

Cloud Point Extraction Used for Separation and Preconcentration of Trace Elements in Food Samples: A Review of Recent Applications

Ingrid Hagarová

*Comenius University in Bratislava, Faculty of Natural Sciences, Institute of Laboratory Research on Geomaterials, Mlynská dolina, Ilkovičova 6, 842 15 Bratislava, Slovak Republic
E-mail: ingrid.hagarova@uniba.sk*

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Abstract: Food safety analysis involves many subfields. One of them is inorganic analysis aimed to the quantification of various trace elements. The main attention in this field is paid to toxic, potentially toxic, and essential trace elements. However in many cases, direct quantification of trace elements in a complex food matrix is almost impossible. To resolve this problem, a combination of a suitable separation procedure with a reliable quantification method is required to deliver accurate results. One of the separation techniques that is currently receiving considerable attention is cloud point extraction (CPE). The use of optimized CPE procedures with commonly available spectrometric methods (e.g., UV-Vis spectrophotometry, flame atomic absorption spectrometry, electrothermal atomic absorption spectrometry, hydride generation atomic absorption spectrometry, cold vapor atomic absorption spectrometry, inductively coupled plasma optical emission spectrometry) provides the powerful tool for reliable quantification of many trace elements (e.g., Al, As, Cd, Cu, Hg, Pb, Mn, Ni, Sb, Se, Sn, Zn, and many others) in various types of food matrices (e.g., fresh vegetables, ground grain samples, canned food samples, various powdered food samples, and many others), as documented by studies included in this review.

Keywords: Cloud point extraction; Food samples; Trace elements; Spectrometric methods.

1. Introduction

The quality and safety of food products should be the primary concern of people working within the food processing industry. To ensure these requirements, reliable procedures for checking the food composition are required. Since food matrices are complex, heterogeneous mixtures of numerous and diverse biochemical substances, their analysis is a difficult task. For instance, food safety analysis involves many subfields, such as detection of pesticides and veterinary drug residuals, measurement of heavy metal ions, and assessment of banned food additives [1]. It means that development of reliable procedures for quantification of various organic as well as inorganic components is necessary. In the case of trace elements, the main attention is aimed to toxic and potentially toxic ones. It is due to the fact that many of them have cumulative properties and longstanding intake even trace concentrations can negatively affect human health [2]. On the other hand, the attention may be focused to the deficit of essential trace elements and their reliable quantification is also very important [3]. A special interest is paid to those essential trace elements which can become toxic after exceeding a certain concentration limit [4].

Spectrometric methods such as flame atomic absorption spectrometry (FAAS), electrothermal atomic absorption spectrometry (ETAAS), inductively coupled plasma optical emission spectrometry (ICP-OES), and inductively coupled plasma mass spectrometry (ICP-MS) are the most commonly used for the quantification of trace elements in various samples, including foodstuffs [5]. Elements that form volatile hydrides, such as As, Sb, Bi, Ge, Pb, Se, Te and Sn, can be analyzed by hydride generation atomic absorption spectrometry (HG-AAS) [6]. Cold vapor atomic absorption spectrometry (CV-AAS) is usually used for the quantification of Hg [6]. The connection of hydride generation with inductively coupled plasma optical emission spectrometry (HG-ICP-OES) or mass spectrometry (HG-ICP-MS) is widely used to enhance the sensitivity of semimetal quantification and to eliminate the majority of matrix interferences [7]. Hydride generation atomic fluorescence spectrometry (HG-AFS) is also a suitable detection method for the quantification of hydride forming elements (mainly As, Se, and Sb), and cold vapor atomic fluorescence spectrometry (CV-AFS) can be successfully used for the quantification of Hg [8,9]. In addition to the methods stated above, UV-Vis spectrophotometry can be also used for quantification of trace elements after their effective preconcentration using a suitable separation technique [10]. The suitability of a spectrometric method for the quantification of a target element is related to the problems to be examined. Analytical parameters such as quantification limit, precision and linear dynamic range play the most important role before making the decision [11].

However in many cases, direct quantification of (ultra)trace elements in a complex food matrix using above mentioned instruments is almost impossible. To resolve this problem, a combination of a suitable separation procedure with a reliable quantification method is required to deliver accurate results. Among separation techniques, extractions occupy an irreplaceable position in sample pretreatment procedures. Depending on the extraction phase being used, two main groups can be distinguished; liquid-liquid extraction (LLE) and solid phase extraction (SPE). Since their introduction, the both extraction techniques have undergone significant modifications. The main trend such as miniaturization of analytical systems results in new configurations and arrangements of these separation techniques. In addition to miniaturization, the effort to replace toxic organic solvents is another important step in development of new extraction modes. The use of surfactants instead of toxic organic solvents can be found in cloud point extraction (CPE) procedures. Therefore, CPE can be considered as a new alternative of LLE, which is consistent with principles of green analytical chemistry.

The aim of this paper is to show analytical potential of CPE procedures connected with commonly available spectrometric methods stated above for quantification of (ultra)trace elements in complex food matrices. Published papers describe low limits of detection, acceptable precision, and accurate results achieved for analysis of fresh vegetables (e.g., spinach, lettuce, cabbage, and many others), legumes (e.g., peas, lentils, and many others), ground grain samples (e.g., wheat flour, rice flour, corn flour), canned food samples (e.g., tomato paste, fish, okra, beans, peas, and many others), various powdered food samples (milk powder, chocolate powder, potato starch, maize starch), fruit juices (cherry, orange, peach, pear, apricot, apple, grape, and others), tea samples, and many others.

2. Cloud point extraction

Cloud point extraction (CPE) uses neutrally charged surfactants (nonionic or zwitterionic). An aqueous solution of such surfactants at a concentration higher than critical micellar concentration (CMC) becomes turbid and separates into two isotropic phases if an external condition is changed (e.g., temperature, pressure, pH, or ionic strength). The surfactant solution becomes turbid because it attains the cloud point (i.e. incomplete solubilization) [12]. At this point, the original surfactant solution separates into a surfactant phase of a small volume, which is rich in surfactant and contains an analyte trapped by micellar structures (so-called surfactant-rich phase; SRP) and a bulk diluted aqueous phase (so-called surfactant-poor phase or equilibrium solution).

In element analysis, the CPE methodology can be briefly summarized as follows. In the first step, a complexing agent is usually added to a system to obtain the hydrophobic complex which remains in the hydrophobic core of the micelles in the SRP. This is followed by the addition of a surfactant and heating in a water bath to induce cloud point formation. In this moment, two isotropic phases are formed and their separation is accelerated by centrifugation. Afterwards, the system is usually cooled in an ice-bath in order to increase the viscosity of the SRP. The final step of CPE procedure is decantation of an aqueous phase. The highly viscous SRP is obtained and conventionally diluted by organic solvents (mainly methanol or ethanol) acidified by mineral acids (mainly HNO_3 or HCl). Such diluted sample is now ready for measurement. Schematic diagram showing the CPE procedure can be seen in Figure 1.

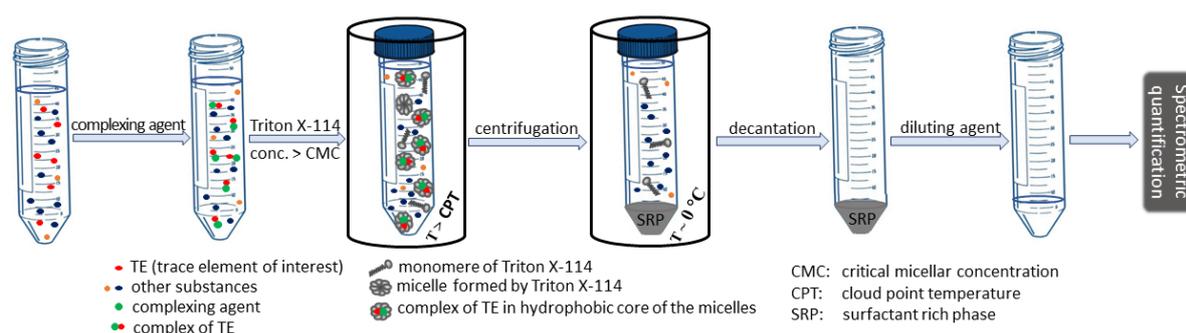


Figure 1. Schematic diagram of CPE procedure developed for separation and preconcentration of trace elements.

From the methodology stated above, it is evident that optimization of various experimental conditions needs to be done, including optimizing pH (which plays a crucial role in complex formation and subsequent extraction), concentration of a surfactant, concentration of a complexing agent, incubation temperature and time, and centrifugation time. In some cases, the addition of salts, alcohols, some other surfactants and some organic compounds may also be helpful (salting-out effect). The factors, such as pH, surfactant concentration, complexing agent concentration, ionic strength, incubation temperature and time, have significant effects on the extraction

recoveries achieved. The factors, such as time for centrifugation and time for ice bath, have less significant effects on the extraction recoveries achieved [13].

Selection of a suitable diluting agent for decreasing viscosity of the SRP is also important step. It is considerably dependent on the detection method used. In the case of AAS methods, no serious difficulties are described in the literature after using acidified organic solvents [14,15]. In the case of ICP methods, the main characteristics of plasma can be negatively influenced, and so, the SRP is usually diluted by concentrated mineral acids [13,14]. In the case of UV-Vis spectrophotometry, dilution with pure organic solvents (such as methanol, ethanol, acetone, acetonitrile, tetrahydrofuran, etc.) is usually done [16].

Surfactants and complexing agents are the key components in most CPE procedures. Nonionic surfactants (mainly polyoxyethylated alkylphenols, from the Triton and PONPE series) are the most widely employed for CPE in element analysis because of their commercial availability of high purity grade, relatively low price, stability, non-volatility, low toxicity and low flammability. Among them, Triton X-114 (polyoxyethylene-7.5-octylphenoxy ether) is preferably used due to its low cloud point temperature (23-25 °C; which is particularly important for the extraction of thermally unstable complexes) and high density of the SRP (1.052 g/mL; which facilitates phase separation by centrifugation) [13,17]. Majority of the published CPE procedures are associated with the use of Triton X-114 (more than 80%).

Various complexing agents are used in CPE procedures. Among them, pyridylazo and thiazolylazo derivatives have been widely employed due to their low solubility in water and ability to form hydrophobic complexes with a large number of elements [11,18,19]. Reagents, such as dithiocarbamates, dithizone and its derivatives, 8-hydroxyquinoline and its derivatives, diethyldithiophosphate, or Schiff bases are the other groups of complexing agents frequently used in CPE procedures [11,13,18].

3. Sample preparation

A great number of treatments are used to prepare foods for quantification of elements. Liquid food samples have an advantage over those associated with solid samples; they usually require less pretreatment steps, due to their liquid form. In some cases, very little sample preparation may be required. It can be simple sample dilution, evaporation, or distillation. Solid food samples are usually washed with deionized water, dried to constant weight, ground into fine powder, and sieved. After homogenization, an aliquot of the powdered sample is used for wet (acid) digestion or dry ashing [20]. In this case, the organic matter is removed or converted to simpler inorganic forms. Acid digestion can be done by using HNO₃ [21-24], or a combination of HNO₃ and HClO₄ [25-29]. Often, a combination of HNO₃ and H₂O₂ is applied [26,31-44]. Special combinations, such as HNO₃/HCl/H₂O₂ [45], or H₂SO₄/H₂O₂ and HCl/HClO₄ [46] can be also found in the published literature. Dry ashing at high temperatures (in the range of 500-600 °C) can be used in the case of non-volatile elements. After that, the ash is usually moistened with a mixture of acids [35,40,47]. After achieving a clear solution, its dilution to a final desired volume by deionized water is made. Finally, an aliquot of such prepared solution is transferred to an extraction vessel and used for a CPE procedure.

Optimization of the CPE procedure for reliable separation of the target element can take some time. A number of researchers use the univariate strategy to find the optimal experimental conditions. This methodology is supposed to have easier interpretation but requires more experiments which increases the consumption of reagents, time, and energy. Multivariate optimization is faster, more economical and effective, due to the reduction of experiments. Several multivariate approaches such as the response surface methodology based on the central composite design [24], fractional factorial design [24,43], and Box-Behnken design [21,30,38,43] were exploited to identify interactions between the variables.

Optimization of the CPE procedure is always done on model solutions. After validation of the developed procedure by analyzing certified materials, the procedure is usually applied to water samples of various origin. Analysis of more complex matrices (such as geological, biological, or food samples) has been described more rarely. Examples of CPE procedures used for separation and preconcentration of trace elements in food samples will be discussed in the following paragraph.

4. Examples of CPE procedures for separation and preconcentration of (ultra)trace elements in food samples

Summarizing the works dedicated to the CPE procedures used for separation and preconcentration of (ultra)trace elements in food samples, these statements can be recorded.

In CPE procedures, nonionic surfactant Triton X-114 is the most often used. As it was mentioned above, it is due to its optimal physicochemical characteristics, such as low CPT (23-25 °C) and high density of the SRP. Nevertheless, other surfactants than Triton X-114 can be also found in CPE procedures. Using Triton X-100 [23,32,35], higher incubation temperatures have to be applied due to the fact that its CPT is around 65 °C [13,17].

Nonionic surfactant PONPE 7.5 has low CPT (in the range of 5-20 °C, depending on its concentration used), but it can be found in CPE procedures more rarely [40]. Special nonionic surfactants such as Igepal CO-630 (nonylphenoxy poly(ethyleneoxy)ethanol, unbranched) [42] or copolymer L44 [(PEO)₁₀ (PPO)₂₃ (PEO)₁₀] [38] were also used in CPE procedures for separation of trace elements from food samples. While all important characteristics of Igepal CO-630 were thoroughly described, for copolymer L44 just molar mass of 2200 g/mol was stated.

In most CPE procedures, single surfactant solutions are applied. In the current literature, mixed surfactant solutions can be also found. The main reason is an effort to enhance measurement sensitivity. The cationic surfactant such as cetyltrimethylammonium bromide (CTAB) was used in combination with Triton X-114 [29,45] or Igepal CO-630 [42]. The cationic surfactant plays a dual role. It can serve both as a sensitivity enhancer as well as a counter ion. In these cases, lower limits of detection were achieved.

In conventional CPE procedures, clouding is usually initiated by heating the mixture consisting of sample, complexing agent and surfactant in a thermostated water bath. The other type of energy which can be used to accelerate the reactions and clouding phenomena is ultrasound. The heat generated by the high-frequency sound waves enhances intensity and rate of interactions between the surfactant and an aqueous phase. The rise in popularity of ultrasound in chemistry can be attributed to its ease of use, low cost and green nature. Ultrasonic process plays an important role in ultrasound-assisted CPE (UA-CPE), which was successfully applied also in analysis of food samples [24,29,40,42,43,45,46].

Extraction time usually takes around 40 min. A novel arrangement of this extraction which is called rapidly synergistic CPE (RS-CPE) uses octanol as cloud point reagent and synergic reagent. In this arrangement, extraction can be accomplished in 1 min. In this case, CPT of the used surfactant is lowered and extraction can be done at room temperature without necessity of heating. The RS-CPE procedures were successfully applied for separation of trace Ni [28] and trace Pb [26] from various food samples. In the case of Pb, ligandless RS-CPE procedure was developed.

A new pH-mediated ligandless extraction for trace Pb in a dual CPE (d-CPE) arrangement can be also found in the published literature [38]. In d-CPE, two extraction procedures follow each other. The first one is a conventional CPE procedure. In the second one, the SRP containing analytes is treated with aqueous solution followed by heating and centrifugation. The target analytes are back-extracted into the aqueous phase. Extraction time is doubled in comparison with conventional CPE, but selectivity of the method is significantly improved due to the removing of interfering species.

A combination of two CPE procedures was described for distinguishing V(IV) and V(V) in water and food samples [27]. This combination was based on the use of highly selective laboratory-made complexing agents. In the first CPE, V(IV) was retained in the SRP and aqueous phase was carefully collected and used for the second CPE in which extraction of V(V) was done.

A special method combining UA-CPE and dispersive μ -solid phase extraction (D- μ -SPE) was used for preconcentration of As, Cd, Cr, Co, Sb, Pb and Tl [24]. In this case, a nanocomposite (Mg/Al-LDH@CNTs) was used as an adsorbent for the analytes followed by its extraction into the SRP.

A brief summary of analytical methods where a CPE procedure was used for separation and preconcentration of trace elements in various food samples before their spectrometric quantification can be seen in Table 1.

5. Concluding remarks

In this paper, the use of greener extraction procedures for separation and preconcentration of (ultra)trace elements in food samples has been summarized. Cloud point extraction as a technique in which small amounts of surfactants are used instead of high-volumed toxic organic solvents follows the principles of green analytical chemistry. After optimization of all experimental conditions, the developed CPE procedures can offer high extraction efficiency, high preconcentration factors, low cost, and safety. High efficiency and high preconcentration factors are the most important parameters for (ultra)trace analysis of complex matrices. Complexity of foodstuff matrices and the strict limits established for various toxic substances make necessary the continuous improvement of the current sample pretreatment procedures for food analysis. In case of trace elements, the possibility to use commonly available spectrometric methods in connection with CPE procedures is a great benefit for any food safety laboratory which uses such instrumentation. After CPE preconcentration, limits of detection for all spectrometric methods used can be improved, in some cases, by several orders of magnitude. Connection of CPE procedures with spectrometric methods have demonstrated the high analytical potential for separation/preconcentration and quantification of many (ultra)trace elements (e.g., Al, As, Cd, Cu, Hg, Pb, Mn, Ni, Sb, Se, Sn, Zn, and many others) in various types of food samples (e.g., fresh vegetables, ground grain samples, canned food samples, various powdered food samples, and many others). It is well documented by examples reviewed in this paper.

Table 1. A brief summary of analytical methods where a CPE procedure was used for separation and preconcentration of trace elements in various foodstuffs

Food sample	Trace element	Complexing agent	Detection method	Limit of detection	Ref.
Tomato paste, white bread, spinach, lettuce, cabbage	Mn	Quinalizarin	UV-Vis	0.8 µg/L	[22]
Canned lychee, tomato paste, pickled lettuce	Zn	EDTA	UV-Vis	0.3 µg/L	[23]
Rice flour, wheat flour	Cu	Isoleucine	UV-Vis	5 µg/L	[32]
Fruit juices (cherry, orange, peach, pear, apricot, apple, grape), ice tea	Cd	VBB ⁺ + I ⁻	UV-Vis	0.34 µg/L	[36]
Fruit juices (orange, apple, grape), tomato paste, onion, potato, rice, spinach, lettuce, cabbage, apple	Al	ARS	UV-Vis	1.0 µg/L	[44]
Maize starch, rice flour, potato starch	Cu; Ni	BDAP	FAAS	0.1; 0.4 µg/g	[21]
Tomato paste, hazelnut, white bread, spinach, lettuce, cabbage	Ni; Mn	Magneson I	FAAS	2.7; 2.9 µg/L	[25]
Spinach, rice, black tea	Pb	None	FAAS	1.6 µg/L	[26]
Cabbage, black tea	Ni	Furildioxime	FAAS	0.6 µg/L	[28]
Canned fish, black and green tea, honey, tomato sauce	Pb; Co; Cu	1-PTSC	FAAS	0.50; 0.10; 0.15 µg/g	[31]
Rice samples, milk powder, walnut powder, laver, kelp, millet	Cd	MG + I ⁻	FAAS	0.9 µg/L	[33]
Canned fish, canned okra, canned beans, canned peas	Cu; Pb; Cd; Fe	DPTA	FAAS	0.48; 1.33; 0.38; 1.85 µg/L	[34]
Millet samples	Co	MOSDAA	FAAS	0.47 µg/L	[37]
Fish, spinach	Pb	None	FAAS	1.9 µg/L	[38]
Milk samples, cereals, whole meal biscuit, mint, green beans, lentils, carrots, cabbage, green tea, tomato	Mo; V	NBH ⁺	FAAS	0.86; 1.65 µg/L	[40]
Juices (orange, apple, tomato), rice, spinach, cabbage	Fe; Co; Cu; Zn	ETB	FAAS	1.5; 0.23; 0.71; 0.35 µg/L	[41]
Lettuce, spinach, mint, peas, etc.	Zn; Ni; Co	Carmine	FAAS	0.5; 0.6; 0.6 µg/kg	[42]
Lentils, nuts, oats, rice, etc.					
Chocolate samples	Co; Ni	HNB	FAAS	0.56; 0.78 µg/L	[45]
Milk powder	Cu	DDTC	FAAS	1.1 µg/L	[47]
Oats, powdered chocolate, corn flour, wheat flour	Cu; Zn	PAN	FS-FAAS	0.10; 0.15 µg/L	[30]
Wine samples, tea and tomato samples	V	TAC + AA	ETAAS	0.05 µg/L	[35]
Carrot, beetroot, canned beans, spinach	Sb; Sn; Tl	PAN	ICP-OES	8; 7; 10 ng/L	[43]
Seafood samples	Hg	MG + I ⁻	ICP-OES	56.3 ng/L	[48]
Broiler chicken tissues	Hg	DDTP	CV-AAS	0.117 µg/kg	[49]
Corn, rice, fresh tomato, mushroom, green and black tea	As, Se	TR + TA	HG-AAS	1.1; 3.5 ng/L	[50]
Corn and rice samples	As	DDTP	HG-AFS	1.34 µg/kg	[51]

EDTA: ethylenediaminetetraacetic acid; VBB⁺: Victoria blue B; I⁻: iodide; ARS: alizarin red S; BDAP: 2-(2'-benzothiazolylazo)-5-(*N,N*-diethyl)aminophenol; 1-PTSC: 1-phenylthiosemicarbazide; MG: methyl green; DPTA: 2,6-diamino-4-phenyl-1,3,5-triazine; MOSDAA: 4-methoxy-2-sulfobenzene diazotaminoazo-benzene; NBH⁺: Nile blue A; ETB: 2-(3-ethylthioureido)benzoic acid; HNB: hydroxy naphthol blue; DDTC: diethyldithiocarbamate; PAN: 1-(2-pyridylazo)2-naphthol; TAC: 2-(2'-thiazolylazo)-*p*-cresol; AA: ascorbic acid; DDTP: *O,O*-diethyldithiophosphate; TR: toluidine red; TA: tartaric acid.

6. References

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