Novel, energy efficient and green cloud point extraction: technology and applications in food processing

S. S. Arya¹ · Admajith M. Kaimal¹ · Moksha Chib¹ · Sachin K. Sonawane² · Pau Loke Show³

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Abstract Recently, a novel technique for extraction of functional thermally sensitive bioactive components from food has been developed due to its green efficacy (no toxic chemicals) and cost effectiveness. Cloud point extraction (CPE) is one of the such best alternative techniques that can be used for extraction of wide range of organic and inorganic components using green surfactants. It is a simple, rapid and inexpensive extraction technique which involves clustering of non-ionic surfactant monomers to form a hydrophobic core (micelle), which then entraps the hydrophobic bioactive compounds within it. CPE can be applied for extraction of bioactives from food processing waste as well as separation and purification of proteins. Besides that, research has received special attention on sample preparation for analysis of food constituents in the last decade. The scope of CPE is very vast in these sectors because of the advantages of CPE over other methods. This review deals with significance of CPE method and their potential green applications in food processing.

Keywords Cloud point extraction · Critical micelle concentration · Surfactants · Green technology · Food processing

Introduction

Food industry has experienced a revolutionary development for more green and efficient technologies for extraction of food bioactives due to the technical, scientific and economical headrace of traditional extraction techniques. These food bioactives are vital nutrients that are present in food in very small quantities. These components have a wide range of activity in biological systems, such as antioxidant, metal chelator, anti-allergic, antimicrobial, and clarifying agents (Huie 2002). Enzyme assisted extraction, ultrasound assisted extraction, microwave assisted extraction, solid–liquid extraction, and liquid–liquid extractions are most common methods for extraction of biological molecules from food matrixes. Degradation of bioactives during extraction is a major challenge in these techniques as later is sensitive to temperature, light and oxygen. Novel technologies like supercritical fluid, solid-phase microextraction, and liquid-phase microextraction can be used for extraction. However, they require expensive and special equipment (Huie 2002).

Cloud point extraction (CPE) is a technique in which extraction of organic/inorganic compounds from chemical or biological systems, using benign extractants like non-ionic surfactants is done which tend to separate out from the bulk solution forming clouds, when heated to critical temperature or above the temperature (Costi et al. 2010). They are also known as micelle-extraction, micelle-mediated extraction or liquid-concentration technique (Melnyk et al. 2015). Usually surfactants are absorbed at the interface between the phases where the polar head directs to aqueous part and hydrophobic tail towards lipophilic layer.

Depending on surfactant and solution conditions, the form of micelles will vary from rough spherical to ellipsoidal. The number of surfactants present in a micelle is

✉ S. S. Arya
ss.arya@ictmbai.edu.in

¹ Food Engineering and Technology Department, Institute of Chemical Technology, NM Parekh Marg, Matunga, Mumbai, India

² Food Science and Technology, School of Biotechnology and Bioinformatics, D. Y. Patil University, Navi Mumbai, India

³ Department of Chemical and Environmental Engineering, Faculty of Engineering, University of Nottingham Malaysia Campus, Jalan Broga, 43500 Semenyih, Selangor Darul Ehsan, Malaysia

termed as degree or the aggregation number (nagg). This number depends on surfactant type, structure of groups present, electrolyte characteristics and concentration, solvent nature, temperature and pH of solution (Melnik et al. 2015). The comparison between conventional and cloud point extraction method is shown in Table 1.

Principle

Initially, in CPE extraction, a micellar (surfactant-rich) phase is added to the sample which is originated from homogeneous surfactant solution. A non-polar core is developed due to its hydrocarbon tails towards the centre by a micelle (Melnik et al. 2015). Then the separation of bioactive compounds occurs in the hydrophobic core of micelles. During heating, cloud is generated due to non-ionic surfactants. These clouds then form two coexisting isotropic phases. At a specific temperature, also called as clouding point temperature; surfactant-rich and a surfactant-lean phases are formed due to physical change in the homogeneous solutions of amphiphilic substances. Because of the attraction a cluster is formed. The mechanism by which this separation occurs is attributed due to the rapid increase in aggregation number of the surfactant's micelles, as a result of the increase in temperature, or any other critical phenomena (Fig. 1). This effect causes a decrease in the effective area occupied by the polar group on the micelle surface, increasing the size of the micelle that can be considered to become infinite at the cloud point, resulting in phase separation.

Since, high temperatures cannot be applied to thermally sensitive compounds like food bioactive vitamins, pigments, polyphenols, tocopherols, antioxidant compounds etc., cloud point extraction which is usually performed at mild or low temperature and do not use harmful and toxic chemicals is most preferred technique. Therefore, this extraction technique recently has been widely used (Racheva et al. 2018; Gortzi et al. 2008).

Key steps in CPE

The key steps in cloud point extraction are depicted in Fig. 2. It is very difficult to remove aqueous surfactant phase from micellar phase which contained isolated analytes. However, the separation is followed by cooling in which viscosity of the micelles increases and then supernatant decanted. Complete removal of traces of water can be achieved by evaporation under a stream of neutral gas (for example, nitrogen). The ingredients used in CPE extraction with their significance are listed in Table 2.

Types of surfactant micelle systems

Depending on the types of surfactant used for extraction, the characteristics of the micelle system changes. Different types of surfactant micelle systems are discussed briefly (Taylor et al. 1993):

- (1) **Non-ionic micellar media:** This surfactant's polar chain contains hydrophilic groups which form inter-molecular hydrogen bonding with water. Critical micelle concentration (CMC) values of surfactants can be altered by additives and improvers. The phase separation will happen above the cloud point temperature (CPT) which is increased with decrease in molecular mass and branching of hydrophobic tail. It is observed that the CPT decreases with addition of neutral electrolyte (sulphates, carbonates) and polar organic compounds (aliphatic alcohols, fatty acids). In contrast, addition of salting in type salts (nitrates, thiocyanates) increases the CPT. Triton X-45, Triton X-100, and Triton X-114 are some of the widely used non-ionic micellar medium.
- (2) **Zwitterionic surfactant micelle system:** The behaviour of Zwitterionic surfactant are utilized for extraction. Most of these surfactants exist in isotropic phase at higher temperature, and they separates on cooling time. Presents of salting in type salts lowers CPT and

Table 1 Comparison between conventional and cloud point extraction method

Solvent extraction	Cloud point extraction
Use of toxic and flammable organic solvents	Lower toxicity; use of benign surfactants
Longer extraction time	Simple and rapid; reduce extraction time
Low concentration efficiency for solute	Powerful even at low concentrations of surfactants
Mass action of extractant is decreased due to dilution	Provides high preconcentration factors even with low concentrations of surfactants
Expensive	Inexpensive
Some concern regarding the environmental pollution caused	Negligible environmental pollution

Fig. 1 Mechanistic overview of cloud point extraction. (Modified fig of Samaddar and Sen 2014)

Fig. 2 Key steps in cloud point extraction. (Modified fig of Samaddar and Sen 2014)

Table 2 The chemical used in CPE extraction

Chemical	Role of chemicals
Surfactant	Cluster formation occurs at CPT, where surfactant micelles attract each other due to dehydration. This clouding behavior depends on the hydrogen bonds between water and surfactant molecules. When clustering or aggregation of micelles occurs that time surface area decreases which is occupied by the polar group on micelle with increasing the size (infinite) of the micelle at cloud point
Sample extract	It needs to be made by dissolving the source in an organic solvent for the extraction of the target analyte
Salt	The hydrophobic interactions between analytes and surfactant aggregates improve by salts and also facilitates extraction from the aqueous to the micellar phase
Organic solvent	Presence of ethanol increases the CPT of the system, higher pre-concentration factor and an enhanced phase separation. They can also be used as diluting agent

addition of sulphates increases the CPT, which is exactly opposite of non-ionic micelles. Lecithins, dimethylalkylphosphone oxides, ammonioethylsulfates are some of the Zwitterionic surfactants.

- (3) Cyclodextrin systems: These molecules have a hydrophobic cavity inside and hydrophilic minorities outside. Requirement of minimum CMC is not there for cyclodextrin system due to their rigid structure. Similar to non-ionic micellar system, they exist in isotropic phase below the CPT, and on heating above CPT they separate, but the entire process is characterised by hysteresis loop. Generally derivatives of cyclodextrin exhibit phase separation. *O*-methyl- β -cyclodextrin and permethylhydroxypropyl- β -cyclodextrin do exhibit phase separation.

Application of CPE in food processing

Several authors have reported the theory and application of cloud point technology, however very little focus has been given to application of CPE in food processing (Taylor et al. 1993; Huie 2002; Ojeda and Rojas 2009; Ballesteros-Gómez et al. 2010; Melnyk et al. 2015). The main objective is a detailed review on the opportunity of CPE in various dimensions across food processing. More emphasis is given to the recent research findings which highlights the advantages of CPE in extracting, analysing bioactives and other constituents in food.

CPE is one of the promising novel technologies for extraction of functional components due to their mild conditional requirements. Being a promising technique, this can be amalgamated with food technology for the efficient extraction of food bioactives. There are reports on cloud point technique widely used for sample preparation for analysis of different constituents in food.

Extraction of bioactives

The specificity, efficiency, low temperature and solvent requirement of CPE make it an effective technology for extraction. Thermo-sensitivity and purification requirement for extraction of bioactives are one of the challenges faced on extraction of the major challenges faced. CPE can be used for extracting these components by addition of additives to reducing the CPT.

Bioactive extraction from food processing byproducts

Last decade, CPE assisted bioactive extraction created interest among researchers. Use of CPE for extraction of

polyphenols from industrial waste is one of the major areas of study. Papaioannou and Karabelas (2012) studied the extraction of lycopene from the tomato peel residues which usually create from the tomato processing industry. Extraction efficiency was improved by enzymatic pre-treatments. They investigated 8 surfactants for extraction and where they found SPAN 20 was most suitable with 6–7 optimum ratios of surfactant molecules per lycopene. The lycopene extraction yield was improved by enzymatic pre-treatment followed by surfactant-assisted extraction.

Similar studies were performed for extraction of phenols and carotenoids from red-flesh orange juice and olive mill wastewater by using CPE (Katsoyannos et al. 2012). Authors compared the suitability of tween 20 and 80, PEG 400, and span 20 for extraction. Tween 80 recovered maximum extracts and maintained high antiradical activity. Double step CPE retained phenols up to 94.4% from olive mill wastewater while 79.8% of the total carotenoids were recovered from red-flesh orange juice. El-Abbassi et al. (2014) also used CPE techniques for separation of phenolic compounds from wastewater olive mill. Before CPE extraction, it was ultra-filtered by passing through 50 kDa polyethersulfone membrane. CPE recovered 66.5% of the phenolic content using surfactant (Triton X-100) where it heated above cloud point temperature. The thermal stability of polyphenols remained unaffected with stabilization of the antioxidant activity by using salting-out-assisted cloud point extraction with Tween 80 from olive leaf, which is a by-product obtained from cleaning of olive berries.

Wine sludge which is a by-product of wine fermentation is rich in polyphenols like proanthocinidins. Chatzilazarou et al. (2010) reported a CPE procedure for removal of polyphenols. Polyphenols were recovered from wine sludge using surfactants like PEG 8000 and Genapol X-080. Genapol X-080 recovered 75.8% of phenols from sludge where PEG 8000 recovered 95.8%. Vichapong et al. (2014) developed CPE procedure for sample preparation for HPLC quantification of phenolic compounds from selected local wines of Thai where it enriched the concentration of phenols.

Xanthohumol is polyphenol which have positive effect on carcinogenesis by modulating the activity of detoxifying enzymes and pro-carcinogen activating enzymes. Hops used in beer are a main dietary source. CPE can be used for extracting xanthohumol from beer using Triton X-114 as the extraction media (Chen et al. 2010). Authors optimized the method for highest extraction yield. They recommended the CPE procedure driven by the low cost and eco-friendly technique which does not require any organic solvents.

Mohammadzadeh et al. (2018) recovered 80% betaine from beet molasses by using three steps CPE extraction

technique under optimum conditions, such as 0.5% (w/v) surfactant concentration, 27.5% (w/v) of molasses concentration, 20 min of incubation time, at 6.1 pH, and 1.5% (w/v) of surfactant. The nature of betaine is hydrophobic, so it solubilized in surfactant and extraction was carried at pH 6. There have been various reports that showed neutral forms of organics mostly extracted into surfactant rich phase comparatively in the ionized forms. Therefore, pH should be adjusted prior to conduct the CPE step. Further surfactant rich phase has to be adjusted to pH 2.5 and 40 min of incubation time to recover 100% betaine was few suggestions from the authors.

Kiai et al. (2018) recovered phenolic compounds by using CPE technique with three different non-ionic surfactants (Triton X100, Genapol X-080 and Tween 80). The phenolic compounds recovered as were 62% using 10% Tween 80, 65% by using 10% Triton X100, and 68% by using 10% Genapol X-080 at optimum conditions such as 70 °C, pH 2 and 30 min of equilibrium time. The micellar aqueous phase was less hydrophobic than the surfactant-rich phase. The author observed increased separation for caffeic acids which is a hydrophilic molecule. This was due to the fact that the surfactant rich phase was a stronger hydrogen-bond acceptor than the bulk phase. Therefore, increased separation was observed in case of phenolic acids having higher hydrogen acidity. The detailed overview of application of CPE in extracting bioactive from food processing in various by-products is shown in Table 3.

Bioactive extraction from medicinal plants

Medicinal plants are great source of bioactive. Usually, the component of interest in medicinal plants will be the bioactive responsible for the medicinal properties. Huie (2002) reviewed various extraction procedures for bioactive separation for analysis. Recent years, focus on extraction of bioactive from medicinal plants using CPE increased due to its advantages over conventional extraction. CPE can be assisted for isolation of isoflavanone daidzein from *Puerariae radix* (He et al. 2005). *Puerariae radix* are used in treatment of headache, wrist stiffness, and influenza, it is also well known for antipyretic actions and exerts as sedative. These effects are due to daidzein which is difficult to determine as the presence of matrix components in the extracts. CPE is assisted with ultrasonic for efficient extraction. They used sodium chloride for facilitating the phase separation for pre-concentration, and this increased the pre-concentration factor by 13. CPE showed highest yield when compared with methanol, *n*-hexane and cyclohexane.

Ardisia japonica is a shrub and familiar in China which contain bioactive molecule, i.e., bergenin that is known for its antiulcer, hepatoprotective, antidiabetic, antiarrhythmic, and antitussive activities. Bergenin extraction with the help of CPE has been investigated by Xing and Chen (2013). Triton X-114 was very effective in extraction and pre-concentration of bergenin. CPE was combined with ultrasonic for efficient extraction. Zhou et al. (2015) also

Table 3 Overview of application of CPE in extracting bioactive from food processing by-products

Bioactive Extracted	Raw material used	Technology used-extracting media	Inference
Lycopene	Tomato peel residues	Enzyme Assisted CPE-SPAN 20	Yield 4 times more than EAE and 10 than SLE (Papaioannou and Karabelas 2012)
Phenols and Carotenoids	Red-flesh orange juice and Olive mill wastewater	CPE- Tween 80	Recovered up to 94.4% maintaining antiradical activity (Katsoyannos et al. 2012)
Phenolic compounds	Olive mill wastewater	Ultrafiltration assisted CPE- Triton X-100	The highest yield at 10% of Triton X-100 at 90 °C (El-Abbassi et al. 2014)
Polyphenols	Olive leaf	CPE- Tween 80- Genapol X-080 and PEG 8000	Extracted without affecting the antioxidant activity (Stamatopoulos et al. 2014)
Polyphenols	Wine sludge	CPE- Triton X-114	High phenol recovery values (75.8% and 98.5%) (Chatzilazarou et al. 2010)
Phenolic compounds	Thai local wines	CPE	15-fold enrichment (Vichapong et al. 2014)
Xanthohumol	Beer	CPE- Triton X-114	Increased Thermal stability without affecting AOX activity (Chen et al. 2010)
Thymol	Ajwain seeds	SPAN 80 surfactant	The maximum recovery of thymol observed with SPAN 80 surfactant as compared to Triton X-100 and TWEEN 80 (Chatterjee et al. 2017)

focused on developing extraction and pre-concentration of *Apocynum venetum* leaf samples for analysis of flavonoids. Leaf of the herb is a popular Chinese medicine used for lowering blood pressure. They used mixed micellar system of non-ionic surfactant (cetyl-trimethyl ammonium bromide and Genapol X-080) for extracting. Under optimized conditions, CPE could enrich all the six flavonoids by 75 times.

As discussed in above sections, combination of different extraction techniques with CPE will increase the yield of extraction. Tang et al. (2017) used microwave-assisted CPE for separation of alkaloids and flavonoids from *Crotalaria sessiliflora* by using Triton X-100-NaCl-HCl which could efficiently separate. This bioactives commonly used in the treatment of cancer like skin, esophageal, and cervical. The flavonoids and alkaloids from the Chinese leguminous plant (*Crotalaria sessiliflora* L) which are commonly used in the treatment of cervical cancer have been extracted. A microwave-assisted cloud-point extraction (MACPE) technique was successfully used to extract and separate these components (Tang et al. 2017). Overview of application of CPE in extracting bioactive from medicinal plants is shown in Table 4.

Separation of bioactives from surfactant rich phase can be achieved by liquid–liquid extraction. Generally, polyphenols can be separated from surfactants by partitioning it with green solvents like ethyl acetate and ethanol. Lycopene from Span 20 can be recovered by ethyl acetate partitioning (Papaioannou and Karabelas 2012).

It is to be noted that bioactives are more stable and bioactive in emulsion system than in free form (Stamatopoulos et al. 2014). Commercially, after purification these bioactives are emulsified for various applications. It is possible to use the same surfactant for CPT which is used for formulation. By doing this can bypass the conventional isolation and formulation process.

Separation and purification of protein

Purification and separation of protein is comparatively critical than bioactive extraction. Depending on the end application of protein, constraints while extraction will change. For example, there will be less constraints in extraction parameters like temperature if the application is as a protein source. While if the application is for bioactivity of the protein, then the extraction should not have an effect on the protein structural integrity. CPE is best suitable for separation and purification of protein because of its mild conditional requirements. Table 5 describes recent studies on separation and purification of protein. The purification of casein proteins was optimized by using CPE method (Lopes et al. 2007). Main motive in this research was to separate casein and whey from milk, where hydrophobicities was the basis of separation. The non-ionic surfactant (Triton® X-114) and electrolyte (sodium chloride) were utilized. The results elucidated that at optimum conditions, surfactant-rich phases showed highest concentration of protein as compared to surfactant-poor phases. Even α -lactalbumin and β -lactoglobulin separated effectively from the whey by using CPE (Monteiro et al. 2008). The copolymers (ethylene oxide and propylene oxide) developed thermo-separation properties with the CPE by using aqueous biphasic systems responsible for partition where α -lactalbumin accumulated in aqueous phase, and distribution of β -lactoglobulin observed in both the phases. Potassium phosphate used as additive to adjust the CPT. Overview of application of CPE in separation and purification of protein are reported in Table 5.

Separation of proteins from surfactant rich phase can be performed by precipitation. Casein can be precipitated from Triton® X-114 by using acetone (Lopes et al. 2007).

Table 4 Overview of application of CPE in extracting bioactive from Medicinal plants

Bioactive Extracted	Raw material used	Technology used- extracting media	Inference
Isoflavone Daidzein	<i>Puerariae radix</i>	Ultrasonic-assisted CPE- Genapol X-080	Highest yield when compared with MeOH, n-hex and cyclo-hex. 13 fold increase in preconcentration (He et al. 2005)
Bergenin	<i>Ardisia japonica</i>	Ultrasonic-assisted CPE- Triton X-114	Higher yield than methanol extraction (Xing and Chen 2013)
Flavonoids	<i>Apocynum venetum</i> leaf	CPE- Genapol X-080 and CTAB	Enrichment of six flavonoids was greater (Zhou et al. 2015)
Flavonoids and Alkaloids	<i>Crotalaria sessiliflora</i> L	Microwave-assisted CPE- Triton X-100-NaCl-HCl	Flavonoids and alkaloids can be purified from bottom and top phase. 1.5 times higher yield than HRE and UAE (Tang et al. 2017)

Table 5 Overview of application of CPE in separation and purification of protein

Protein Extracted	Raw material used	Technology used- extracting media	Inference
Casein and Whey	Cow milk	CPE- Triton® X-114	Separated casein and whey. The surfactant-rich phase enriched with casein (Lopes et al. 2007)
α -lactalbumin and β -lactoglobulin	Whey	CPE- Biphasic polymer of ethylene oxide and propylene oxide	α -lactalbumin concentrated in the upper phase, while protein β -lactoglobulin was distributed (Monteiro et al. 2008)
Betaine	Beet molasses	Tx-114, Tx-100	Betaine recapture from beet molasses was attained up to 80% (Mohammadzadeh et al. 2018)

Food constituent analysis

Food samples are too complex or dilute for analysis or for direct analysis. Therefore, sample preparation is necessary. Sample preparation procedures are continuously improved for higher recovery and reproducibility of analytes. Degradation of analytes is one of the biggest challenges while preparation. The mild conditions, specificity and lower requirements of organic solvents in CPE make it a perfect technology for extraction of analytes from sample.

Food additive analysis

Sensitivity of a method is also depends on the enrichment factor of extraction process. CPE can be used to directly enrich and extract the analytes from sample. CPE assisted procedure invented for determining citrates concentration in food matrix (Pourreza et al. 2016). They determined citrates in food by combining curcumin nanoparticles with surfactant Triton X-100 which is assisted via ultrasound extraction. The main principle of assay is in presence of Fe^{3+} ions the curcumin nanoparticles forms a complex which can be analysed calorimetrically. Citrate ion which when extracted in non-ionic surfactant phase will form new complex with curcumin nanoparticle- Fe^{3+} complex, which in turn decreases the absorption of curcumin nanoparticle- Fe^{3+} complex.

Altunay et al. (2017) developed an effective method for estimation of maltol as flavour enhancer, which is extracted by using ultrasound assisted-CPE and analysed through flame atomic absorption spectrometry. At pH 6.5, maltol converts Cu (II) to Cu (I) which measure concern of the analysis. The Cu (I) and bathocuproine (BCP) was easily and rapidly extracted into the micellar phase of Tween 80 using ultrasound with the presence of an anionic surfactant where sodium dodecyl sulphate (SDS) the selectively interacted. Various food and beverages like dark chocolate and fruit-flavoured beverages (lemon juice, grape juice and

apple juice) were used for evaluating maltol which shows that selectivity, and sensitivity for the rapid, accurate and reliable determination.

Mineral analysis

ICP mass spectrometry (MS), atomic absorption spectrometry, and optical emission spectrometry are well known and established spectro analytical techniques for estimation of metal/minerals. The separation and pre-concentration for determination of metals by using CPE was reviewed by Ojeda and Rojas (2009). Advantages of CPE in terms of metal analysis are that, it has a large preconcentration factor due to the presence of surfactant which minimizes analytes losses by adsorption onto the container. This is also leads to higher recovery efficiency. Main advantage is that it uses water and avoids the use of large amounts of toxic and flammable organic solvents. This method successfully tested for metal analysis if food samples like canned fish, green tea, black tea, tomato sauce, apple leaves, and honey (Lemos et al. 2008; Citak and Tuzen 2010).

Pesticide residue analysis

Pesticides in food are difficult to analyse due to several factors including complexity of food matrix, the significant amount related to that of target pesticide and pesticides may be possible in very low levels. CPE is a very apt technique for extraction and preconcentration due to its advantages as discussed earlier. New procedures for determination of Carbamates, a class of pesticides, in corn by using CPE and HPLC were developed (Zhou et al. 2009). They focused on developing a highly sensitive method for the determination of carbofuran, fenobucarb, arprocarb and isoprocarb. The alkaline hydrolysis of four carbamate pesticides reacted with 4-aminoantipyrine and

formed red colour products which were then enriched and were separated by CPE. The compounds present in coacervate phase were determined with HPLC system. Triton-100 and Na_2SO_4 were used as surfactant and additive respectively for CPE. The authors concluded that CPE-HPLC-Vis method was very effective in detection of carbamate pesticides. The background absorbance of Triton X-100 did not overlap with the peak of targets. Therefore, the surfactant-rich phase was directly analyzed with the HPLC system in the visible region. The color derivants were determined by UV-vis detector; the absorptive signals of the derivants were much higher than those of the original carbamate pesticides and a higher concentration factor was obtained by CPE. Hence it was concluded by the authors that the sensitivity of the new method was much higher than that of determination of carbamate pesticides directly. Organic solvent was not used in procedures of sample treatment and CPE; the analysis method was found to be more friendly to both the environment and operators.

Antibiotic residue analysis

Direct analysis of antibiotic residues from the food is very challenging because of the complexity of food matrix. Sample preparation and concentration is necessary prior to the analysis. Antibiotic are present in the food in much lower levels and are usually intermingled with the matrix, so extraction and concentration is very critical. A penicillin residues in bovine milk were extracted by using a mixed micelle-cloud point extraction (MM-CPE) and detected by HPLC which is discovered by Kukusamude et al. (2010). MM-CPE was performed in milk sample by using mixed micellar extractant, such as cethyl trimethylammonium bromide and Triton X-114. Electrolyte salt used was Na_2SO_4 . The separation of penicillins was achieved within 8 min under the HPLC conditions. Author observed a good reproducibility with relative standard deviation $< 5\%$ for peak area and $< 3\%$ for retention time. High accuracy, with recoveries higher than 80%, was obtained. Thus the author concluded that the proposed mixed micelle-CPE-HPLC method is of high potential for the analysis of penicillin residues in milk with LOD comparable to the established maximum residue limits ($4\text{--}30 \text{ ng mL}^{-1}$). In the present experiment the optimum MM-CPE conditions were able to give a 15–40 fold enhancement.

Packaging material residue analysis

Plastic additives and residual monomers are known as packaging material residues and move freely in polymer matrix because they are not chemically bound to the

polymer molecules. But there may be chance that residues may dissolve in food when they contacted and adversely affect the safety, flavour and acceptability of the food. The residues levels present are very less thus sample extraction and concentration is necessary.

Polycarbonate plastic is made by using bisphenol-A (BPA) and in certain conditions it leach from plastic. Their negative health effects at low doses levels are because of its capability to mimic body's hormones. The presence of BPA in canned vegetables and fruits such as sweet corn, peas, red peppers, green beans, and peaches in syrup, mango slices and fruit salad were extracted by using decanoic acid reverse micelle-based CPE technique (Prieto et al. 2008). They quantified by using liquid chromatography.

Formaldehyde is another migrant molecule from packaging materials. The occurrence of formaldehyde is only possible in two ways one is illegally applied in food industry and other is naturally produced during fermentation. Ultrasonic assisted CPE procedure for pre-concentrating formaldehyde from beverage matrices has been developed (Temel and Gürkan 2017). Formaldehyde reacts with Variamine blue in mixed micellar media at pH 7 which is extracted in surfactant rich phase. They used Triton X-114 and sodium dodecylsulfate mixture for extraction. Formaldehyde was determined in milk and butter milk.

Mycotoxin analysis

Mycotoxin is chemical toxins produced by fungus which are developed on food commodities. Fungal species mostly *Penicillium Aspergillus*, and *Fusarium* sp. are main producers of mycotoxins. The major classes, such as ochratoxins, fumonisins, aflatoxins, patulin and zearalenone showed toxicological impact on human health. CPE can be used for extraction of Ochratoxin A in wines. Furthermore, it was determined by using liquid chromatography/fluorescence (García-Fonseca et al. 2008). Extraction was based on both hydrophobic and hydrogen bond Ochratoxin A-surfactant interactions. They recovered Ochratoxin A from white, rose and red wines in surfactant rich phase which is then quantified by liquid chromatography equip with florescence detector. Overview of application of CPE in sample preparation for food constituent analysis reported in Table 6.

Advantages, limitations and future scope of CPE

The Advantage of coacervate-based extraction (Melnik et al. 2015):

Table 6 Overview of application of CPE in sample preparation for food constituent analysis

Analytes	Food matrix	Technology used- extracting media	Inference
Citrates	Lemon juice	Ultrasonic-assisted CPE- Triton X-100	Linear calibration intervals 3–100 ng mL ⁻¹ and 100–600 ng mL ⁻¹ of citrate with a detection limit of 1.7 ng mL (Pourreza et al. 2016)
Maltol	Soups, Chocolates, Milk based products and Fruit Juices	Ultrasonic-assisted CPE- Tween 80	Higher sensitivity rapid, accurate and reliable determination of trace maltol (Altunay et al. 2017)
Copper And Nickel	Apple Leaves, Spinach Leaves and Tomato Leaves	BDAP complex extracted by CPE- Triton X-114	Higher sensitivity The L.O.D- 0.1 µg g ⁻¹ (Cu) and 0.4 µg g ⁻¹ (Ni) (Lemos et al. 2008)
Lead, Cobalt And Copper	Apple leaves, canned fish, honey, tea and tomato sauce	1-PTSC complex extracted by CPE- Triton X-114	L.O.D.—3.42, 1.00, and 0.67 µg L ⁻¹ preconcentration factor of 25 (Citak and Tuzen 2010)
Carbamates	Corn	Hydrolysed 4-aminoantipyrine extracted by CPE- Triton-100	Developed highly sensitive method for the determination of aprocarb, carbofuran, isoprocarb and fenobucarb (Zhou et al. 2009)
Penicillin	Milk	MM-CPE- CTAB and Triton X-114	LOD2–3ng mL ⁻¹ and 15–40 fold enhancement (Kukusamude et al. 2010)
Bisphenol-A	canned vegetables and fruits	RM-CPE- Decanoic acid	Higher sensitivity rapid, accurate and reliable determination of trace bisphenol-A (Prieto et al. 2008)
Formaldehyde	Milk and Butter milk	ultrasonic assisted MM-CPE Triton X-114 and SDS	Sensitivity enhancement of 65 after preconcentration were 0.53 and 1.76 µg L ⁻¹ (Temel and Gürkan 2017)
Orange II	Chewing gum and sweets	MM-CPE- CTAB and Triton X-100	Higher sensitivity rapid, accurate and reliable determination of Orange II (Pourreza and Zareian 2009)
Sudans dyes	chilli and Curry powder	RM-CPE- Decanoic acid	The detection limits of the method were 4.2, 2.7, 6.5 and 7.4 µg kg ⁻¹ for Sudan I, II, III and IV (López-Jiménez et al. 2010)
Allura red	Candy, drink, pastel or jelly	MM-CPE- CTAB and Triton X-100	Much safer. LOD was better or comparable to some of the previously reported techniques (Pourreza et al. 2011)
Carmoisine and Brilliant blue FCF	raspberry jelly, fruity candy, smarties, candy	CPE Triton X-100	Low detection limit (1 ng mL ⁻¹ levels), wider linearity and also good standard deviations (Pourreza and Ghomi 2011)
Ochratoxin A	white, ros'e and red wines	RM-CPE- Decanoic acid	Detection limits of 4.5ng L ⁻¹ for white and ros'e wines, and 15ng L ⁻¹ for the red wine (García-Fonseca et al. 2008)

- Elimination of certain procedure which are required for conventional extraction technique such as purification of extract, concentration, additional clean up etc.
- Non-toxic surfactant
- Requirement of smaller amount of chemicals
- Option of simultaneous extraction of multiple compounds
- Possibility of mild extraction conditions
- Lower probability of emulsion formation while extraction
- Compatibility with wide range of food matrix

On the other hand, limitations of CPE include:

- Limit in detection of analytes due to complexity of surfactants

- Lower efficiency in extracting polar components by non-ionic surfactants
- Requirement of further treatment of extract before analysis
- Temperature constrains for phase separation while extracting thermally-labile components
- Difficulty in automation

Future Scope

These are some areas where CPE deserve more attention:

- Extraction of polar bioactive components
- Simultaneous flavour extraction and encapsulation

- Zwitterionic surfactant micelle system for extraction of heat sensitive biomolecules
- Application of Cyclodextrin system for extraction
- Separation and purification of enzymes using CPE
- Modification of the extraction medium for efficient extraction
- Designing of commercial CPE systems
- Automation in sample preparation

Conclusion

Our review concludes that CPE is a promising method of extraction of bioactive from food. As pointed out in this review, great effort has been made in extraction of bioactive from food processing by-products as well as separation and purification of proteins. The scope of CPE is very vast in food processing because of the advantages of CPE over other methods. Besides, extraction of bioactive and protein from food, research has received special attention on sample preparation for analysis of food constituents. It can be therefore concluded that there are several possibilities of extending the range of applications for CPE in food processing.

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Compliance with ethical standards

Conflict of interest Authors have declared that no conflict of interest exist.

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