Encapsulation of Pistachio Green Hull Phenolic Compounds by Spray Drying

A. P. Ghandehari Yazdi[1], M. Barzegar[1*], M. A. Sahari[1], and H. Ahmadi Gavlighi[1]

ABSTRACT

Application of antioxidants is a common way for retarding oxidation. Due to adverse effects of synthetic antioxidants on health, the use of natural and safe antioxidants is considered essential. Pistachio green hull is a waste product and low-cost source of phenolic compounds. The use of phenolic compounds in food formulations has some limitations. In this study, the encapsulation of Pistachio Green Hull (PGH) phenolic compounds was carried out by spray-dryer using Maltodextrin (MD) as a wall material. For this purpose, the effective factors including the inlet temperature, dilution factor, wall:core ratio, and rate of feeding were optimized. MD, PGH extract powder, and encapsulated phenolic compounds produced under optimum conditions (ME) were characterized by Scanning Electron Microscopy (SEM), FTIR, X-ray Diffractometry (XRD), and Differential Scanning Calorimetry (DSC).Under optimum conditions, the amount of phenolic compounds and the encapsulation efficiency were 32.1 mg GAE g^{-1} dp and 81%, respectively. DSC results showed that the microencapsulation had improved thermal stability of phenolic compounds. The DPPH test results indicated that the antioxidant activity of the free PGH extract was 10% higher than encapsulated one (ME). Storage stability results indicated that the amount of phenolic compounds of PGH extracts and ME after 60 days storage decreased by more than 29 and 4%, respectively. The microcapsules obtained can be used in the production of functional foods and pharmaceutical products, due to their antioxidant content and presence of phenolic compounds.

Keywords: Antioxidant activity, Functional foods, Maltodextrin, Polyphenols, Microencapsulation.

INTRODUCTION

Pistachio Green Hull (PGH) is one of the rich sources of antioxidants, which also has antimicrobial activity. PGH extract contains many phenolic compounds (Goli *et al.*, 2005). Ghandahari Yazdi *et al.* (2019) reported that the main extracted phenolic compounds of PGH were gallic acid and phloroglucinol. PGH extract has been used as a good natural preservative in different food stuff (Abolhasani *et al.*, 2018).

The use of phenolic compounds in the formulation of functional food and pharmaceuticals is recommended for the promotion of consumer health. However, phenolic compounds are susceptible to decomposition during process and storage due to the presence of oxygen, light, and high temperatures. Other limitations of direct applications of phenolic compounds in the formulation of food and pharmaceuticals are as follow: cause unpleasant taste, their low solubility, and interaction with food components. For this reason, the encapsulation of these compounds is an effective way to increase their physical stability, controlled release, and preventing them from the interaction with food ingredients, and increasing their functional

---

[1] Department of Food Science and Technology, Tarbiat Modares University, Tehran, Islamic Republic of Iran.
*Corresponding author; e-mail: mbb@modares.ac.ir.

properties (Ćujić-Nikolić *et al.*, 2019; Kuck and Noreña, 2016).

Researchers have reported the improvement of stability of the phenolic compounds extracted from many different natural sources during the storage by encapsulation (Saénz, *et al.*, 2009; Çam *et al.*, 2014). Among the several encapsulation techniques, spray drying is recommended because this technique is continuous, economical and flexible, and it is used as a method for preparation of flavors and food additives in food industries (Dalmoro *et al.*, 2012). In this technique, several factors such as inlet temperature, feed flow rate, and characteristics of the feed liquid are effective on the physicochemical properties of the powder produced (Tonon *et al.*, 2008). Therefore, optimizing the drying conditions is important to obtain products with better sensory and nutritional characteristics and better processing yield.

In the process of encapsulation, cellulose and various types of carbohydrates, gums, lipids, proteins and polymers are often used as a wall or carrier material. Among the available wall material, Maltodextrin (MD) is widely used due to high solubility in water, low viscosity, mild flavor, reasonable price, availability even at high concentrations, access to different molecular weights, and its colorless solutions (Ballesteros *et al.*, 2017).

In this study, Maltodextrin (MD, as a carrier) and spray drying method were used to encapsulate phenolic compounds of pistachio green hull extracts. The purposes of this research were as follow: (i) Optimization of effective factors of encapsulation by spray dryer (MD concentration, feed flow rate, inlet temperature, and dilution factor of PGH extract); (ii) To determine the antioxidant activity of free PGH extract and encapsulated PGH extract (ME); (iii) To investigate the stability of phenolic compounds of free PGH extract and encapsulated one (ME) during 60 days storage; and (iv) To evaluate the thermal

stability and morphological characteristics of the produced microcapsules.

MATERIALS AND METHODS

Plant Materials

Pistachio green hull (*Ahmadaghaei* variety), as a by-product of pistachio garden, was obtained from Yazd Agricultural Research Center (Yazd, Iran). It was dried and then ground and sieved through different meshes (18, 30, and 40) and was kept in a freezer at -20°C until extraction.

Chemical

Folin–Ciocalteu, 2,2-DiPhenyl-1-PicrylHydrazyl (DPPH), 2,2′-azino-bis (3 ethylbenzothiazoline- 6-sulphonic acid) diammonium salt (ABTS), potassium persulfate and maltodextrin (dextrose equivalent 13.0-17.0) from Sigma (St. Louis, MO, USA), 2, 4, 6-TriPyridyl-s-Triazine (TPTZ), acetic acid and methanol were obtained from Merck Chemical Co. (Darmstadt , Germany). Cellulase enzyme from Sigma (St. Louis, MO, USA)**,** tannase enzymefrom Kikkoman Biochemifa (Japan, Tokyo) and Pectinex BE color enzyme from Novozymes Ferment (Bagsvaerd, Denmark) were purchased.

Enzymatic Extraction of Phenolic Compound from PGH

In this study, an enzymatic extraction method was used to increase the extraction yield of phenolic compounds from PGH. For this purpose, the combination of three enzymes, namely, pectinase, cellulase, and tannase was used according to the method and optimum conditions that were reported in our previous study (Ghandehari Yazdi *et al.*, 2019). The optimum parameters were used as follows: pectinase (3.8 U mL^{-1}), cellulase (2.5 U mL^{-1}), tannase (4.0 U g^{-1}),

time (4 hour), particle size (0.4> mm), solid to liquid ratio (1:80), pH= 4.5 and temperature (40°C).

Preparation of the Microcapsules

The encapsulation was accomplished according to the method of Robert *et al.* (2010). Maltodextrin was heated to 40°C, and mixed with enzymatic extract (20 g) at constant stirring. The mixtures were homogenized by Ultraturax (IKA, T50, Germany) at 1,400×g for 5 minutes and the mixtures were fed to a mini spray dryer (Buchi-220, Switzerland). Finally, the produced microcapsules were kept at -20°C until the time of analyses. In this study, the effect of four variables, i.e. inlet temperature (140, 150, and 160°C), wall:core ratio (0.5:1, 1:1, 2:1, and 3:1), feeding rate (7, 10, and 13 mL min⁻¹) and extract dilution factor (0, 1.33, and 2 folds v/v) were evaluated to find optimum conditions using one-factor-at-a-time statistical method.

Microcapsule Powder Analysis

Total Phenolic Contents

To investigate the total phenolic contents, the structure of the microcapsules was destructed. For this purpose, 0.2 g of microcapsules were added to 2 mL of methanol:acetic acid:water (50:8:42 v/v/v) and the dispersion was vortexed for 1 minute. After that, the dispersion was ultrasonicated (James, 6D, UK) for 40 minutes and, finally, the resultant dispersion was centrifuged at 11,200×g for 5 minutes and then filtered through 0.45 μm filter (Saénz *et al.*, 2009; Robert *et al.*, 2010). The concentrations of phenolic compounds of microcapsules were quantified according to the Folin- Ciocalteu method (Slinkard and Singelton, 1977). The concentration of phenolic compounds was calculated according to the standard curve of gallic acid (Y= 0.0013x-0.00553; r= 0.9955) and reported in milligrams of Gallic Acid

Equivalent per gram of dry powder (dp) (mg GAE g⁻¹ dp).

Surface Phenolic Compounds

To determine surface phenolic compounds, 0.2 g of microcapsules were added to 2 mL of methanol:ethanol (1:1 v/v) and the dispersion was vortexed for 1 minute. Then, the dispersion was filtered through a 0.45 μm filter. The concentrations of surface phenolic compounds were determined according to the Folin-Ciocalteu method, which was previously described. The Surface phenolic compound percentage (SB), and the Encapsulation Efficiency (EE%) (Robert *et al.*, 2010), were calculated according to the following formulas:

$$SB\ (\%) = \frac{SPC}{TPC} \times 100$$

EE (%)= 100-SB

SPC= Surface phenolic compounds

TPC= Total phenolic compounds

Physicochemical Characterization of Microcapsules

Scanning Electron Microscopy (SEM)

The morphology of microcapsules was studied by Scanning Electron Microscopy (Phenom, Pro X, Netherlands) at 15kV with a magnification range of 500-5,000. Powders were mounted to SEM aluminum stubs via a 2-sided adhesive tape and they were coated with a thin layer of gold before imaging.

Differential Scanning Calorimetry (DSC)

The glass transition temperatures of the MD, PGH extract powder (dried with spray dryer), and ME were accomplished by DSC (Netzsch-DSC 200F3, Germany). Each sample (8 mg) was placed in standard aluminum crucibles and an empty crucible

was used as a reference. The measurements were carried out between 10 and 300ºC at a heating rate of 5ºC min⁻¹, under a nitrogen flow rate of 100 mL min⁻¹.

X-Ray Diffractometry (XRD)

Diffractograms of the MD, PGH extract powder and ME were obtained by X-ray diffractometer (XRD, X'Pert MPD, Philips, Netherlands). X-ray source was CuKα radiation (λ= 1.54056 Å) with 40kV and a 30mA current, measured and scanned in the 2θ angle range between 10 and 80° with a scan rate of 8° min⁻¹, and a step size of 0.02°.

FTIR

Functional groups and bonding arrangement of existing components in the samples were investigated by infrared spectroscopy in the region from 4,000 to 400 cm⁻¹, by a FTIR spectrometer (Nicolet, USA).

Antioxidant Activity

Antioxidant activity of free PGH extracts and Microencapsulated PGH Extracts (ME) were evaluated by DPPH· assay. DPPH radical-scavenging activity was determined according to the method of Hatano *et al.* (1988).

Storage Stability of Produced Microcapsules

The stability of ME was accomplished by Aliakbarian *et al.* (2018) with some modifications. Free PGH extract (control) and produced ME were stored at room temperature (25ºC) and at the light protected for 60 days. The amounts of phenolic compounds were determined on the first, 20th, 40th, and 60th days.

Statistical Analysis

All experiments were done in triplicate. Results were reported as the average value±standard deviation and considered significantly different when P< 0.05. Statistical analysis was done using SAS software program version 9. Analysis Of Variance (ANOVA) and LSD test was applied to characterize the significant differences between different treatments.

RESULTS AND DISCUSSION

Effects of MD:Core Ratio on EE%

At first, to optimize the MD:Core ratio, all factors were considered constant (extract dilution factor 0 v/v, feeding rate 10 mL min⁻¹ and inlet temperature 140ºC). The effect of MD:Core ratio on the EE% of phenolic compounds was evaluated at five levels (0.5:1, 1:1, 1.5:1, 2:1, and 3:1 w/w). Obtained results showed that by increasing the MD:Core ratio from 0.5:1 to 2:1, the EE% increased about 1.5 times, then, the EE% decreased significantly (Figure 1A). Different wall:core ratios have been reported by various researchers (Saénz*et al.*, 2009; Robert *et al.*, 2010; Çam *et al.*, 2014; Aliakbarian *et al.*, 2018).

According to the reported results, probably, by increasing the wall:core ratio, viscosity increases, and this leads to a decrease in the movement of phenolic compounds to the surface. Çam *et al.* (2014) mentioned that the increment of the MD to phenolic compounds ratio increases the stability of phenolic compounds. Young *et al.* (1993) suggested that increasing the concentration of wall materials increased the encapsulation efficiency, which can be related to the effect of wall materials concentration on the formation of surface core prior to the formation of crust around the drying droplets. Based on our results, the MD:Core ratio of 2:1 w/w was selected as an optimum ratio for encapsulation of PGH phenolic compounds.
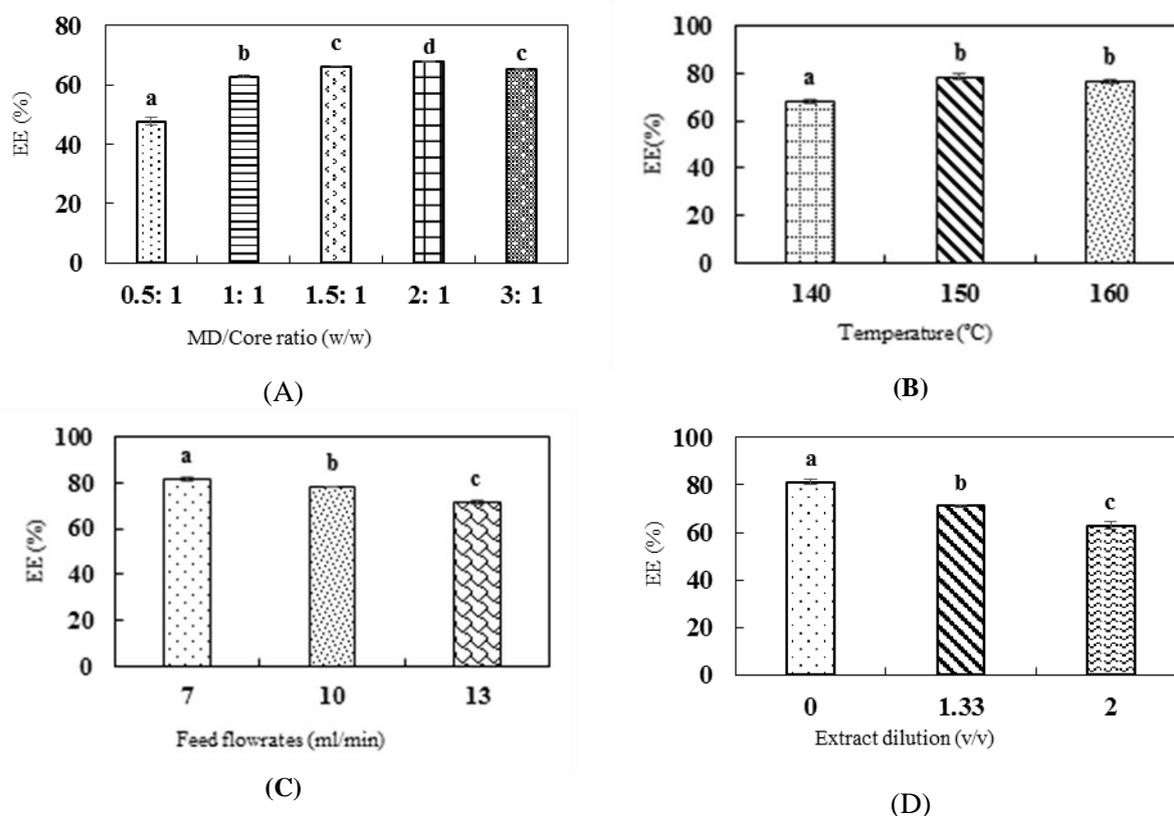
Figure 1. Effect of Maltodextrin (MD):Core ratio (A), inlet temperature (B), feed flow rates (C), and extract dilution (D) on the Encapsulation Efficiency (EE%) of phenolic compounds of Pistachio Green Hull extracts (PGH).

Effect of Inlet Temperature on EE%

Effect of inlet temperature (140, 150 and 160°C) on the EE% of PGH phenolic compounds were studied at constant conditions (extract dilution factor 0 v/v, feeding rate 10 mL min^{-1} and MD:Core ratio= 2:1). According to the Figure 1B, increasing the temperature from 140 to 150 °C increased the EE% of phenolic compounds of PGH by 15% and then remained constant (P< 0.05). Similar results have been published by others (Kaderides *et al*., 2015). In contrast, Saénz*et al*. (2009) reported that the temperature had no significant effect on the EE% of bioactive compounds from cactus pear. As a result, microcapsule drying rate depends on inlet temperature and higher drying air

temperatures accelerated the fast formation of a firm membrane on the droplet surface, giving optimum core material retention (Kaderides *et al*., 2015). In this study, the amount of phenolic compounds in the powder obtained at temperatures of 140, 150 and 160°C was 123.5, 147.5 and 118.0 mg GAE g^{-1} dp, respectively. These results showed that drying temperature had influence on the amount of phenolic compounds. Similar results were reported by Sablania and Bosco (2018). Also, Podsedek (2007) suggested that phenolic compounds are sensitive to heat; but the finding of Robert *et al*. (2010) and Çam *et al*. (2014) indicated that the drying temperature did not affect the amount of phenolic compounds. In addition to the mentioned points, by increasing the temperature, evaporation was also increased and excessive evaporation caused fissures and deformations in the wall materials, causing premature release of their

contents and degradation of the encapsulated ingredient (Ramírez *et al.*, 2015). Increasing the amount of phenolic compounds at 150°C could be related to the hydrolysis of PGH polyphenols conjugated during the preparation of the samples or during the drying process (Turkmen *et al.*, 2005). According to our results, the inlet temperature of 150ºC was chosen for encapsulation of PGH phenolic compounds.

Effects of Feed Flow Rates on EE%

The effect of different feed flow rates (7, 10 and, 13 mL min^{-1}) at constant conditions (extract dilution factor 0 v/v, Inlet temperature: 150ºC and MD:Core ratio= 2:1 w/w) was studied on the EE%. Increasing the feed flow rates from 7 to 13 mL min^{-1} decreased EE% of phenolic compounds by about 10% (Figure 1-C). This effect has been observed by other researchers (Tonon *et al.*, 2008; Murugesan and Orsat, 2011). Contrary to these results, Paini *et al.* (2015) indicated that the feed flow rates did not affect the EE% of olive pomace. The negative effects of increasing feed flow rates on the EE% could be a consequence of slower heat and mass transfer and also the amount of the blend passed straight to the chamber and was not atomized (Tonon *et al.*, 2008). Therefore, 7 mL min^{-1} was selected as optimum feed flow rate.

Effects of the Dilution Factor of Extracton EE%

The effect of different dilution factors of extract (0, 1.33 and 2 folds v/v) at constant conditions (Inlet temperature: 150ºC, rate of feeding 7 mL min^{-1} and MD:Core ratio= 2:1) on the EE% of PGH phenolic compounds was also evaluated. Increasing the dilution factor from 0 to 2 v/v decreased the EE% of phenolic compounds about 19% (Figure 1-D). Tumbas Šaponjac *et al.* (2016) reported that beetroot pomace extract without dilution in soy protein was suitable for obtaining the

highest encapsulation efficiency (86.14%). The reason for these results could be attributed to the dextrin's starch properties. In this type of starch, in addition to α-(1→4)-linkages and α-(1→6)-linkages, new linkages may be created and provide conditions to increase the reduction of glucose with other compounds (core).Thus, by increasing the amount of the PGH extract, a greater amount of the extract can be bonded to maltodextrin. According to the results, extraction without dilution was used for encapsulation.

Spray drying under optimum conditions, i.e., Extract dilution: 0 v/v, Feed flow rates: 7 mL min^{-1}, MD:Core ratio= 2:1 w/w and inlet temperature of 150 ºC, resulted in the highest EE% (81%) and with high polyphenols content (32.1 mg GAE g^{-1} dp).

Morphology

The morphological characteristics of Microencapsulated PGH Extracts (ME) are presented in Figure 2. The particles of MD were spherical with dented surface and amorphous structures. Similar observations of morphology have been reported by Robert *et al.* (2010). Indentation on the surface could be a consequence of the shrinkage of the maltodextrin particles during the drying process (Robert *et al.*, 2010). It can be seen that some ME have been damaged (arrows in Figure 2-A). Same results were reported by Aliakbarian *et al.* (2018). The structure of amorphous microcapsules increases their spreadability and solubility properties in food products, in order to improve the functional properties of food (Robert *et al.*, 2010).

DSC Analysis

The PGH dry extract showed two significant endothermic peaks at 154 and 162ºC and several endothermic peaks in a range of temperatures between 165 and 300ºC, related to the melting point of the
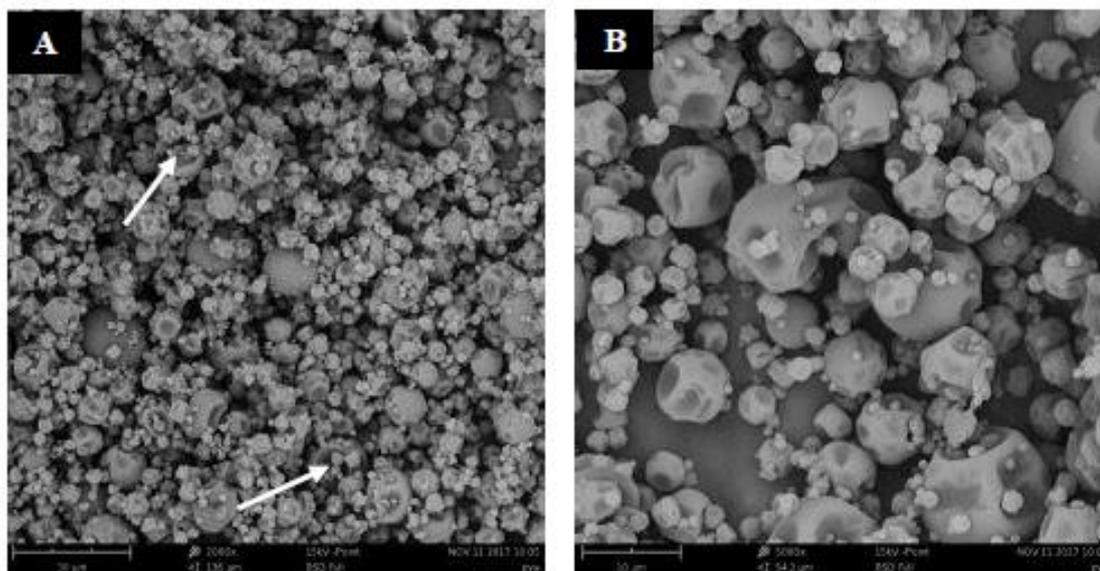
Figure 2. Scanning electron microscopy images of Microencapsulated pistachio green hull Extracts (ME): (A) ×2000, (B) ×5000.
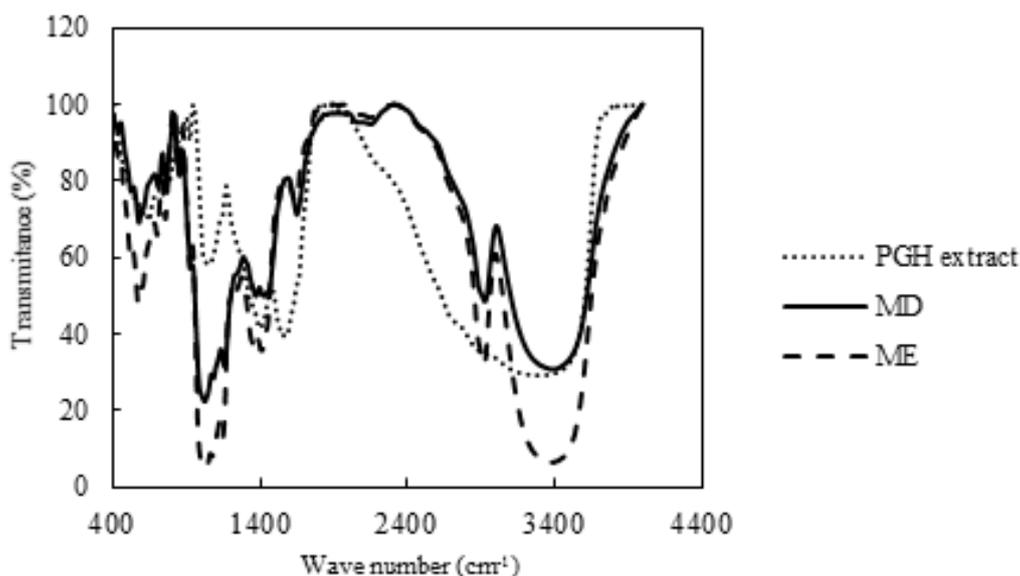

.
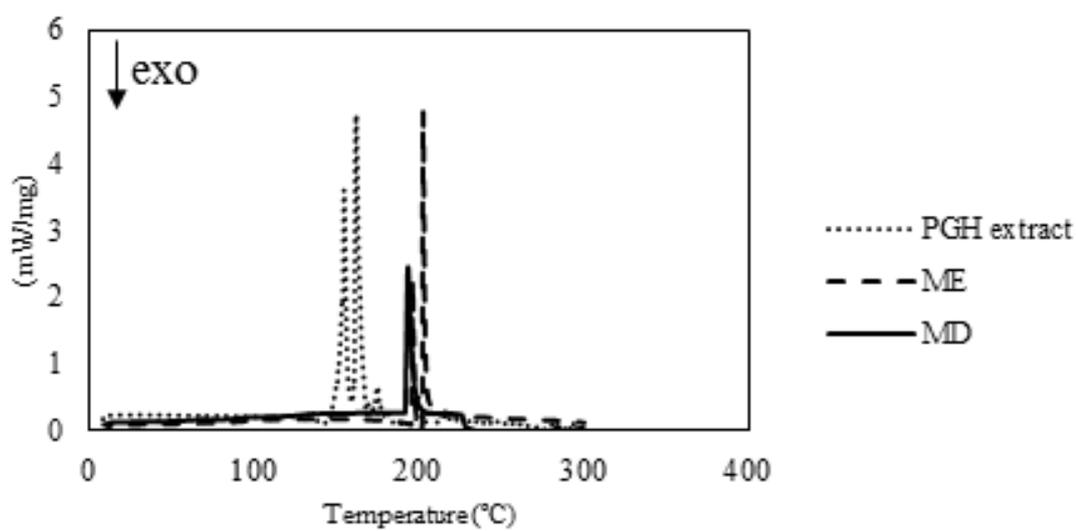
Figure 3. DSC thermograms of free Pistachio Green Hull extracts powder (PGH), Maltodextrin (MD), and Microencapsulated pistachio green hull Extracts (ME).

active compounds, mainly phenolic compounds (Figure 3) (Sansone *et al*., 2011). An endothermic peak observed at 193ºC for MD was related to the thermal degradation of MD. Due to the variable dextrose equivalents of maltodextrin, its melting point and degradation can be different. Souza *et al*. (2017) reported the melting point and beginning of thermal degradation of maltodextrin at 211ºC. According to Figure 3, two endothermal peaks were observed at temperatures of 196 and 202°C for ME. The absence of the peaks of the PGH dry extract in the thermal profiles of ME confirmed that PGH extract was well encapsulated within MD, as previously revealed by SEM, and thermal stability increased. Similar results have been reported in relation to the increase of thermal stability of bioactive compounds by encapsulation. Ballesteros *et al*. (2017) indicated that thermal stability of phenolic compounds extracted from coffee ground improved by maltodextrin and gum Arabic about > 190ºC and > 225ºC, respectively. Negrão-Murakami *et al*. (2017) reported that maltodextrin (Dextrose equivalent= 10.2) enhanced thermal stability of the mate

microcapsules to 184ºC. The presence of new peak (at 202ºC) suggested that chemical interactions occurred between MD and PGH (Naidu *et al*., 2004). Due to the high thermal stability of ME and the typical food industry sterilization temperature. It can be concluded that ME can be used to enhance the functional qualities of food.

FTIR Spectroscopy

The FTIR spectra of MD, PGH dry extract and ME are presented in Figure 4. The FTIR spectrum of MD indicated a strong and broad band at 3,398.94 cm^{-1} which is attributed to the stretching vibrations of OH, 2,926.84 cm^{-1} to C–H stretching vibrations, 1,648.77 cm^{-1} to C=O stretching, 1,424.29 cm^{-1} to C–H vibration, 1,371.90 cm^{-1} to O–H bending, 1,156.31 and 1,082.36 cm^{-1} to C–O stretching, 930.56 cm^{-1} related to the deformation of the =CH and =CH$_2$ bonds and 850.81 and 762.52 cm^{-1} to C–H bending and ring puckering. Yingngam *et al*. (2018) observed similar spectra for maltodextrin. FTIR spectra of PGH dry extract (Figure 4) indicated several peaks at 3,308.81 cm^{-1} (OH

Figure 4. IR spectra of free Pistachio Green Hull extracts powder (PGH), Maltodextrin (MD) and Microencapsulated pistachio green hull Extracts (ME).
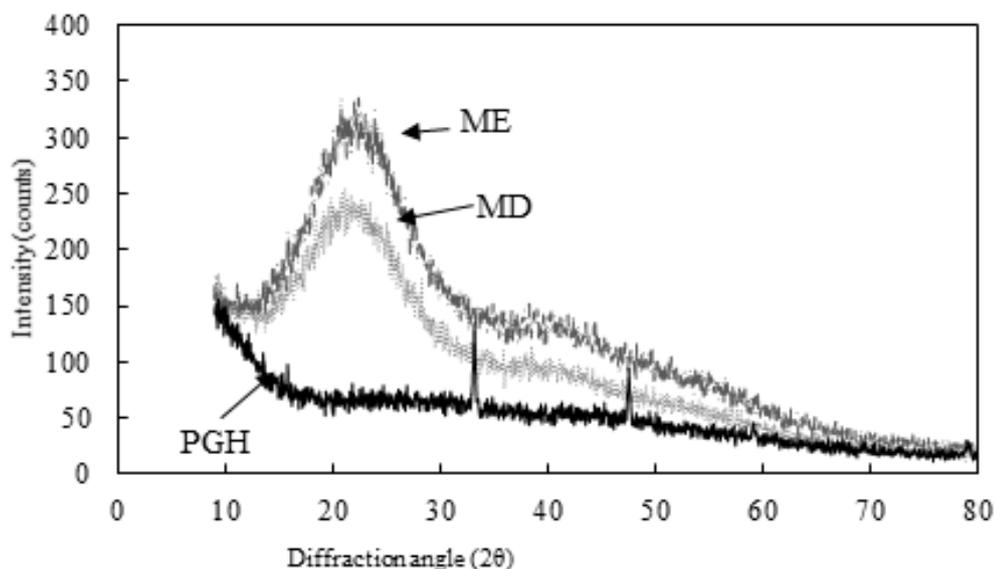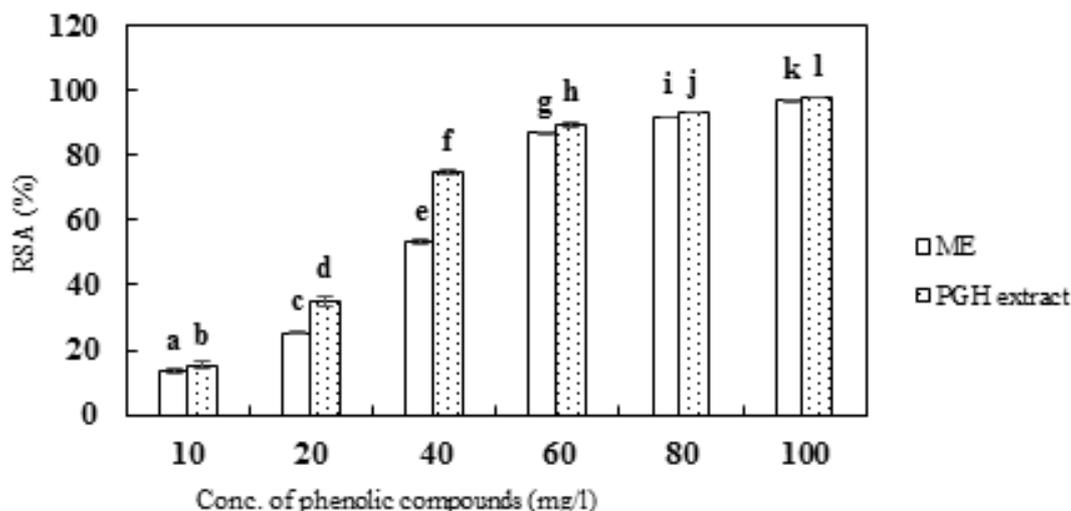
Figure 5. The X-Ray diffractograms of free Pistachio Green Hull extracts powder (PGH), Maltodextrin (MD) and Microencapsulated pistachio green hull Extracts (ME).

stretching band of phenolic and hydroxyl groups), 1,585.41 cm^{-1} (C=C relates to the vibration stretching band of aromatic rings), 1,405.96 and 1,402.80 (CH$_3$ bending) and 927.09 and 651.09 (CH bending). Rafiee *et al*. (2017) observed prominent absorption bands at 3,419, 1,719, 1,650, 1,508, 1,357, 1,203, 1,074 and 1,029 cm^{-1}for PGH dry extract. Bands in the range of 1700 and 900 cm^{-1} could be assigned to the bands of PGH phenolic compounds (Yingngam *et al*., 2018) and also the existence of carboxylic acids and sugars were confirmed by the spectrum obtained at 1430-1330 cm^{-1} (Fragoso *et al*., 2011). The FTIR spectrum of ME was almost like the spectrum of pure maltodextrin and the PGH bands were almost covered by MD bands. According to Figure 4, the intensity of the peak of the ME was higher compared with that of the PGH and MD and also the absence of peak at 1585.41 cm^{-1} in the spectrum of ME compared with the spectrum of PGH indicated that there might be some interactions between PGH extract and MD.

X-Ray Diffractometry (XRD)

X-Ray Diffractogram`s patterns with broad bands showed amorphous structures because the molecules in the amorphous state are disordered and thus yield dispersed bands, while crystalline materials yield sharp and defined peaks since they are presented in a highly ordered state (Caparino *et al*., 2012). As seen in Figure 5, the presence of sharp peaks at the diffraction angles (2θ) of 33.17, 47.54 and 59.15$^{°}$ showed semi crystalline structure of PGH dry extracted. The diffraction pattern of MD and ME showed completely amorphous structure, without intense and sharp peaks. Similar diffraction pattern has been observed for MD by Ballesteros *et al*. (2017). The differences between XRD profiles of the ME and PGH dry extracted indicate that the PGH extract was encapsulated in the MD. Due to the maltodextrin amorphous structure, the microcapsules' structure was also non-crystalline; this result could be

Figure 6. Antioxidant activity of free Pistachio Green Hull extracts powder (PGH) and Microencapsulated pistachio green hull Extracts (ME).

related to the point that PGH extract was spread at the molecular level in the maltodextrin matrix (Desai and Park, 2005). These outcomes confirmed the results of the SEM morphologies, which showed the structure of amorphous ME. Our results agree with reports of Ballesteros *et al.* (2017) and Tao *et al.* (2017).

Antioxidant Activity

Figure 6 indicates the antioxidant activity of free PGH extract and microencapsulated one (ME). As seen, there is a direct and positive correlation between the amount of PGH extract and ME and their DPPH radical scavenging ability. Increasing the radical scavenging capacity could be related to the number of hydroxyl groups in the reaction medium. In fact, the probability of hydrogen donation to free radicals increases by increasing the total phenolic content (Pyo *et al.*, 2004). Encapsulation of PGH extract significantly decreased the radical scavenging capacity (EC$_{50}$= 27.46 mg L^{-1}), which was about 10% lower than that of the free PGH extract (EC$_{50}$= 37.64 mg L^{-1}). Reduction of the antioxidant activity of ME might be consequence of the interactions

between PGH extract and MD, which has been confirmed by previous tests (DSC, FTIR, and XRD).

Storage Stability

The stabilities of the phenolic compounds of free PGH extract and ME are shown in Figure 7. According to the results, the stability of the Microencapsulated PGH Extract (ME) is more than the free PGH extracts. The amount of phenolic compounds of free PGH extracts and ME, after 60 days storage, decreased by more than 29 and 4%, respectively. Çam *et al.* (2014) showed that microcapsules containing phenolic compounds of pomegranate peels were stable at 4°C for 90 days. Also, Paini *et al.* (2015) indicated that microcapsules covering phenolic compounds of olive pomace were stable up to 28 days at 25 °C. The results can be related to the protective role of the wall material against oxidation (Çam *et al.*, 2014) and the degree of susceptibility may affect the oxidation stability of phenolic compounds, which differs in stability during storage. Robert *et al.* (2010) and Murugesan and Orsat (2011) showed that maltodextrin, as one of the best
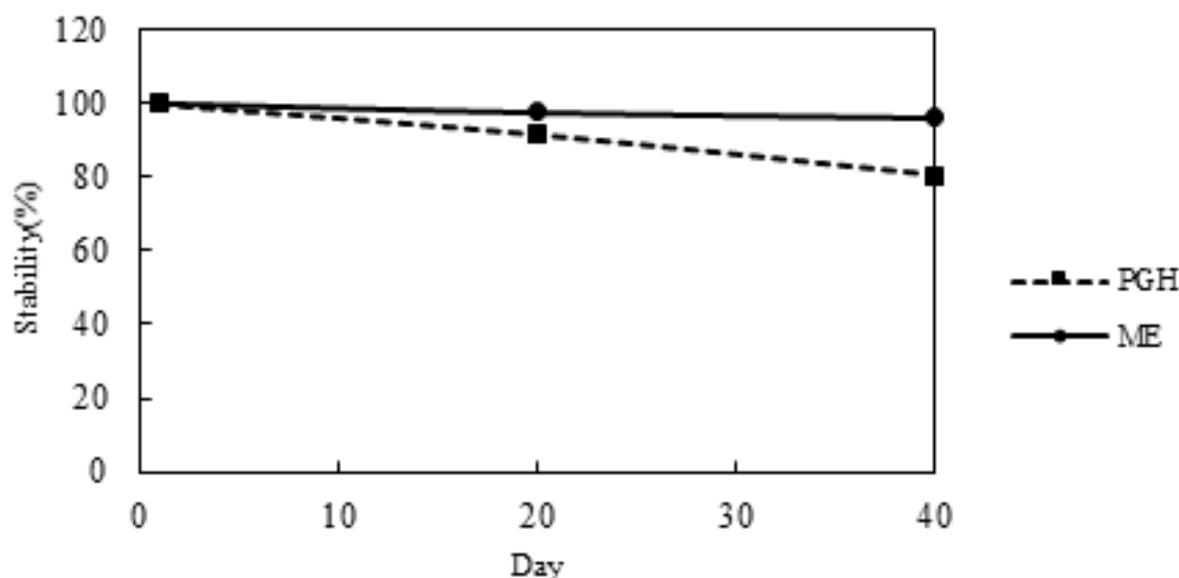
Figure 7. Storage stability of phenolic compounds of free Pistachio Green Hull extracts powder (PGH) and Microencapsulated pistachio green hull Extracts (ME)

wall materials, increased the stability of phenolic compounds during the storage.

CONCLUSIONS

Utilization of pistachio green hull as a source of phenolic compounds in food industry is recommended. Pistachio green hull extract was successfully encapsulated in maltodextrin by spray drying for the first time. This study showed that feed flow rate, wall to core ratio, dilution factor, and inlet temperature were effective on encapsulation efficiency, and under optimum conditions (Extract dilution: 0 v/v, Feed flow rates: 7 mL min^{-1}, MD:Core ratio= 2:1 w/w and inlet temperature of 150ºC), the efficiency of encapsulation and the amount of phenolic compounds were 81% and 32.1 mg GAE g^{-1} dp, respectively. The encapsulation was proved by SEM, FTIR, XRD and DSC. Additionally, this showed that thermal stability of phenolic compounds extracted from pistachio green hull was improved by encapsulation.

REFERENCES

1. Abolhasani, A., Barzegar, M. and Sahari, M. A. 2017. Effect of Gamma Irradiation on the Extraction Yield, Antioxidant, and Antityrosinase Activities of Pistachio Green Hull Extract. *Radiat. Phys. Chem.*, **144**: 373-378.
2. Aliakbarian, B., Sampaio, F. C., de Faria, J. T., Pitangui, C. G., Lovaglio, F., Casazza, A. A., Converti, A. and Perego, P. 2018. Optimization of Spray Drying Microencapsulation of Olive Pomace Polyphenols Using Response Surface Methodology and Artificial Neural Network. *LWT-Food Sci. Technol.*, **93**: 220-228.
3. Ballesteros, L. F., Ramirez, M. J., Orrego, C. E., Teixeira, J. A. and Mussatto, S. I. 2017. Encapsulation of Antioxidant Phenolic Compounds Extracted from Spent Coffee

Grounds by Freeze-Drying and Spray-Drying Using Different Coating Materials. *Food Chem*., **237**: 623-631.

4. Çam, M., İçyer, N. C. and Erdoğan, F. 2014. Pomegranate Peel Phenolics: Microencapsulation, Storage Stability and Potential Ingredient for Functional Food Development. *LWT-Food Sci. Technol*., **55**: 117-123.

5. Caparino, O.A., Tang, J., Nindo, C. I., Sablani, S.S., Powers, J. R. and Fellman, J. K. 2012. Effect of Drying Methods on the Physical Properties and Microstructures of Mango (Philippine 'Carabao'var.) Powder. *J. Food Eng*., **111**: 135-148.

6. Ćujić-Nikolić, N., Stanisavljević, N., Šavikin, K., Kalušević, A., Nedović, V., Samardžić, J. and Janković, T. 2019. Chokeberry Polyphenols Preservation Using Spray Drying: Effect of Encapsulation Using Maltodextrin and Skimmed Milk on Their Recovery Following in Vitro Digestion. *J. Microcapsul.*, **36**: 693-703.

7. Dalmoro, A., Barba, A. A., Lamberti, G. and d'Amore, M. 2012. Intensifying the Microencapsulation Process: Ultrasonic Atomization as an Innovative Approach. *Eur. J. Pharm. Biopharm*., **80**: 471-477.

8. Desai, K. G. H. and Park, H. J. 2005. Encapsulation of Vitamin C in Tripolyphosphate Cross-Linked Chitosan Microspheres by Spray Drying. *J. Microencapsul*., **22**:179-192.

9. Fragoso, S., Aceña, L., Guasch, J., Busto, O. and Mestres, M. 2011. Application of FT-MIR Spectroscopy for Fast Control of Red Grape Phenolic Ripening. *J. Agric. Food Chem*., **59**: 2175-2183.

10. Goli, A. H., Barzegar, M. and Sahari, M. A. 2005. Antioxidant Activity and Total Phenolic Compounds of Pistachio (*Pistachia vera*) Hull Extracts. *Food Chem*., **92**: 521-525.

11. Ghandahari Yazdi, A. P., Barzegar, M., Sahari, M. A. and Ahmadi Gavlighi, H. 2019. Optimization of the Enzyme-Assisted Aqueous Extraction of Phenolic Compounds from Pistachio Green Hull. *Food Sci. Nutr*., **7**: 356-366.

12. Hatano, T., Kagawa, H., Yasuhara, T. and Okuda, T. 1988. Two New Flavonoids and Other Constituents in Licorice Root: Their Relative Astringency and Radical Scavenging Effects. *Chem. Pharm. Bull*., **36**: 2090-2097.

13. Kaderides, K., Goula, A. M. and Adamopoulos, K. G. 2015. A Process for Turning Pomegranate Peels into a Valuable Food Ingredient Using Ultrasound-Assisted Extraction and Encapsulation. *Food Sci. Emerg. Technol*., **31**: 204-215.

14. Kuck, L. S. and Noreña, C. P. Z. 2016. Microencapsulation of Grape (*Vitis labrusca* var. Bordo) Skin Phenolic Extract Using Gum Arabic, Polydextrose, and Partially Hydrolyzed Guar Gum as Encapsulating Agents. *Food Chem*., **194**: 569-576.

15. Murugesan, R. and Orsat, V. 2011. Spray Drying of Elderberry (*Sambucus nigra L.*) Juice to Maintain Its Phenolic Content. *Dry. Technol*., **29**: 1729-1740.

16. Naidu, N. B., Chowdary, K. P. R., Murthy, K. V. R., Satyanarayana, V., Hayman, A. R. and Becket, G. 2004. Physicochemical Characterization and Dissolution Properties of Meloxicam–Cyclodextrin Binary Systems. *J. Pharm. Biomed. Anal*., **35**: 75-86.

17. Negrão-Murakami, A. N., Nunes, G. L., Pinto, S. S., Murakami, F. S., Amante, E. R., Petrus, J. C. C., Prudêncio, E. S. and Amboni, R. D. 2017. Influence of DE-Value of Maltodextrin on the Physicochemical Properties, Antioxidant Activity, and Storage Stability of Spray Dried Concentrated Mate (*Ilex paraguariensis* A. St. Hil.). *LWT-Food Sci. Technol*., **79**: 561-567.

18. Paini, M., Aliakbarian, B., Casazza, A. A., Lagazzo, A., Botter, R. and Perego, P. 2015. Microencapsulation of Phenolic Compounds from Olive Pomace Using Spray Drying: A Study of Operative Parameters. *LWT-Food Sci. Technol*., **62**: 177-186.

19. Podsędek, A. 2007. Natural Antioxidants and Antioxidant Capacity of Brassica Vegetables: A Review. *LWT-Food Sci. Technol*., **40**: 1-11.

20. Pyo, Y. H., Lee, T. C., Logendra, L. and Rosen, R. T. 2004. Antioxidant Activity and Phenolic Compounds of Swiss Chard (*Beta vulgaris* Subspecies Cycla) Extracts. *Food Chem*., **85**: 19-26.

21. Rafiee, Z., Barzegar, M., Sahari, M. A. and Maherani, B. 2017. Nanoliposomal Carriers for Improvement the Bioavailability of High–Valued Phenolic Compounds of Pistachio Green Hull Extract. *Food Chem*., **220**: 115-122.

22. Ramírez, M. J., Giraldo, G. I. and Orrego, C. E. 2015. Modeling and Stability of Polyphenol in Spray-Dried and Freeze-Dried Fruit Cncapsulates. _Powder Technol._, **277**: 89-96.

23. Robert, P., Gorena, T., Romero, N., Sepulveda, E., Chavez, J. and Saenz, C. 2010. Encapsulation of Polyphenols and Anthocyanins from Pomegranate (_Punica granatum_) by Spray Drying. _Int. J. Food Sci. Technol._, **45**: 1386-1394.

24. Sablania, V. and Bosco, S. J. D. 2018. Optimization of Spray Drying Parameters for _Murraya koenigii_ (Linn) Leaves Extract Using Response Surface Methodology. _Powder Technol._, **335**: 35-41.

25. Saénz, C., Tapia, S., Chávez, J. and Robert, P. 2009. Microencapsulation by Spray Drying of Bioactive Compounds from Cactus Pear (_Opuntia ficus-indica_). _Food Chem._, **114**: 616-622.

26. Sansone, F., Picerno, P., Mencherini, T., Villecco, F., D'ursi, A. M., Aquino, R. P. and Lauro, M. R. 2011. Flavonoid Microparticles by Spray-Drying: Influence of Enhancers of the Dissolution Rate on Properties and Stability. _J. Food Eng._, **103**: 188-196.

27. Slinkard, K. and Singleton, V. L. 1977. Total Phenol Analysis: Automation and Comparison with Manual Methods. _Am. J. Enol. Viticult._, **28**: 49-55.

28. Souza, A. C. P., Gurak, P. D. and Marczak, L. D. F. 2017. Maltodextrin, Pectin and Soy Protein Isolate as Carrier Agents in the Encapsulation of Anthocyanins-Rich Extract from Jaboticaba Pomace. _Food Bioprod. Process._, **102**:186-194.

29. Tao, Y., Wang, P., Wang, J., Wu, Y., Han, Y. and Zhou, J. 2017. Combining Various Wall Materials for Encapsulation of Blueberry Anthocyanin Extracts: Optimization by Artificial Neural Network and Genetic Algorithm and a Comprehensive Analysis of Anthocyanin Powder Properties. _Powder Technol._, **311**: 77-87.

30. Tonon, R. V., Brabet, C. and Hubinger, M. D. 2008. Influence of Process Conditions on the Physicochemical Properties of Açai (_Euterpe oleraceae Mart._) Powder Produced by Spray Drying. _J. Food Eng._, **88**: 411-418.

31. Tumbas Šaponjac, V., Čanadanović-Brunet, J., Ćetković, G., Jakišić, M., Djilas, S., Vulić, J. and Stajčić, S. 2016. Encapsulation of Beetroot Pomace Extract: RSM Optimization, Storage and Gastrointestinal Stability. _Molecules_, **21**: 584.

32. Turkmen, N., Sari, F. and Velioglu, Y. S. 2005. The Effect of Cooking Methods on Total Phenolics and Antioxidant Activity of Selected Green Vegetables. _Food Chem._, **93**: 713-718.

33. Yingngam, B., Tantiraksaroj, K., Taweetao, T., Rungseevijitprapa, W., Supaka, N. and Brantner, A. H. 2018. Modeling and Stability Study of the Anthocyanin-Rich Maoberry Fruit Extract in the Fast-Dissolving Spray-Dried Microparticles. _Powder Technol._, **325**: 261-270.

34. Young, S.L., Sarda, X. and Rosenberg, M. 1993. Microencapsulating Properties of Whey Proteins. 1. Microencapsulation of Anhydrous Milk Fat. _J. Dairy Sci._, **76**: 2868-2877.

پوشینه سازی ترکیبات فنولی پوست سبز پسته با خشک کن پاششی

ا. پ. قندهاری یزدی، م. برزگر، م. ع. سحری، و ح. احمدی گاولیقی

چکیده

یکی از راه‌های متداول تأخیر در اکسایش استفاده از ضداکساینده ها است. به دلیل اثرات نامطلوب ضداکساینده های سنتزی بر سلامت مصرف‌کنندگان، به‌کارگیری ضداکساینده های طبیعی و ایمن

ضروری به نظر می‌رسد. پوست سبز پسته یکی از ضایعات فرآورده‌های کشاورزی و منبع ارزان‌قیمت ترکیبات فنولی است. استفاده از ترکیبات فنولی در فرمولاسیون مواد غذائی دارای محدودیت‌هایی است. در این مطالعه، پوشینه سازی ترکیبات فنولی پوست سبز پسته به روش خشک‌کن پاششی و توسط مالتودکسترین، به‌عنوان دیواره، انجام شد. بدین منظور، فاکتورهای مؤثر در پوشینه سازی شامل دمای ورودی، فاکتور رقت، نسبت دیواره:هسته و سرعت خوراک‌دهی بهینه‌سازی شدند. خصوصیات مالتودکسترین، پودر عصاره آبی پوست سبز پسته و ریز پوشینه‌های حاوی عصاره آبی پوست سبز پسته توسط میکروسکوپ الکترونی روبشی (SEM)، FTIR، پراکنش اشعه ایکس (XRD) و گرماسنجی روبشی تفاضلی (DSC) بررسی شدند. تحت شرایط بهینه، مقدار ترکیبات فنولی و کارایی پوشینه سازی به ترتیب mg GAE/g dp ۳۲/۱ و ۸۱ درصد بود.نتایج DSC نشان داد که ریز پوشینه سازی پایداری حرارتی ترکیبات فنولی را بهبود بخشیده است. نتایج آزمون DPPH مشخص نمود که فعالیت ضد اکسایشی عصاره آزاد پوست سبز پسته ۱۰ درصد بیشتر از عصاره ریز پوشینه شده است. نتایج بررسی پایداری ترکیبات فنولی عصاره آزاد و ریز پوشینه شده طی ۶۰ روز نگهداری مشخص کرد که پایداری آن‌ها به ترتیب ۲۹ و ۴ درصد کاهش‌یافته است. ریز کپسول‌های به‌دست‌آمده به دلیل وجود ترکیبات فنولی در آن‌ها و خاصیت ضد اکسایشی که دارند می‌توانند برای تولید غذاهای فراسودمند و فرآورده‌های داروئی به‌کاربرده شوند.

64