Quality evaluation of peony seed oil spray-dried in different combinations of wall materials during encapsulation and storage

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Abstract This study aimed at evaluating the performance of peony seed oil microencapsulated by spray drying during encapsulation and storage. Four different combinations of gum arabic (GA), corn syrup (CS), whey protein concentrate (WPC) and sodium caseinate (CAS) were used to encapsulate peony seed oil. The best encapsulation efficiency was obtained for CAS/CS followed by the CAS/GA/CS combination with the encapsulation ratio of 93.71 and 92.80 %, respectively, while the lowest encapsulation efficiency was obtained for WPC/GA/CS (85.96 %). Scanning electron microscopy and confocal laser scanning microscopy revealed that the particles were spherical in shape and did not exhibit apparent cracks or fissures, and gum arabic was uniformly distributed across the wall of the microcapsules. Oxidative stability study indicated that the CAS/GA/CS combination presented the best protection against lipid oxidation and the smallest loss of polyunsaturated fatty acid content among all of the formulas as measured by gas chromatography. Therefore, CAS/GA/CS could be promising materials encapsulate peony seed oil with high encapsulation efficiency and minimal lipid oxidation.

Keywords Peony seed oil · Microencapsulation · Spray drying · Encapsulation efficiency · Oxidative stability

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Introduction

Tree peony (*Paeonia* section *Moutan* DC.) is a popular traditional ornamental plant in China existing for more than 2000 years. It has been widely cultivated because of its ornamental characteristics and medicinal properties. According to statistics, with the expansion cultivated area of tree peony in China, the annual seed yield reached 57,855 tons (Li et al. 2015b). Peony seeds are used in Chinese folk medicine for whitening skin, easing waist and leg pains, and curing oral ulcers. The seeds also exhibit strong anti-inflammatory properties, inhibitory activity against soybean lipoxygenase (He et al. 2013), and protection on HEK 293 cells from irradiation-induced DNA damage (He et al. 2012). Recent studies demonstrated that the peony seeds are notable for its high oil content, which varies from 24.12 to 37.83 %, and contains more than 90 % unsaturated fatty acids, especially α -linolenic acid (31.56 ~ 66.85 %) (Zhang et al. 2015). It is well known as that α -Linolenic acid (ALA) as the precursor of EPA (eicosapentaenoic acid, 20:3n-5) and DHA (docosahexaenoic acid, 22:3n-6), is an essential fatty acid that humans cannot synthesize and must be supplied by diet (Kim et al. 2014). These two omega-3 fatty acids serve positive physiologic roles, especially during fetal and infant growth, in the prevention of cardiovascular diseases, and in their effects against inflammation, platelet aggregation, hypertension, and hyperlipidemia (Kaur et al. 2014; Lorente-Cebrián et al. 2013). In 2011, peony seed oil was identified as a new food resource by the Ministry of Public Health of China (Li et al. 2015a). However, further development and application of tree peony seeds has long been neglected (Li et al. 2015b). Therefore, comprehensive development of technologies involving tree peony oil is believed to be a promising avenue for nutritional research and application. Moreover, oils rich in polyunsaturated fatty acids (PUFAs) are usually highly susceptible to

oxidative rancidity and nutritional loss, which then form volatile compounds that can produce undesirable flavor and free radicals (Ahn et al. 2008). To address this issue, a convenient solution to achieve the oxidative protection of the oils against environmental conditions during processing and storage is in need.

Microencapsulation is a technique used to envelop sensitive ingredients with an edible coating material. Through this process, lipid oxidation during storage would be retarded. Consequently, their shelf lives would lengthen, the taste or odor of the core material would be masked, and the liquid would be converted to freely flowing powders (Ahmed et al. 2010; Koç et al. 2015; Tatar et al. 2014). Among the different microencapsulation methods available, spray drying is the most commonly used in the food industry, due to its low cost and high efficiency. Microencapsulation of edible oils has been widely adopted as an approach to protect PUFAs from environmental factors. The majority of literatures on the microencapsulation of functional lipids have been carried by using fish oils, chia oils, or flaxseed oils as core material (Martínez et al. 2015; Tirgar et al. 2015; Tonon et al. 2011). Dried microencapsulated edible oil has gained considerable interest in food industries, since it is easily incorporated into many food products, such as bread, low-fat cakes, cookies, fruit juice, cheese, yogurt, soups powder, and infant formula (Bakry et al. 2016). The health benefits of functional oils consumption may further drive the development of microencapsulated oils for nutraceutical and food enrichment applications.

To effectively encapsulate edible oil, an appropriate choice of wall materials that meets the required criteria is very important. Selection of wall material will impact the stability of emulsion during its formation, as well as the physicochemical features of the oil microcapsules (Jiménez-Martín et al. 2015). Generally, different wall materials are varied in different physical and chemical characteristics. Proteins are considered as potential wall material with many desirable characteristics and have been widely used in food products. The most commonly used proteins are sodium caseinate and whey protein because of their excellent film formation capacity and emulsification properties (Charve and Reineccius 2009; Rodea-González et al. 2012). Corn syrup functions as fillers and matrix-forming agents due to low viscosities at high solids contents and good solubility, but it lacks the interfacial properties (Silva et al. 2014). Gum arabic presents many desirable characteristics to be a good wall material with high solubility, low viscosity and good emulsifying properties. However, high cost, limited supply and quality variations have restricted the use of gum arabic for encapsulation purpose (Subtil et al. 2014). As no single wall material possesses all the properties required for an ideal encapsulating agent, therefore, combinations of various encapsulating agents are necessary.

Previous studies have primarily focused on the extraction technology, nutritional value, and qualitative and quantitative analysis of peony seed oil (Su et al. 2016; Wang et al. 2015).

However, none of these published works have reported the microencapsulation of tree peony seed oil by spray-drying. This study aimed at evaluating the performance of peony seed oil microencapsulated by spray drying during encapsulation and storage, and screening the optimal wall matrix systems to encapsulate peony seed oil by spray-drying with high encapsulation efficiency and minimal lipid oxidation to promote its application in food industry. The microcapsules were evaluated for microencapsulation efficiency, particle size, superficial morphology, inner structure, lipid oxidation and fatty acids profile.

Materials and methods

Materials

Gum arabic (GA) was purchased from Haibinjiecheng Chemicals (Tianjing, Hebei, China). Sodium caseinate (CAS) and Whey protein concentrate (WPC) were purchased from Mingrui Chemicals Company (Zhengzhou, Henan, China). Corn syrup (CS) was donated by Weibao Company (Yichun, Jiangxi, China). Peony seed oil was purchased from Zhonghejianyuan Company (Heze, Shandong, China). All chemicals used were of reagent grade. All solutions were prepared with distilled water.

Preparation of emulsion

For microencapsulation of peony seed oil four formulations emulsion were prepared. Various wall material formulations including CAS/CS, CAS/GA/CS, WPC/CS, WPC/GA/CS were dissolved with distilled water following the depicted in Table 1. Formulations of emulsions were prepared with 30 % total solid concentration (wall materials + oil). The feed emulsions were produced by blending peony seed oil with wall material solution using an ULTRA-TURRAX T18 high-shear probe mixer (Janke & Kunkel GmbH, Staufen, Germany) operated at 20,000 rpm for 60 s to give pre-emulsions. The emulsions were further homogenized at 30 Mpa with three round-trips using a high-pressure laboratory valve homogenizer (GYB60-6S, Donghua Company, Shanghai, China).

Microcapsulation with spray-drying

The stable emulsions were fed to a mini spray dryer (SD-06; LabPlant, England) equipped with a 0.5-mm atomizer, and a chamber with height and diameter at 44 and 10.5 cm, respectively. The inlet and outlet air temperatures were maintained at 180 ± 0.5 and 90 ± 5 °C, respectively. The feed pump was set at 15 rpm and compressed air for the spraying flow was established at 0.6 MPa. The microcapsules were stored in a sealed plastic bag for further analysis.

Table 1 Description of formulations

	CAS/CS	CAS/GA/CS	WPC/CS	WPC/GA/CS
Sodium caseinate (%)	5	5	—	—
Whey protein concentrate (%)	—	—	5	5
Gum arabic (%)	—	3	—	3
Corn syrup (%)	56.7	53.7	56.7	53.7
Emulsifier (%)	3.3	3.3	3.3	3.3
Peony seed oil (%)	35	35	35	35

CS Corn Syrup, CAS Sodium Caseinate, WPC Whey Protein Concentrate, GA Gum Arabic

Microencapsulation efficiency

Total oil (*TO*) content in microcapsules was quantified using the AOAC Official Method 925.32 including an acid hydrolysis, solvent extraction and gravimetric analysis. Briefly, 1 g of powder was transferred to a fat-extraction tube and 10 mL HCl was slowly added. The tubes were placed in a water bath at 70 °C, then the temperature was heated to 100 °C and then boiled for 30 min. After cooling to room temperature (25 °C), 25 mL ethyl ether and 25 mL petroleum ether were added and the tubes were shaken vigorously for a minute. The ether phase was separated and filtered through packed cotton. The remaining aqueous phase was further extracted twice with 15 mL ethyl ether and 15 mL petroleum ether. The solvent was evaporated (V-1001, Ailang Company, Shanghai, China) and the oil was dried in a vacuum oven at 100 °C to constant weight.

Extractable oil, usually referred to surface oil (*SO*), was determined according to Davidov-Pardo et al. (2008). This non-encapsulated oil can be defined as the fraction easily extracted with organic solvents without disrupting the solid matrix. Briefly, 4 g microcapsule powder was drip washed with 75 mL ethyl ether for 15 min at 25 °C. The suspension was filtered through a filter paper and the powder on the filter was rinsed three times with ethyl ether. The solvent was dried and rota-evaporated to obtain the surface oil mass. Encapsulation efficiency (*EE* %) was calculated from the following equation:

$$EE\% = \left(\frac{TO-SO}{TO} \right) \times 100$$

Particle size

Microparticles were dispersed in ultra-pure water, the particle size was measured by a particle size analyser (Mastersizer 2000-Malvern Instruments, England) under scattering pattern of a transverse laser light. The particle size was expressed as D_{43} , which is defined as the maximum size of 50 % analyzed particles and the particles size range.

Microstructure

Scanning electron microscopy

Surface morphology of microcapsules was analyzed by scanning electron microscopy (SEM). Microcapsules were adhered to a cover slip, observed with a scanning electron microscope (XL-30 ESEM, Philips, Netherlands) under high vacuum with acceleration voltage at 5 kV.

Confocal laser scanning microscopy (CLSM)

For visualisation of the wall material in microcapsules, the fluorescent dye N-Methylisatoic Anhydride was used to mark GA prior to emulsion formation. A Zeiss LSM 710 confocal laser scanning microscope (Zeiss, Oberkochen, Germany) was used to investigate the distribution of wall material and the morphology of microcapsules. All confocal fluorescence pictures were taken with a $\times 40$ objective (oil immersion, numeric aperture 1.30). The software used for the CLSM imaging was Laser Sharp MRC-1024 Version 3.1 (Bio-Rad, Deisenhofen, Germany). For imaging, a dispersion of dry microparticles in neutral oil was prepared.

Lipid oxidation analysis

The oxidative stability of peony seed oil encapsulated into the different wall materials combinations was evaluated by determining the peroxide value, during 4 weeks of storage, at 45 °C. A sample powders (5 g) were weighed and suspended in 50 mL petroleum ether followed by vigorously shaking for 2 min. The suspension was filtered through a filter paper and the sediments were rinsed three times with petroleum ether. The solvent was evaporated and the extractable oil was taken for analysis. The peroxide value determination was carried out spectrophotometrically according to the IDF standard method 74A:1991 using the Unico 2800UV/VIS spectrophotometer (United Products & Instruments Inc, New Jersey, USA). All measurements were performed in triplicate. Hydroperoxide concentration was measured by the ferric

standard curve with iron concentration varying from 1 to 40 µg, as described by Shantha and Decker (1994).

Fatty acids analysis

Fatty acid methylation: Fatty acid derivatization was carried out to obtain the corresponding methyl esters. Briefly, 2 mg oil was dissolved in 1.5 mL *n*-hexane. Then, 40 µL methyl acetate and 100 µL 0.5 N sodium metoxide were added in, vortexed for 1 min. The sample was kept at room temperature for 20 min and then placed in −20 °C freezer for 10 min to induce derivatization. Afterwards, 60 µL of formic acid was added to terminate the derivatization reaction. Fatty acid methyl esters (FAMES) were subsequently centrifuged in a LD centrifuge (2500 rpm, 10 min), the supernatant collected, then the samples were dried with a nitrogen blowing instrument. The concentrated solution was re-dissolved in 1 mL *n*-hexane volume, transferred to 2 mL vials in sample volumes of 1.0 mL.

Chromatographic conditions: Fatty acid analysis was carried out by using a gas chromatograph-mass spectrometer (GC 6890 N, Agilent) equipped with a flame ionization detector (FID) and a fused silica capillary CP-Sil88 (100 m × 0.25 mm i.d., 0.20 µm film; Agilent). Operating conditions were as follows. The injector and detector temperature was set at 240 °C and 280 °C, respectively. The initial oven temperature was maintained at 45 °C for 13 min, raised to 175 °C for 27 min (13 °C /min). The temperature was finally raised to 215 °C at rate of 4 °C /min, and held for 35 min. The sample size was 1.0 µL and flashed through with carrier gas (helium) at rate of 1.6 mL/min. Identifications of the methyl esters were made by comparison of retention times of FAMES with the standard 37 components FAMES mixture.

Statistical analysis

The obtained data were statistically analyzed by analysis of variance using the software SPSS version 17.0 for Windows (SPSS Inc., Chicago, IL) and mean analysis was performed using Duncan's procedure at $p < 0.05$.

Results and discussion

Encapsulation efficiency

Successful spray-drying encapsulation relies on achieving high retention of the core materials and minimum amounts of surface oil on the powder particles during processing and storage. Encapsulation efficiency determines the grade of oil protection and is dependent on many factors. The properties of wall and the prepared emulsion along with the drying process conditions influence the efficiency and retention of core oils.

Table 2 presents the surface oil, total oil contents, microencapsulation efficiency and particle size D_{43} of particles prepared with different wall materials. The total oil content was similar for the four samples and close to the theoretical value (35 %). The encapsulation efficiency varied from a minimum value of 85.96 % to a maximum value of 93.71 %. No significant difference ($p > 0.05$) in encapsulation efficiency was found between CAS/CS and CAS/GA/CS, both of these combinations presented higher encapsulation efficiency (93.71 % and 92.80 %, respectively) than other formulas. These values were similar to those obtained by Ixtaina et al. (2015) for chia seed oil encapsulated with a binary biopolymer blend of CAS and lactose which achieved the encapsulation efficiency more than 90 %. WPC/GA/CS coated microcapsules provided the lowest encapsulation efficiency. This discrepancy among the formulas may be explained by the more effective coverage of oil droplet surfaces by surface active CAS than by WPC. The non-micellar casein found in sodium caseinate may have served as a flexible protein that readily unfolded to form an interfacial layer. By contrast, WPC denaturation may have occurred during evaporation and drying, this denaturation could generate a less stable emulsion, increased surface fat, and larger droplets after reconstitution (Vega and Roos 2006).

Particle size

Particle mean diameters varied from 0.27 to 0.39 µm. The microcapsules produced from the mixtures of protein and GA were larger than those of the other formulations. This finding may be attributed to the increase in emulsion viscosity contributed by GA, which is generally used as a thickening agent because of its ramified structure with long chains. According to Carneiro et al. (2013), in a spray-drying system the size of the dried particles depends on the size of the atomized droplets, whereas the atomized droplet size varies directly with emulsion viscosity at a constant atomization speed. Therefore, larger particles tend to form in mixtures with higher emulsion viscosities. The large protein–GA microcapsules may also be explained by the competitive emulsifying activity between the protein and GA, producing less rigid and viscoelastic films around oil droplets that will result to larger droplet sizes. Moreover, the presence of gum could also increase the droplet size during homogenization because of its ability to suppress the formation of small eddies during turbulence (Wang et al. 2011).

Microstructure

Scanning electron microscopy

The microstructure of spray-dried microcapsules is affected by their wall composition and properties, core-to-wall ratio, and drying parameters.

Table 2 Characterization of microcapsules prepared with different types of wall materials

Formulation	Surface oil content (%)	Total oil content (%)	Encapsulation efficiency(%)	Particle size (μm)
CAS/CS	2.14 ± 0.09 ^a	34.02 ± 0.22 ^a	93.71 ± 0.28 ^a	0.27 ± 0.00 ^a
CAS/GA/CS	2.45 ± 0.17 ^a	34.00 ± 0.21 ^a	92.80 ± 0.52 ^a	0.31 ± 0.21 ^a
WPC/CS	3.74 ± 0.12 ^b	33.97 ± 0.21 ^a	89.00 ± 0.41 ^b	0.28 ± 0.21 ^a
WPC/GA/CS	4.75 ± 0.15 ^c	33.83 ± 0.25 ^a	85.96 ± 0.53 ^c	0.39 ± 0.00 ^b

CS Corn Syrup, CAS Sodium Caseinate, WPC Whey Protein Concentrate, GA Gum Arabic

Different letters in the same column indicate significant difference ($p < 0.05$) between samples.

The external morphologies of microcapsules with different wall materials were presented in Fig. 1. The peony seed oil encapsulated with CAS/CS, CAS/GA/CS, and WPC/CS exhibited spherical shapes and smooth surface without apparent cracks or fissures. This type of morphology was necessary to protect the core material from oxygen and the undesired release of oil droplets to the particle surface. On the other hand, the samples encapsulated with WPC/GA/CS were nearly round and slight rough, with no obvious cracks and pores on the surface. This morphology may be attributed to uneven shrinkage at the early stages of drying as previously reported by Santiago-Adame et al. (2015).

Confocal laser scanning microscopy

CLSM allows the inspection of internal particle structures without prior sample destruction. It can be used to localize the encapsulated compounds and to detect special structural details of the wall composition of particle.

The internal structure of the microcapsules and distribution of GA in the microcapsule were studied by CLSM. As shown in Fig. 2a and b, the blue fluorescence ring indicated that the microcapsules assumed spherical, the single-core structure and indicated that the peony seed oils were successfully encapsulated into the microcapsules. In theory, the core-shell

Fig. 1 SEM microphotographs of the external morphology of peony seed oil microcapsules. (a) CAS/CS, (b) CAS/GA/CS, (c) WPC/CS, (d) WPC/GA/CS. CS Corn Syrup, CAS Sodium Caseinate, WPC Whey Protein Concentrate, GA Gum Arabic

Fig. 2 Microcapsules with fluorescent labeling of gum arabic with N-Methylisatoic Anhydride (**a**), and the Fluorescence intensity across the capsule wall (**b**)

and spherical structure is conducive for increasing the loading capacity and encapsulation efficiency of the microcapsule. A homogeneous distribution of the fluorescence intensity throughout the capsule wall was also observed in this case. GA was uniformly distributed across the entire microcapsule wall, increasing wall density and mechanical strength. These results are consistent with those of Lamprecht et al. (2000), who performed a structural analysis of different microcapsules by CLSM. A homogeneous thickness of the microcapsule shell is beneficial to improve the oxidative stability of the microcapsules.

Oxidation stability

Generally, the peroxide value (PV) used to evaluate the quality of oil product. This parameter is obtained by measuring the content of hydroperoxides in the oil, which are formed by the reaction between oxygen and unsaturated fatty acid. The

oxidative stability of powder is strongly influenced by the wall material combination.

The oxidative stability of microencapsulated oil was assessed under accelerated storage conditions. The PV values of peony seed oil encapsulated with different wall materials are shown in Fig. 3. At time zero, the PV values ranged between 8.04 and 8.12 meq/kg oil, with no significant differences ($p > 0.05$) was observed among the samples. All of the powders showed a low level of oxidation, indicating that peony seed oil remained relatively stable against oxidation during the encapsulation process. The microcapsules produced by CAS/CS presented increased peroxide concentrations after 2 weeks of storage, reaching 28.4 meq/kg oil. With prolonged storage time, the samples continued to oxidize. In the fourth week, the microcapsules coated with CAS/GA/CS and WPC/GA/CS showed less oxidative degradation than other microcapsules encapsulated with different wall materials. The combination of CAS/CS showed the poorest oxidative stability. Gallardo et al. (2013) encapsulated linseed oil using whey

Fig. 3 Oxidative stability of encapsulated peony seed oil evaluated by peroxide value method. CS Corn Syrup, CAS Sodium Caseinate, WPC Whey Protein Concentrate, GA Gum Arabic. Different letters indicate significant difference ($p < 0.05$) between samples during the same storage time

Fig. 4 Gas chromatography profiles of peony seed oil. Peaks: 1 = C14:0 (myristic acid, MA); 2 = C16:0 (palmitic acid, PA); 3 = C18:0 (stearic acid, SA); 4 = C18:1 (oleic acid, OA); 5 = C18:2 (linoleic acid, LA); 6 = C18:3 (α -linolenic acid, ALA)

Table 3 Comparison of fatty acid contents of peony seed oil before and after encapsulation and accelerated storage

Fatty acids	Peony seed oil	After spray-dried				After accelerated storage			
		CAS/CS	CAS/GA/CS	WPC/CS	WPC/GA/CS	CAS/CS	CAS/GA/CS	WPC/CS	WPC/GA/CS
C14:0	0.69 ± 0.06	1.43 ± 0.13	1.59 ± 0.09	1.35 ± 0.05	1.46 ± 0.08	6.48 ± 0.03	4.45 ± 0.08	5.57 ± 0.01	5.29 ± 0.05
C16:0	5.88 ± 0.02	6.05 ± 0.18	6.38 ± 0.12	6.15 ± 0.07	6.31 ± 0.14	9.43 ± 0.23	7.44 ± 0.17	7.86 ± 0.16	8.06 ± 0.09
C18:0	2.24 ± 0.01	3.49 ± 0.04	3.36 ± 0.06	3.38 ± 0.01	3.44 ± 0.00	8.19 ± 0.14	6.17 ± 0.21	6.72 ± 0.02	5.51 ± 0.33
C18:1	22.06 ± 0.22	22.87 ± 0.45	22.46 ± 0.33	22.51 ± 0.26	22.57 ± 0.35	27.28 ± 0.41	23.33 ± 0.28	24.02 ± 0.21	24.13 ± 0.36
C18:2	27.99 ± 0.01	26.28 ± 0.38	26.22 ± 0.41	26.71 ± 0.29	26.46 ± 0.44	21.81 ± 0.26	23.03 ± 0.17	22.09 ± 0.07	22.18 ± 0.03
C18:3	41.15 ± 0.04	39.90 ± 0.54	39.99 ± 0.60	39.87 ± 0.76	39.76 ± 0.69	26.84 ± 0.53	35.61 ± 0.29	33.78 ± 0.48	34.89 ± 0.29
ΣSFA	8.81 ± 0.09	10.97 ± 0.35 ^a	11.33 ± 0.27 ^a	10.88 ± 0.13 ^a	11.21 ± 0.22 ^a	24.10 ± 0.4 ^b	18.06 ± 0.46 ^a	20.15 ± 0.19 ^c	18.86 ± 0.47 ^a
ΣMUFA	22.06 ± 0.22	22.87 ± 0.45 ^a	22.46 ± 0.33 ^a	22.51 ± 0.26 ^a	22.57 ± 0.35 ^a	27.28 ± 0.41 ^b	23.33 ± 0.28 ^a	24.02 ± 0.21 ^c	24.13 ± 0.36 ^c
ΣPUFA	69.14 ± 0.05	66.18 ± 0.92 ^a	66.21 ± 1.01 ^a	66.58 ± 1.05 ^a	66.22 ± 1.13 ^a	48.65 ± 0.79 ^a	58.64 ± 0.46 ^b	55.87 ± 0.55 ^c	57.07 ± 0.32 ^c

SFA Saturated fatty acid, PUFA Polyunsaturated fatty acid, MUFA Monounsaturated fatty acid, CS Corn Syrup, CAS Sodium Caseinate, WPC Whey Protein Concentrate, GA Gum Arabic

Different letters indicate significant difference between samples at $p < 0.05$ after spray-dried and accelerated storage

protein concentrate with maltodextrin (WPC/MD) and gum arabic (GA) as wall materials, and also studied the microparticles oxidative stability. The authors found that this combination presented the highest protection from oxidation. By analyzing the results, we inferred that the addition of GA increase the protective effect of the coating material. It is well known that GA has a “wattle blossom” type structure, in which a number of polysaccharide units are linked to a common and hydrophobic polypeptide chain. In this regard, the protein and GA would form complexes and consequently produce a thicker complex layer adsorbed onto the interface of droplets as a barrier to oxygen. Ye et al. (2011) demonstrated that the hydrophobic polypeptide chains of GA can bind the hydrophobic apolar residues of caseins at high temperatures to form complex composite particles through hydrophobic interactions on oil–water interfaces. Klein et al. (2010) reported that the positively charged domains of WPI interact with the negatively charged GA to generate complexes by electrostatic interactions within pH 5–7. Therefore, it could be inferred that addition of GA could increase the protective effect of coating material.

Fatty acid analysis

It has been reported that peony seed oil is rich in oleic and linoleic acids, and dietary intake of these fatty acids has been proven to be beneficial to humans (Calder 2015; Dilzer and Park 2012; Ning et al. 2015). Therefore, investigating the alteration of fatty acid composition in peony seed oil during encapsulation and storage is important.

The fatty acid composition of peony seed oil was determined by GC, and six representative gas chromatograms of fatty acid methyl esters are depicted in Fig. 4. Myristic acid (MA, peak 1) palmitic acid (PA, peak 2), stearic acid (SA, peak 3), oleic acid (OA, peak 4), linoleic acid (LA, peak 5)

and ALA, (peak 6) were the dominant fatty acids. A comparison of fatty acid composition between the peony seed oil before and after encapsulation and accelerated storage is shown in Table 3. The fatty acids contents were similar to bulk oil for all formulations after encapsulation. Particularly, the fatty acid composition in encapsulated peony seed oil powder was preserved. Furthermore, the monosaturated fatty acids (SFAs) were more stable during the spray-drying process as comparison with PUFAs. Similar results were reported by Calvo et al. (2010), who found that, the fatty acid profile of olive oil was unaltered during the microencapsulation process. After the accelerated oxidation experiments, the contents of saturated and monosaturated fatty acids increased, whereas the content of PUFAs decreased. These results were consistent with those previously shown by Roman et al. (2013), who studied the oxidation kinetics of three vegetable oils (sunflower, high oleic sunflower and rapeseed). These observations might be explained by a higher number of double bonds in the chemical structure of PUFAs, which can be easily oxidized by heat and oxygen during storage. Compared with other three formulations, particles produced from CAS/CS combinations showed a significant decrease from 66.18 to 48.65 % in PUFAs content. This finding indicated that CAS/CS cannot effectively protect peony oil against oxidation. CAS/GA/CS showed the best protection among the formulations tested.

Conclusion

The performance of different wall material combinations for microencapsulation of peony seed oil by spray drying was evaluated. The best encapsulation efficiency of 93.71 % was obtained for CAS/CS. The obtained particles were spherical in shape, and gum arabic was uniformly distributed across the

wall of the microcapsules. The combination of CAS/GA/CS presented the best protection on the active material against oxidation among all of the formulas during storage, and exhibited the smallest loss of polyunsaturated fatty acid. The results demonstrated that the CAS/GA/CS mixture can serve as a suitable wall-material alternative for the microencapsulation of peony seed oil.

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