanical shaking to accelerate the *in-situ* metathesis reaction. A 3-min ultrasonic treatment provided similar extraction efficiency as a 120-min mechanical shaking. Due to their strong acidity and lower solubility than traditional hydrophilic ILs, utilization of [C_4MIM][NCA] in the IL-IL-DLLME procedure increased extraction recoveries (ERs) for triclosan (TCS) and methyltriclosan (MTCS) by 10–12% and also avoided an extra pH adjustment step. A series of operational parameters were optimized using single-factor screening and central composite design as follows: 65 μL extraction solvent, 150 μL [C_4MIM][BF_4] and [C_4MIM][NCA] (132/18, v/v, μL) as dispersive solvent, 0.16 g NH_4PF_6 and 3.3 min ultrasonic time. Under optimized conditions with a fortification of 100 μg kg^{-1}, ERs were 92.6–93.4% for TCS and 92.7–94.2% for MTCS in bovine milk and chicken egg samples. LODs for TCS and MTCS were 0.16–0.24 μg kg^{-1} and the enrichment factors were 21.8–23.1. Inter- and intra-day precisions had relative standard deviations of 3.3–5.4% for the optimized method. Overall, this newly developed IL-IL-DLLME method was effective for detecting trace levels of TCS and MTCS in real-world, animal-based foods. Prominent advantages of the new method include high precision and accuracy, high extraction efficiency, simple analytical operations, and no use of organic solvents making the procedure environmentally benign.

1. Introduction

Triclosan (TCS; 2-(2,4-dichlorophenoxy)-5-chlorophenol) is a non-ionic, chlorinated phenolic compound that is frequently employed as an antimicrobial, antibacterial and preservative agent in many household and personal care products [1,2]. Widespread use of TCS has led to its presence at relatively high concentrations (1–50 μg L^{-1}) in many environmental matrices [3,4]. TCS (pK_a = 7.8) can be degraded by exposure to UV radiation to chlorophenols and dioxin, or by microorganisms into methyltriclosan (MTCS) [5]. Both TCS and MTCS bioaccumulate in lipid tissues with a bioaccumulation factor of 2000 to 8700 [6]. MTCS is more lipophilic (log*Kow* = 5.4) and persistent than its parent compound (log*Kow* = 4.8) [7]. TCS is currently used as an additive in food packaging polymers and to treat surfaces in contact with foodstuff in the food processing industry [8]. Canosa et al. (2008) demonstrated that TCS could migrate from TCS-containing kitchenware or food packaging films to food in both domestic and food processing environments [9]. TCS has been identified in breast milk, as a probable result of topical transfer and oral intake of foods treated with this bactericide [10]. If people ingest TCS (or MTCS)-contaminated foods, it can affect the conformation of human serum albumin (HSA) by forming TCS (or MTCS)-HSA complexes and altering protein function in humans [11]. Therefore, the potential risk to human health due to food contaminated with TCS and MTCS has raised great concern worldwide. In order to perform risk assessment, a convenient, rapid and highly sensitive method is required for the determination of TCS and MTCS in food products.

In recent decades, conventional methods, such as liquid-liquid

* Corresponding authors.
E-mail addresses: ghdfrank@aliyun.com (H. Gu), whuili@163.com (H. Wang).

https://doi.org/10.1016/j.ultsonch.2018.04.006
Received 11 February 2018; Received in revised form 5 April 2018; Accepted 12 April 2018
Available online 26 April 2018

extraction [9], solid-phase extraction [12] and solid-phase microextraction [13,14], have been replaced by a variety of liquid phase microextraction (LPME) methods, such as ionic liquid-based dispersive liquid-liquid microextraction (IL-DLLME) [15]. Three IL-DLLME methods have been widely reported [15–17]. The first is based on traditional DLLME and involves a small amount of organic solvent that functions as disperser. The second approach is *in situ* ILs combined with DLLME involving an *in situ* metathesis reaction [16]. The third technique involves microextraction based on ILs as both extractor and disperser (IL-IL-DLLME). This method uses hydrophilic ILs $[C_nMIM]BF_4$ or $[C_nMIM]Cl$ as the dispersive solvent to aid in the dispersion of the hydrophobic ILs $[C_nMIM]PF_6$ extractor into the aqueous phase [17]. Importantly, no organic solvent is utilized in IL-IL-DLLME procedure making this method more environmentally benign.

In traditional IL-IL-DLLME procedures, the hydrophilic ILs-based dispersers, such as $[C_nMIM]BF_4$, $[C_nMIM]Cl$ or $[C_nMIM]Br$, are discarded after the microextraction procedure. Although these ILs-based dispersers are water-soluble, they have a small amount of dissolution or extraction capacity for target analytes, especially for medium to highly polar chemicals [18,19]. Consequently, discarding the disperser will lead to some loss of target analytes resulting in a decrease in extraction recoveries (ERs). However, if an *in-situ* metathesis reaction is introduced into the IL-IL-DLLME procedure, the water-soluble disperser will be converted to a water-insoluble form that will increase the ERs for target analytes. Our previous investigations using the *in-situ* metathesis reaction (especially between $[C_nMIM]BF_4$ and NH_4PF_6) revealed that the reaction is slow (~30 min for complete reaction) [19], and therefore an enhanced diffusion step is required to facilitate the operational efficiency of the procedure.

Nowadays, ultrasonic energy has gained considerable attention due to its low cost and green nature for use as a safe and effective method to disperse solutions [20]. Ultrasonic treatment accelerates the mass transfer and contact area between the two media by producing a cavitation effect in solution, while propagating through the solution due to physical phenomenon, such as micro-streaming, micro-turbulence, and acoustic waves [21]. In ILs-based microextraction procedures, ultrasonic treatment can enhance the migration of analytes into fine droplets of ILs, and consequently result in increased extraction efficiency [22–24]. Viscous analytes containing an IL phase require dispersion by an energy source, such as mechanical or ultrasonic energy assisted agitation [25]. Nizamani et al. (2018) reported that ultrasonic energy could enhance ILs-based dual microextraction to preconcentrate lead (Pb) in rain water samples. However, no studies have assessed the use of ultrasonic treatment on the *in-situ* metathesis reaction between hydrophilic ILs and substituted salts [26].

Because of the structural adjustability of ILs, functionalized ILs are easily produced [27]. However in IL-DLLME approaches previously reported, the methods only exploited their hydrophilic and hydrophobic properties, but their functional properties were not fully utilized. In this investigation, we introduced 1-naphthalene carboxylic acid into the imidazolium ring to synthesize a novel IL, 1-butyl-3-methylimidazolium naphthalene carboxylic acid salt ($[C_4MIM][NCA]$). In the microextraction procedure, the mixture of two ILs, including $[C_nMIM]BF_4$ and $[C_4MIM][NCA]$, was introduced as the dispersive solvent, which was combined with $[C_nMIM]PF_6$ as the extraction solvent in the IL-IL-DLLME procedure. Addition of this novel IL promoted a non-polar environment due to its lower solubility than $[C_nMIM]BF_4$ in aqueous media, increased the volume of sedimented phase resulting from $[C_nMIM]^+$, and thereby increased ERs. Because $[C_4MIM][NCA]$ has strong acidity in aqueous media, it also served as a pH modifier avoiding an extra pH adjustment step.

Based on the above considerations, this study developed a novel IL to enhance the IL-IL-DLLME procedure for determination of trace levels of TCS and MTCS in animal-based foods. In the IL-IL-DLLME procedure, the *in-situ* metathesis reaction was accelerated by ultrasonic energy and further compared to conventional mechanical shaking. Optimization of the major parameters in the IL-IL-DLLME method was conducted by integrating single-factor optimization with a response surface method (RSM) based on central composite design (CCD). The optimized method was compared with previously reported conventional methods to evaluate its advantages and feasibility for determining trace levels of TCS and MTCS in bovine milk and chicken egg samples. To the best of our knowledge, this is the first application of an IL-IL-DLLME method combined with ultrasonic energy-enhanced *in-situ* metathesis reaction and using a naphthalene carboxylic acid-based IL for preconcentration of trace TCS and MTCS in animal-based foods.

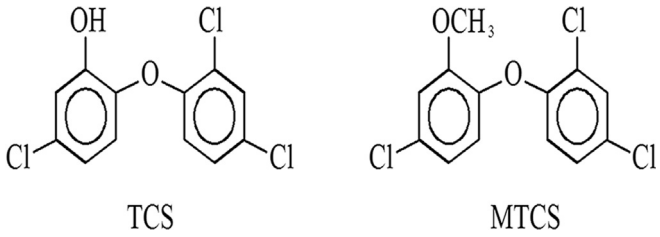

Fig. 1. The chemical structures of TCS and MTCS.

2. Experimental

2.1. Reagents and materials

Certified reference standards for TCS and MTCS (purities > 99.0%) were obtained from Sigma-Aldrich (Shanghai, China); see molecular structures in Fig. 1. Chromatographic-grade methanol and acetonitrile were purchased from Merck (Darmastadt, Germany). The following ILs were obtained from Shanghai Chengjie Chemical Company (Shanghai, China) with purities > 99.0%: 1-butyl-3-methyl-imidazolium hexafluorophosphate ($[C_4MIM][PF_6]$), 1-hexyl-3-methylimidazolium hexafluorophosphate ($[C_6MIM][PF_6]$), 1-octyl-3-methylimidazolium hexafluorophosphate ($[C_8MIM][PF_6]$), 1-butyl-3-methylimidazolium tetrafluoroborate ($[C_4MIM][BF_4]$) and 1-ethyl-3-methylimidazolium tetrafluoroborate ($[C_2MIM][BF_4]$). Ammonium hexafluorophosphate (NH_4PF_6, 98.0%) was received gratis from Shanghai Chengjie Chemical Company. Ammonium sulfate ($(NH_4)_2SO_4$) and ammonium chloride (NH_4Cl) with purities > 99% were obtained from Aladdin Industrial Company (Shanghai, China). Millipore-Q ultrapure water (> 18.20 MΩcm, 25 °C) was used for preparation of all aqueous solutions (Millipore, Billerica, MA, USA). Stock standard solutions of TCS and MTCS were prepared in methanol with a concentration of 20 mg L^{-1} and stored at 4 °C.

2.2. Preparation of bovine milk and chicken egg samples

Bovine milk and chicken egg samples from Jiangxin Milk Company and Ronghe Agricultural Product Company, respectively, were purchased from Baixin Supermarket, Wenzhou, China. Milk and egg samples were mixed with deionized water at a volume ratio of 1:1, ultrasonically treated for 1 min, centrifuged for 15 min at 3000 rpm, and filtered through a 0.22 μm PTFE membrane filter to remove denatured proteins [18]. The supernatant was decanted and stored at 4 °C for subsequent IL-IL-DLLME procedures [28]. Fortified TCS and MTCS samples at 10, 50 and 100 μg kg^{-1} levels were prepared by spiking the bovine milk and blended whole egg samples with an appropriate amount of stock solution.

2.3. Instrumentation

TCS and MTCS were analyzed using an Agilent 1260 HPLC equipped with a UV detector. A Zorbax Eclipse SB-C_{18} column (4.6 mm × 250 mm, 5 μm particle size) (Agilent, Santa Clara, CA, USA) was used for separation of analytes. Injections were performed