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Microencapsulation of apricot kernel oil: Utilization of mushroom by-product as an emulsifier in oil-in-water emulsion

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Abstract: The present study investigated mushroom by-products as a substitute for emulsifiers in the microencapsulation of apricot kernel oil. Mushroom by-product emulsions were more viscous and had higher centrifugal (85.88±1.19 %) and kinetic (90.52±0.98 %) stability than control emulsions (Tween 20 was used as emulsifier). Additionally, spray-drying mushroom by-product emulsions yielded a high product yield (62.56±1.11 %). Furthermore, the oxidative stability of powder products containing mushroom by-products was observed to be higher than that of the control samples. For an accelerated oxidation test, the samples were kept at various temperatures (20, 37, and 60 °C). TOTOX values were assessed as indicators of oxidation, with values exceeding 30 indicating oxidation of the samples. Of the samples stored at 60 °C, the non-microencapsulated apricot kernel oil oxidized by the fifth day (41.12±0.13 TOTOX value), whereas the powder samples containing the mushroom by-products remained unoxidized until the end of the tenth day (37.05±0.08 TOTOX value). This study revealed that mushroom by-products could be a viable alternative for synthetic emulsifiers in the microencapsulation of apricot kernel oil. It has been observed that using mushroom by-products instead of synthetic emulsifiers in oil microencapsulation can also delay oxidative degradation in microencapsulated powders.

Key words: Apricot kernel oil, mushroom by-product, oxidative stability, spray drying.

INTRODUCTION

Edible oils play a critical role in human nutrition since they contain essential fatty acids such as linoleic acid. These oils are widely used in the food industry in their raw form and in the cosmetics and pharmaceutical industries in both raw and processed states (Shariatifar et al. 2017). Oils derived from various vegetable sources have begun to be produced in response to growing demand and high economic returns associated with their beneficial health effects. In this context, apricot kernel oil (AKO) is a vegetable oil that has recently been a popular study subject (Akhone et al. 2022, Kilinc & Karakaya 2022, Pawar & Nema 2023).

Apricot kernels contain 48 % oil by weight, of which oleic acid accounts for approximately 68 % and linoleic acid accounts for 25 %. Therefore, AKO is regarded as a vegetable oil rich in unsaturated fatty acids (Özkal et al. 2005a, Shariatifar et al. 2017). Besides being high in unsaturated fatty acids, literature studies report that AKO lowers cholesterol levels and reduces liver fat (Kutlu et al. 2009). Studies with AKO have reported that it positively affects skin diseases and ear inflammation. There are also studies saying that it is used to treat ulcers and anorexia (Siddiqui et al. 2023). Studies on AKO have generally focused on issues such as the extraction of oil from the kernel (Özkal et al. 2005a, b, Gupta & Sharma 2009, Gayas et al.

2017), physical and chemical properties (Ozcan et al. 2010), use in baked goods (Abd El-Aal et al. 1986), oxidative stability and storage stability (Durmaz et al. 2010, Singh Gurau et al. 2016) and determination of fatty acid composition (Turan et al. 2007). However, no study involving microencapsulation of AKO was found during the literature review of the current study. Therefore, this study is based on the fact that the usage area of AKO, which has many benefits for human health, should be expanded. For that reason, it is believed that this study will contribute to food science and literature.

Microencapsulation is an encapsulation technique frequently applied in the food industry to increase the stability of compounds sensitive to external factors. It is based on forming a solid barrier (coating material) around the food component to protect it from stress factors such as oxygen, moisture, and pressure (Lucas et al. 2020, Umaña et al. 2021). Microencapsulation of lipophilic compounds such as AKO by spray drying begins with forming an oil-in-water emulsion of the lipophilic compound (Hernández Sánchez et al. 2016). Proteins, gums, and carbohydrates are commonly used as spray drying coating materials (Shishir & Chen 2017). In recent years, more importance has been given to using natural and plant-based coating materials rather than synthetic ones in microencapsulation. Studies on using by-products from processing specific plant sources in the food industry as a coating material in the microencapsulation process are ongoing (Berton-Carabin & Schroën 2019, Umaña et al. 2021). In a study, tamarind seed mucilage was used as a coating material in the microencapsulation of sesame seed oil. As a result of the study, it was reported that the oxidation mechanisms of sesame seed oil powders, in which tamarind seed mucilage was used as a coating material, were delayed. The powder samples were also reported to have high microencapsulation efficiency and thermal stability (Alpizar-Reyes et al. 2020). Food industry by-products are used as coating materials in edible oil microencapsulation and in the microencapsulation of many different products. A related study used barley residue proteins from beer waste as a coating material in β-carotene microencapsulation. A study using maltodextrin and whey protein as control samples reported that samples containing barley residue proteins had higher encapsulation efficiency and thermal stability (Meira et al. 2023).

In the literature, it has been reported that large amounts of by-products are released after the industrial processing of mushrooms (Wang et al. 2018, Ramos et al. 2019). These by-products are released after ergosterol extraction from the mushroom. It has been reported that the by-products obtained after this process include a small amount of ergosterol. These by-products are also rich in bioactive components (Umaña et al. 2020, 2021). Umaña et al. (2021) conducted the first study in the literature to test mushroom by-products in sunflower oil microencapsulation. They investigated the extent to which the by-products affected sunflower oil oxidation. After the survey, it was reported that mushroom by-products could be successfully employed in the microencapsulation of sunflower oil and that encapsulating sunflower oil with mushroom by-products can reduce its oxidation.

This study investigates the possibilities of using mushroom by-products in the microencapsulation of AKO. Additionally, the present study investigated the effect of microencapsulation with mushroom by-products on the oxidative stability of AKO. Furthermore, since the literature revealed no survey on the microencapsulation of AKO, this study intends to fill this void.

MATERIALS AND METHODS

Materials

Apricot kernels employed in the present study were obtained from a local manufacturer in Uşak, Turkey. Cultivated mushrooms (*A. bisporus*) were supplied from a local market to get their by-products, provided they were from the same batch. The chemicals employed in the analyses were procured from Sigma (Taufkirchen, Germany) and Merck (Darmstadt, Germany) in analytical and chromatographic purity.

Methods

Oil extraction from apricot kernels

A cold press oil machine (NF 100, Karaerler Makine Co. Ltd., Ankara, Turkey) was utilized to obtain AKO from apricot kernels. For this purpose, a cold press oil machine with 1500 W motor power, a 600 W thermostat, and a helical gear wheel were preferred. Approximately 300 g of apricot kernels were fed intermittently into the cold press oil machine each time. The press machine was cleaned between each cycle. Apricot kernel by-products were fed to the system four more times after the initial feeding was completed, and most of the oil was removed from the by-products. Then, the obtained AKO was stored in amber-colored glass bottles at +4 °C until analysis.

Extraction of by-products from cultivated mushrooms

The cultivated mushrooms were separated from their stems to extract the by-products and dried with a freeze-dryer (LGJ-10, VIKUMER, Shenzhen, China). For the freeze-drying process, the temperature was gradually increased from -40 °C to 5 °C for 48 hours. Additionally, the pressure was kept below 70 Pa. Then, the dried mushroom samples were ground with a domestic grinder and sieved through a 60-mesh sieve. After that, ergosterol extraction was carried out as described in the literature (Umaña et al. 2021). An aqueous ethanol solution (96 %) (3:100 w/v) was used as the solvent for ergosterol extraction. The residual by-products from ergosterol extraction were dried under vacuum at 30 °C for three days. The moisture content of the samples after drying was determined to be 3.12±0.02 % (Table I). The dried by-products were utilized as coating material as well as maltodextrin (Sigma–Aldrich, Saint Louis, USA, CAS number: 9050-36-6, EC number: 232-940-4, dextrose equivalent: 15.0-20.0) in AKO microencapsulation.

The resulting by-products were analyzed for moisture content, water activity, lipid content, protein content, ash content, carbohydrate content, total phenolic component content, antioxidant activity, and ergosterol content. While the moisture content of the by-products was determined by the gravimetric method, the water activity value was determined by water activity measurement instruments (AwTherm, Rotronic, Bassersdorf, Sweden) (Gunel et al. 2018). While the Kjeldahl method determined the protein amount, the lipid content was calculated by the gravimetric method. The total ash content

Table I. Some chemical properties of the mushroom by-product.

Chemical Properties	Values
Moisture content (%)	3.12±0.02
Water activity	0.26±0.00
Lipid (g/100 g dm)	1.19±0.03
Protein (g/100 g dm)	20.02±1.19
Ashes (g/100 g dm)	9.96±1.01
Carbohydrate (g/100 g dm)	68.83±2.23
Total phenolic content (g gallic acid/100 g dm)	0.96±0.01
Antioxidant activity (DPPH assay) (g Trolox/100 g dm)	2.21±0.04
Ergosterol (g/100 g dm)	0.096±0.004

was determined according to AOAC method 945.46 (AOAC 1997). The carbohydrate amount of the samples was determined by subtracting the sum of the protein, lipid, and ash amounts from 100. The total phenolic compound amount was estimated with the Folin-Ciocalteu reagent, and the antioxidant activity was determined using the method based on the reduction of DPPH radical (Gunel et al. 2020). The ergosterol content was estimated using the method reported by Shao et al. (2010), and its amount was determined chromatographically (Umaña et al. 2020).

Preparation of emulsions

To prepare emulsions to be spray-dried, the method used by Umaña et al. (2021) was utilized with partial modifications. First, the dry matter contents of the control and experimental group emulsions were adjusted for this purpose. An oil-in-water emulsion containing 40 % w/w maltodextrin (MD), 0.20 % w/w Tween 20, and 5 % w/w AKO was used as a control emulsion. The emulsion was homogenized for 5 min at 5000 rpm. Before preparing the test emulsion, 5 % w/w mushroom by-product was dissolved in half of the water needed for the emulsion, and 35 % w/w MD was added to this solution. The mixture was then added to 5 % w/w AKO and homogenized for 5 min at 5000 rpm using a homogenizer (T-25, IKA, Staufen, Germany). The formulations used in the emulsions were determined to be the maximum AKO concentration, minimum Tween 20 concentration, and maximum mushroom by-product concentration using the Box–Behnken trial design (unpublished data).

Spray drying of emulsions

The prepared emulsions were dried with a laboratory-scale mini spray dryer (OLT-SD8000B, Ollital, Fujian, China). In the double-flow nozzle dryer with an inner diameter of 0.5 mm, the inlet temperature was set to 170 °C, and the outlet temperature was maintained at 95-97 °C. The flow speed of the spray dryer was set to 450 L/h, and the aspiration rate was adjusted to 70 %. The feed rate was varied between 250 and 550 mL/h to maintain a constant temperature at the air outlet. While the powder samples obtained were analyzed as soon as possible, they were stored in sealed bags at +4 °C during the waiting period.

Emulsion analyses

- Apparent viscosity, centrifugal stability, kinetic stability

The apparent viscosities of the prepared emulsions were determined with a viscometer (Fungilab Expert Series, Barcelona, Spain). A spindle maintained a constant temperature of 25 °C throughout the measurements.

10 mL of each emulsion was transferred to a test tube and stored at room temperature for two hours to determine the kinetic stability of the emulsions. At the end of the waiting period, the kinetic stability of the emulsions was calculated as the sedimentation index (Equation 1) (Consoli et al. 2016).

$$SI=H_{l@t}/H_i \times 100 \quad (1)$$

where SI, $H_{l@t}$, and H_i indicate the sedimentation index, lower phase (the phase at the bottom of the tube) height at time t, and initial height of the emulsion, respectively.

Immediately after preparing the emulsions, they were transferred to a 10 mL test tube and centrifuged for 10 min at 10000 rpm. The centrifugal stability of the emulsions was determined at the end of the period using Equation 2 (Galvão et al. 2018).

$$CS= H_l/H_i \times 100 \quad (2)$$

In this formula, CS, H_l, and H_i indicate the centrifuge stability, the lower phase's height, and the emulsion's initial height, respectively.

Powder product analysis

- Product yield

The product yield was determined by using Equation 3.

$$\text{Yield (\%)} = \frac{P}{R} X 100 \quad (3)$$

In this formula, P represents the weight of the powder product obtained after spray drying, and R represents the total dry matter content of the emulsion (Pino et al. 2019).

- Encapsulation efficiency

The encapsulation efficiency value was calculated after determining the AKO microcapsules' free (surface) and total oil contents (Sahin-Nadeem & Ozen 2014). For this purpose, two grams of microcapsules were blended with 15 mL of hexane and vortexed for 2 min. The mixture passed through filter paper and was washed three times with 20 mL of hexane. After that, it was dried at 60 °C until it reached a constant weight. The weight of residual oil was used to determine the encapsulation efficiency and calculated according to Equation 4.

$$EE = \frac{TO - SO}{TO} x 100 \quad (4)$$

In this formula, EE denotes the encapsulation efficiency, TO indicates the total amount of oil (g), and SO represents the amount of free oil (g). Because AKO is not an essential oil, the total amount of oil was assumed to be the same as the amount of oil added to the emulsion. Additionally, this approach has been tested and accepted in previous studies for the non-volatile oils of pomegranate seed oil and flaxseed oil (Tontul & Topuz 2013, Sahin-Nadeem & Ozen 2014).

- Particle morphology (Scanning Electron Microscopy)

To determine the particle morphology of the AKO powders, the powder products were distributed on two-sided adhesive tape and coated with gold spray. Samples were examined at 1 kV. Both overview images (x500) and surface images (x2500) of the samples were taken. The morphological characteristics of AKO powders were observed by scanning electron microscopy (Carl Zeiss 300VP, Birkerød, Denmark).

- Moisture content, water activity, bulk density, hygroscopicity

The moisture contents of the samples were determined by the gravimetric method. A water activity measurement instrument was used to determine the water activity values of the samples (AwTherm, Rotronic, Bassersdorf, Sweden) (Gunel et al. 2018). The bulk density and hygroscopicity of the samples were determined utilizing established methods in the literature (Sahin-Nadeem & Ozen 2014).

- Solubility and particle size analysis

The solubility of AKO microcapsules in cold water was determined by the method reported in the literature (Sahin-Nadeem & Ozen 2014), whereas the particle size distribution was determined by a laser diffraction particle size analyzer (Mastersizer 2000, Malvern, Worcestershire, UK). Analyses were carried out at 25±1 °C.

- Oxidative stability tests

To determine the oxidative stability of AKO powders at different temperatures, 10 g powder samples were placed in disposable Petri dishes. Petri dishes were stored at three different temperatures, 20, 37, and 60 °C, in an oven conditioned to 49 % relative humidity. Next, three Petri dishes were taken from each sample

on separate days. AKO was re-extracted from the samples by the solvent extractor (Dionex-ASE, Sunnyvale, USA) method (Ahn et al. 2008). Peroxide (POV) and *p*-anisidine (pAV) values were determined to ascertain the oxidative stability of the extracted AKO. To determine the POV, 5 g of the sample was weighed into a bottle. Next, 20 mL of acetic acid/isooctane mixture was added, and the bottle was shaken to dissolve. Then, the mixture was incubated at room temperature in a dark environment for 5 min. At the end of the waiting period, 1 mL of 1 % starch solution was added to the mixture. The mixture was titrated with 0.002 N sodium thiosulfate solution until the color became transparent. The POV was calculated with Equation 5 (Kasimoglu et al. 2018).

$$\text{POV } (meq\ peroxide/kg\ sample) = S \times N \times 1000/g\ sample \quad (5)$$

In this formula, S represents the amount of sodium thiosulfate in mL, and N represents the normality of sodium thiosulfate.

The *p*-anisidine standard solution (0.25 %) prepared with glacial acetic acid was used to determine the pAV of the samples. Then, 1 mL (m) AKO was placed in a tube, and 24 mL of n-hexane was added. After mixing the tube, the adsorption levels (Ab) were determined using a spectrophotometer set to 350 nm. Five milliliters of diluted oil were placed in a tube, and 1 mL of *p*-anisidine standard solution was added. After the mixture was kept in the dark for 10 min, its absorbance (Aa) was re-recorded at 350 nm. As a control, 5 mL of n-hexane and 1 mL of *p*-anisidine standard solution were blended in a tube, and the absorbance (Ak) at 350 nm was measured after being kept for 10 min in the dark. The pAV values of the samples were calculated utilizing Equation 6 (Kasimoglu et al. 2018).

$$pAV = 25 \times [(1.2 \times (A_a - A_k)) - A_b]/m \quad (6)$$

Finally, the Totox values of the samples were determined by using Equation 7, and the oxidative stability test was repeated until the Totox values of the samples reached the maximum limit of 30 (Sun-Waterhouse et al. 2011).

$$Totox = 2 \times POV + pAV \quad (7)$$

- Specific extinction value

The specific extinction value indicates the amount of diene and triene formed in the oil during oxidation. To determine the specific extinction value of AKO powders stored at different temperatures, 1 % solutions of oils in cyclohexane were prepared, and the absorbances of the prepared solutions were measured at 232 and 270 nm for diene and triene, respectively (Ayadi et al. 2009).

Statistical analyses

While the microencapsulation of AKO was performed in three replications, all analyses were carried out in three parallels. The analysis results were statistically evaluated using analysis of variance (SPSS package program, Version 23.0, IBM Inc., New York, USA) and Duncan's Multiple Range Test (SAS system for Windows V7, SAS Institute, Cary, NC, USA).

RESULTS AND DISCUSSION

Some chemical properties of the mushroom by-products

Some chemical properties of the mushroom by-products used as a coating material in the present study are presented in Table I. While the moisture content of the mushroom by-products was determined to be 3.12±0.02 %, the water activity value was determined to be 0.26±0.00. The powder products' moisture content and water activity values were relatively low. Similar results were found in some studies using spray drying

in different combinations with MD (Mahdavi et al. 2016, Tolun et al. 2016). In this case, it can be thought that the presence of polysaccharides along with MD further reduces the moisture content of powder products. Considering all these factors, mushroom by-products are believed to be effectively used in producing dry and stable powders with low water activity and moisture content. The mushroom by-products were mainly composed of carbohydrates (68.83±2.23 g/100 g dry matter (dm)), followed by proteins with a dm value of 20.02±1.19 g/100 g. It was determined that 0.096±0.004 g/100 g dm of ergosterol remained in the mushroom by-products after extraction, indicating the presence of antioxidant compounds in this context. The ergosterol content (0.71±0.01 g/100 g dm) of fresh mushrooms used to obtain mushroom by-products at the beginning of the study was also determined. Ergosterol extraction removed approximately 87 % of the ergosterol from fresh mushrooms. The findings obtained for mushroom by-products were consistent with previous studies in the literature.

Apparent viscosities, kinetic stabilities, and centrifugal stabilities of emulsions

The apparent viscosity results of the emulsions are presented in Figure 1. It was determined that adding mushroom by-products increased the apparent viscosity of the emulsions. According to the analysis of variance results, the addition of mushroom by-products was observed to have a statistically significant effect on the emulsion viscosity (p<0.05). The apparent viscosities of the control emulsions were determined to be 119.897±0.68 mPa s, whereas the apparent viscosities of the emulsions containing mushroom by-products were determined to be 181.488±20.08 mPa s. Furthermore, emulsions containing MD and mushroom by-products were observed to have different flow behaviors. While

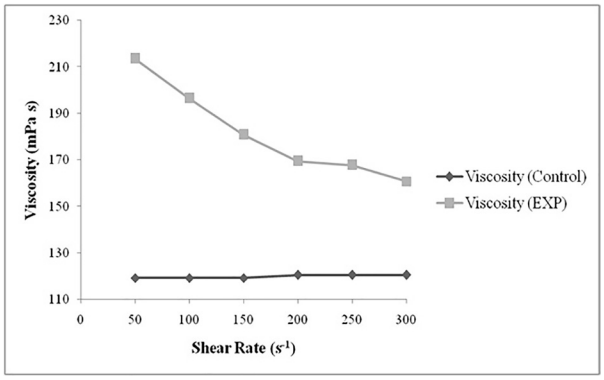

Figure 1. Changes in apparent viscosity of control and mushroom by-product (EXP) emulsions at 25 °C.

the shear rate (0-300 s-1) increased, the apparent viscosity of the control emulsion remained constant. However, the apparent viscosities of emulsions containing mushroom by-products decreased as the shear rate increased. Therefore, emulsions containing mushroom by-products exhibit non-Newtonian flow, while control emulsions exhibit Newtonian flow. The literature has reported that long polymer molecule chains and insoluble particles align in the flow direction when the shear rate increases. This may be why emulsions containing proteins, polysaccharides, and insoluble fibers, such as mushroom by-products, exhibit non-Newtonian flow behavior (Leverrier et al. 2016). Changes in the apparent viscosities of emulsions with the addition of mushroom by-products have also been reported by Umaña et al. (2021).

The results of the kinetic stability analysis indicated that the addition of mushroom by-products partially reduced the kinetic stability of the emulsions. However, this decrease was not statistically significant (p>0.05). The kinetic stability of the control emulsion was determined to be 94.56±1.56 %, while the kinetic stability of the emulsions containing mushroom by-products was determined to be 90.52±0.98 %.

According to the centrifuge stability results, the centrifuge stability of the emulsions was observed to decrease in a statistically

insignificant (p>0.05) way with the addition of mushroom by-products, similar to the kinetic stability results. The centrifugal stability of the control emulsion was determined to be 88.56±2.13 %, while the centrifugal stability of the emulsion containing mushroom by-products was determined to be 85.88±1.19 %.

The lower kinetic and centrifugal stability of emulsions containing mushroom by-products than control emulsions is believed to be due to the lower solubility of mushroom by-products compared to MD. Similar results were reported by Campelo et al. (2018). When whey protein isolate, which has lower solubility than MD, was used in microencapsulation, the stability of emulsions and the solubility of powders were lower.

Product yield (PY) and encapsulation efficiency (EE)

In spray drying, the product yield (PY) is a value that indicates the presence of products that do not dry and/or do adhere to the drying cyclone. The more products that can be collected without adhering to the cyclone, the higher the PY. The literature shows PY values greater than 50 % are successful (Adhikari et al. 2009, Tontul & Topuz 2017). The present study obtained data on PY greater than 50 % in control and emulsions containing mushroom by-products. The PY values of AKO microencapsulation are presented in Table II. Accordingly, the yield value of the control emulsion was determined to be 78.58±2.14 %, while the yield value of the emulsion containing mushroom by-products was identified as 62.56±1.11 %. The variance analysis revealed that adding mushroom by-products to AKO microencapsulation had a statistically significant effect on PY (p<0.05). The addition of mushroom by-products in the emulsion decreased the PY during the spray drying process. High-viscosity emulsions cause large droplets more likely to adhere to the cyclone during spray drying (Sahin-Nadeem & Ozen 2014). The present study concluded that the higher viscosity of the emulsions containing mushroom by-products compared to the control emulsions might have decreased the PY.

Table II. Some physicochemical properties of AKO microcapsules obtained from emulsions (control and mushroom by-product).

Properties	Control	Mushroom By-Product
Product yield (%)	78.52^{a}±2.14	62.56^{b}±1.11
Encapsulation efficiency (%)	90.79^{a}±1.12	82.88^{b}±0.78
Moisture content (%)	1.91^{a}±0.03	1.62^{b}±0.04
Water activity	0.179^{a}±0.008	0.159^{b}±0.006
Bulk density (kg/m^3)	386.22^{a}±11.10	349.52^{b}±21.13
Hygroscopicity (%)	12.56^{a}±0.96	14.02^{a}±0.09
Solubility (%)	87.30^{a}±2.16	72.11^{b}±1.19
Particle size (µm)	20.13^{b}±1.14	32.16^{a}±2.10
Span	1.44^{a}±0.03	1.19^{b}±0.09

Results are mean±standard error; Different letters in the same row indicate statistically significant differences ($p < 0.05$).

The data in Table II indicate that using mushroom by-products in AKO microencapsulation had a statistically significant (p<0.05) effect on EE. The use of mushroom by-products in AKO microencapsulation was observed to decrease the EE values. While the EE values of the control samples were determined to be 90.79±1.12 %, the EE values of the samples utilizing the mushroom by-products were identified as 82.88±0.78 %. Keeping the coated material within the capsule during microencapsulation depends on the coating material's physicochemical properties and molecular weight (Tari & Singhal 2002). The low EE value in samples containing mushroom by-products was thought to be related to the

particle size and solubility of the mushroom by-products. In the literature, materials with low solubility and large particle sizes have been reported to have lower EE values (Márquez Gómez et al. 2018). The EE results obtained from the present study were found to be consistent with studies in the literature that performed microencapsulation of various oils (Sahin-Nadeem & Ozen 2014, Tatar & Kahyaoglu 2015, Márquez Gómez et al. 2018, Umaña et al. 2021).

Particle morphology (Scanning Electron Microscope (SEM))

Images of the particle morphology of the AKO microcapsules are presented in Figure 2. According to SEM images, using mushroom by-products in AKO microencapsulation had no significant effect on the morphology of the powder products. Generally, it has been determined that the morphologies of the powder products obtained from both the control emulsion and the emulsions containing mushroom by-products are similar. When the general view images in Figure 2 are examined, it is clear that the AKO powders exhibit shrinkage as a characteristic of spray-dried powders. Additionally, upon reviewing the surface images in Figure 2, it is apparent that the AKO powders are homogeneous and spherical. Apart from their sphericity and homogeneity, small cracks, wrinkles, and bumps have been observed on the particles. SEM images of AKO powders were found to be consistent with various studies in the literature on spray drying oil encapsulation (Sahin-Nadeem & Ozen 2014, Tatar & Kahyaoglu 2015, Karim et al. 2016, Márquez Gómez et al. 2018, Umaña et al. 2021).

Moisture content, water activity, bulk density, hygroscopicity

Moisture content is a powder property that has a significant impact on the glass transition temperature and crystallization behavior, as well as on transportation, processing, and storage. It is closely related to powder fluidity, drying efficiency, and adherence. In addition, low moisture content also regulates the effect of water as a plasticizer, as it lowers the glass transition temperature (Mahdavi et al. 2016).

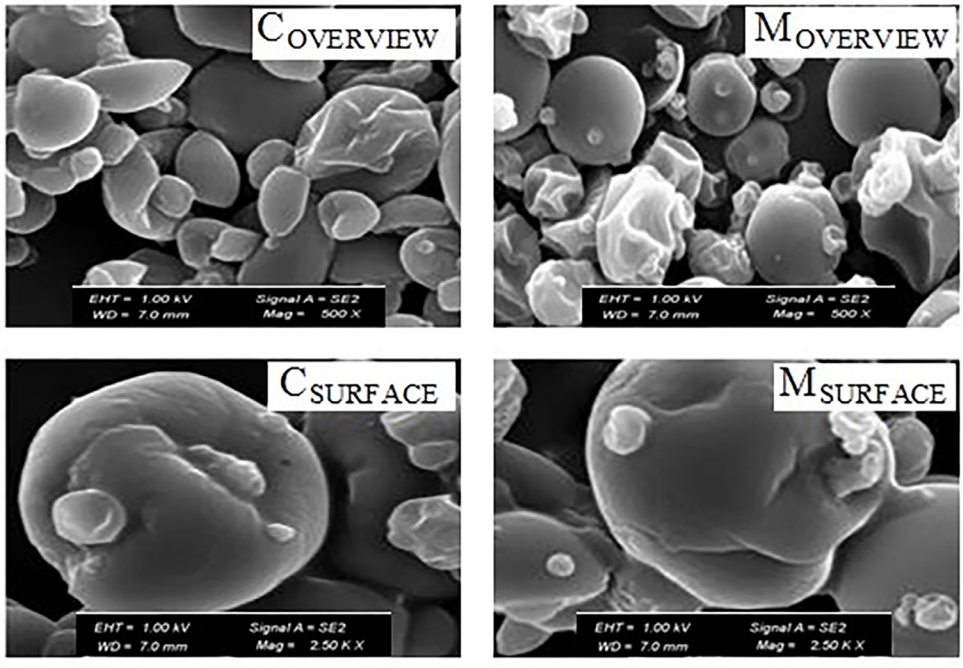

Figure 2. Scanning electron microscopy micrographs of powders produced with control (C) and mushroom by-product (M) emulsions.

Findings regarding moisture and water activity values of AKO microcapsules are presented in Table II. According to the analysis results, the moisture and water activity values of AKO powders obtained from both control emulsions and emulsions containing mushroom by-products were relatively low. The moisture and water activity values of powder samples obtained from control emulsions were determined to be 1.91±0.03 % and 0.179±0.008, respectively, whereas the moisture and water activity values of powder products obtained from emulsions containing mushroom by-products were determined to be 1.62±0.04 % and 0.159±0.006, respectively. The use of mushroom by-products in AKO microencapsulation was observed to have a statistically significant (p<0.05) effect on the moisture and water activity values of the powder products obtained. Moreover, it has been observed that the findings regarding the moisture and water activity values obtained from the present study are compatible with studies in the literature (Geranpour et al. 2019, Umaña et al. 2021). The moisture content and water activity values of AKO powders using mushroom by-products were determined to be lower than those of AKO powders obtained from control emulsions. The primary reason for this situation was believed to be the presence of other polysaccharides in the by-products in addition to MD in emulsions containing mushroom by-products. It has been concluded that the carbohydrates in the mushroom by-products increase dehumidification, hence decreasing the water activity (Lee & Chang 2020, Umaña et al. 2021).

The bulk density of food powders can be affected by many factors. The primary factors affecting bulk density are particle size and shape, core material density, coating material density, and moisture content of microcapsules. Additionally, it has been reported that particles mostly tiny, spherical, and irregular in shape may have a greater bulk density (Bae & Lee 2008, Goula & Adamopoulos 2012). In the present study, the bulk density values of AKO powders obtained from control emulsions were determined to be 386.22±11.10 kg/m^3 (Table II). Moreover, the bulk density values of AKO powders obtained from emulsions containing mushroom by-products were estimated as 349.52±21.13 kg/m^3. According to the statistical analysis results, it was determined that the use of mushroom by-products in AKO microencapsulation had a significant (p<0.05) effect on the bulk density values of the powder products. The use of mushroom by-products in AKO microencapsulation has been observed to decrease the bulk densities of the powders obtained. Similar results were obtained in the study conducted by Umaña et al. (2021), where it was reported that using mushroom by-products in sunflower oil microencapsulation reduces the bulk density values of powder products. This situation was thought to be mainly caused by mushroom by-products having a larger particle size than MD. As specified in the literature, coating materials with large particle sizes reduces the bulk density values of powder products (Bae & Lee 2008).

Hygroscopicity is a fundamental property of food powders, particularly during transportation and storage. The moisture extraction rate and capacity of food powders during transport and storage depend on the hygroscopicity of that powder. In food powders with high moisture, extraction causes a low glass transition temperature, and adhesions occur due to liquid bridges formed between particles. As these adhesions persist, the critical caking problem in food powders emerges. Thus, hygroscopicity is essential for food powders and should be as low as possible (Tontul & Topuz 2013, Oliveira et al. 2014, Juarez-Enriquez et al. 2017).

In the current study, the hygroscopicity of AKO powders obtained from the control emulsion was 12.56±0.96 %. In contrast, the hygroscopicity of AKO powders obtained from emulsions containing mushroom by-products was estimated to be 14.02±0.09 %. Although using mushroom by-products in AKO microencapsulation seems to increase hygroscopicity, this situation was not statistically significant (p>0.05). According to the results in Table II, the moisture content of AKO powders and their hygroscopicity were inversely proportional. Previous studies have also reported similar results (Ferrari et al. 2012, Goula et al. 2004). Powders with low moisture content can absorb ambient moisture since they have a higher water concentration gradient between themselves and the surrounding air (Tonon et al. 2008). Additionally, it is known that MD has a large molecular weight, thus increasing the glass transition temperature of the product, inhibiting adhesion, and reducing hygroscopicity (Bhandari et al. 1997).

Solubility and particle size

Solubility is a term that refers to the ability of AKO microcapsules to form solutions or suspensions in water. Due to the hydrophobic nature of oils, microencapsulation is performed to facilitate their solubility in water. Microencapsulation reduces water solubility by preventing oil phase separation (Felix et al. 2017). The present study observed that the use of mushroom by-products in AKO microencapsulation reduced the solubility. According to the results in Table II, the water solubility value of AKO powders obtained from control emulsions was estimated as 87.30±2.16 %. In contrast, the water solubility value of AKO powders obtained from emulsions containing mushroom by-product was determined as 72.11±1.19 %. This decrease was found to be statistically significant (p<0.05). The study conducted by Umaña et al. (2021) reported that using mushroom by-products in the microencapsulation of sunflower oil reduced the solubility of the microcapsules obtained. Therefore, the solubility results obtained in the present study were consistent with the literature studies. Using mushroom by-products in AKO microencapsulation reduces solubility because the mushroom by-products do not entirely dissolve during emulsion preparation and instead result in a stable suspension. Therefore, since the water solubility of the mushroom by-products is lower than that of MD, this condition also affected the solubility values of the microcapsules. However, even when the mushroom by-products are employed in AKO microencapsulation, the solubility value was estimated to be above 70 %, higher than some literature studies (Alvarenga Botrel et al. 2012, Felix et al. 2017). Accordingly, AKO microcapsules using mushroom by-products can be considered a candidate encapsulated food component in the food industry.

The particle size distributions of AKO powders obtained from emulsions containing control and mushroom by-products are presented in Figure 3. The particle sizes of the AKO powders obtained from both the control emulsion and the emulsion containing the mushroom by-products shared similar distributions. Both powder products began with a slight shoulder and then developed a regular distribution. According to the data in Table II, the d50 values of AKO powders obtained from the control emulsion were 20.23±1.14 µm, and the span value was 1.44±0.03. On the other hand, the particle sizes of AKO powders containing mushroom by-products in the emulsion were observed to be higher than those of the control sample. The d50 value of AKO powders containing mushroom by-products was estimated as 32.16±2.10 µm, and the span value was 1.19±0.09. A statistically significant (p<0.05) effect of using the mushroom

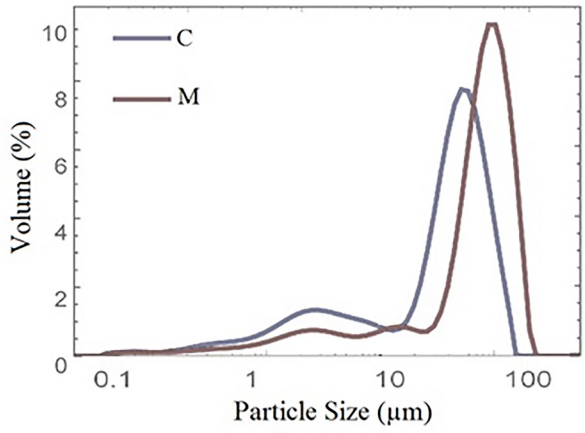

Figure 3. Particle size distribution of powders (C: Control, M: Mushroom by-product).

by-products in AKO microencapsulation on the particle sizes of the powder products was determined. The use of mushroom by-products has increased the particle size of AKO powders, which is thought to be due to emulsions with different properties. The literature specifies that emulsions with a denser (viscous) structure cause larger droplets after atomization (Turchiuli et al. 2014). The effects of mushroom by-products on particle size in the current study were also reported by Umaña et al. (2021), and the results obtained were consistent with the mentioned study. The use of mushroom by-products in AKO microencapsulation increased the particle size of the obtained powder products and decreased the surface area, thus increasing the stability of the microcapsules against oxidation (Kolanowski et al. 2006, Carneiro et al. 2013, Tontul & Topuz 2013).

Oxidative stability

In the present study, the oxidative stability test was carried out at three different temperatures: 20 °C, the ambient temperature; 37 °C, a typical tropical temperature; and 60 °C to accelerate the oxidation reactions of AKO. Generally, when oils achieve the maximum oxidation rate, Totox values are known to be 30 (Sun-Waterhouse et al. 2011). For this reason, analyses were performed while determining the oxidative stability of AKO until the Totox value of the samples stored at high temperature reached 30. Data from accelerated oxidation tests generally do not correlate with stability at room temperature due to the different kinetics of lipid oxidation at high temperatures (Sahin-Nadeem & Ozen 2014). However, they provide simple and quick basic information about the oxidation of fats.

The current study determined that the POV and pAV values of non-microencapsulated AKO were 7.02±0.06 meq peroxide/kg oil and 1.52±0.02 meq p-anisidine/kg oil, respectively. After the POV value of AKO used in the study was determined to be within the acceptable limits (up to 15 meq peroxide/kg oil) according to CODEX-STAN 210-19994, which is defined for cold-pressed edible oils, the storage stage was initiated. Both non-microencapsulated AKO, AKO powders produced from the control emulsion, and AKO powders using the mushroom by-products in the emulsion were stored. The oxidative stability change of all three samples during the storage period is presented in Table III and Figures 4 and 5. The effect of storage temperature on the oxidative stability of the samples was found to be statistically significant (p<0.05). According to the analysis results, the stability of AKO against oxidation increased after microencapsulation, and the microencapsulation process had a significant (p<0.05) effect on oxidative stability. Similarly, using mushroom by-products in AKO microencapsulation had a statistically significant (p<0.05) effect on the oxidative stability of AKO powders.

The samples microencapsulated during storage maintained their oxidative stability at 20 and 37 °C for up to 30 days, and the Totox values did not exceed 30 even after 30 days. However, the Totox value of non-microencapsulated AKO exceeded the maximum

Table III. Totox values of AKO and AKO powders.

Storage Temperature	Storage Days	AKO	C-AKO	M-AKO
20 °C	0	15.61^{Be}±0.08	16.81^{Ad}±0.06	16.40^{Ad}±0.06
	1	15.78^{Ce}±0.04	16.89^{Ad}±0.02	16.43^{Bd}±0.04
	5	16.71^{Bd}±0.03	17.50^{Ac}±0.00	16.74^{Bd}±0.02
	10	18.98^{Ac}±0.08	17.93^{Bc}±0.01	17.42^{Cc}±0.02
	15	23.24^{Ab}±0.08	20.33^{Bb}±0.03	18.17^{Cb}±0.04
	30	36.06^{Aa}±0.06	23.01^{Ba}±0.04	20.79^{Ca}±0.05
37 °C	0	15.61^{Bf}±0.08	16.81^{Ae}±0.06	16.40^{Ae}±0.06
	1	16.17^{Ce}±0.07	17.01^{Ae}±0.00	16.70^{Be}±0.03
	5	18.24^{Ad}±0.10	18.05^{Bd}±0.01	17.76^{Cd}±0.02
	10	19.77^{Ac}±0.09	18.91^{Bc}±0.07	18.58^{Cc}±0.01
	15	24.12^{Ab}±0.11	20.43^{Bb}±0.07	19.97^{Cb}±0.09
	30	44.14^{Aa}±0.14	25.06^{Ba}±0.10	22.76^{Ca}±0.12
60 °C	0	15.61^{Bc}±0.08	16.81^{Ad}±0.06	16.40^{Ad}±0.06
	1	22.10^{Ab}±0.08	18.97^{Bc}±0.04	18.74^{Bc}±0.10
	5	41.12^{Aa}±0.13	21.84^{Bb}±0.06	21.50^{Cb}±0.14
	10	-	40.57^{Aa}±0.09	37.05^{Ba}±0.08
	15	-	-	-
	30	-	-	-

Results are mean±standard error. * A–C Values in the same row at the same storage temperature with different letters are significantly different ($p < 0.05$). ** a–c Values in the same column with different letters are significantly different ($p < 0.05$). * AKO: Apricot kernel oil, C-AKO: AKO powder produced with control emulsion, M-AKO: AKO powder produced with mushroom by-product emulsion.**

limit of 30 on the 30th storage day at both 20 °C and 37 °C storage temperatures. Based on these findings, it is possible to conclude that the microencapsulation process increases the oxidative stability of AKO at both room and tropical temperatures.

During storage at 60 °C, the accelerated oxidation test temperature, the Totox values of both non-microencapsulated AKO and microencapsulated AKO powders exceeded 30 before reaching the 30th storage day. However, it was determined that non-microencapsulated AKO reached 41.12 Totox values at the end of the 5th storage day, while AKO powders reached high Totox values on the 10th storage day. The analysis revealed that mushroom by-products in AKO microencapsulation partially limited oxidation compared to only MD. Indeed, the Totox value of the powder produced from the control emulsion during high-temperature storage was determined to be 40.57 on the 10th storage day, while the Totox value of the powders produced from the emulsion containing mushroom by-products under the same conditions was determined to be 37.05. Similar conditions were valid for POV and pAV values, and the highest values were determined for non-microencapsulated AKO, depending on storage temperature and time. POV and pAV values of the powders obtained from the control

emulsion followed the non-microencapsulated AKO. The lowest data were estimated for the powders containing mushroom by-products in the emulsion.

The study by Umaña et al. (2021) investigated the effect of mushroom by-products in sunflower oil microencapsulation on the oxidative stability of the powder. Similar to the present study, it has been reported that using mushroom by-products in emulsions can slow the oxidation reactions of sunflower oil powders and partially increase oxidative stability.

The results obtained from the present study were consistent with a literature study investigating the effects of caffeic acid addition in olive oil microencapsulation. The mentioned study reported that oxidation could be slowed during storage at 20 and 37 °C by adding caffeic acid in olive oil microencapsulation (Sun-Waterhouse et al. 2011).

On the other hand, pomegranate seed oil was microencapsulated with MD and coating materials containing different combinations, and the powder products were subjected to a rapid oxidation test at 60 °C. The oxidation test revealed that the powder samples were oxidized by the end of the 5th day, although the oxidation varied depending on the combination. In this context, it is possible to state that the results obtained in the current study (stable powders up to 10 days) are higher than those in some literature studies (Sahin-Nadeem & Ozen 2014).

Specific extinction

The specific extinction, also known as specific absorptivity in the literature, is related to the formation of hydroperoxides, conjugated dienes, carboxylic compounds (K_{232}), and conjugated trienes (K_{270}). While the maximum limits of K_{232} and K_{270} values have been determined for most oils, these values are limited to 2.60 and 0.20 for olive oil, respectively (Asensio et al. 2011, Benmoussa et al. 2016, Kasimoglu et al. 2018). For this reason, the K_{232} and K_{270} values are accepted as one of the leading indicators of oil degradation and oxidation. The present study presents the specific extinction values of AKO powders obtained from non-microencapsulated AKO and emulsions (control and mushroom by-products) in Table IV. The results revealed that the storage temperature, the storage time, and the application of microencapsulation

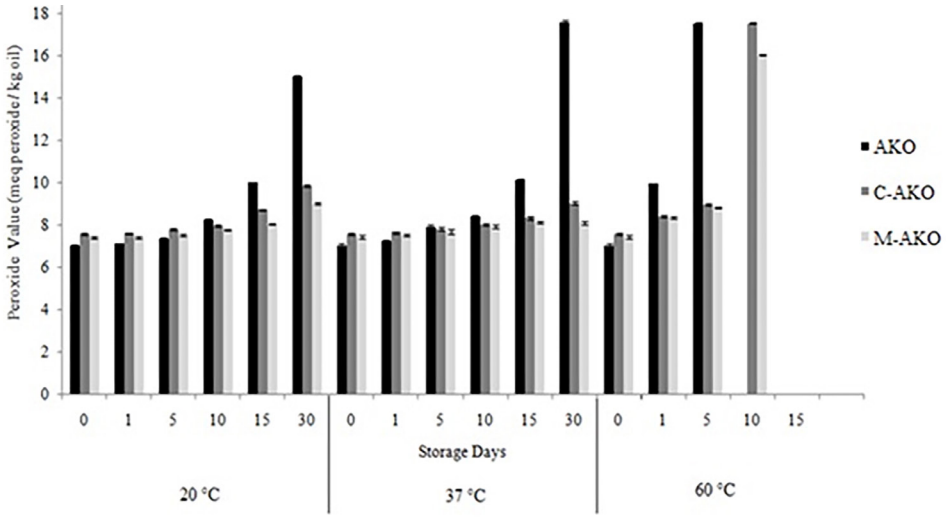

Figure 4. Peroxide values of AKO and AKO powders produced with control (C-AKO) and mushroom by-product (M-AKO) emulsions.

had a statistically significant (p<0.05) effect on the K_{232} and K_{270} values of AKO. As anticipated, the specific extinction values of AKO and AKO powders increased with increasing storage temperature and time. Indeed, the literature has previously reported that the specific extinction values increase with increasing storage time and temperature (Kasimoglu et al. 2018). While there were no significant differences in the specific extinction values of the samples stored at 20 °C, it was observed that the specific extinction values of the samples increased significantly when held at 60 °C. Similar to the POV, pAV, and Totox values, it was observed that mushroom by-products in AKO microencapsulation partially slowed the increase in specific extinction values. This condition was thought to be mainly because the mushroom by-products have antioxidant activity and some ergosterol. Umaña et al. (2021) reported that using mushroom by-products could partially slow down the formation of conjugated dienes.

CONCLUSIONS

This study used mushroom by-products to partially replace maltodextrin and entirely replace Tween 20 in the microencapsulation of AKO. The emulsions using mushroom by-products were more viscous than those using maltodextrin and exhibited high centrifugal (85.88 %) and kinetic (90.52 %) stability. It was determined that using mushroom by-products in the microencapsulation of AKO slowed the oxidation reactions due to the antioxidant activity of the mushroom by-products. AKO powders produced from an emulsion containing mushroom by-products exhibited better properties in all samples stored for one month at three different temperatures: 20 °C (room temperature), 37 °C (tropical temperature), and 60 °C (rapid oxidation test temperature). It was observed that oxidation progressed slowly in these powders. As a result, it has been revealed that mushroom by-products, a residual of (A. *bisporus*) mushroom processing that has not found widespread utilization, can be a potential substitute for synthetic emulsifiers in oil microencapsulation. It has

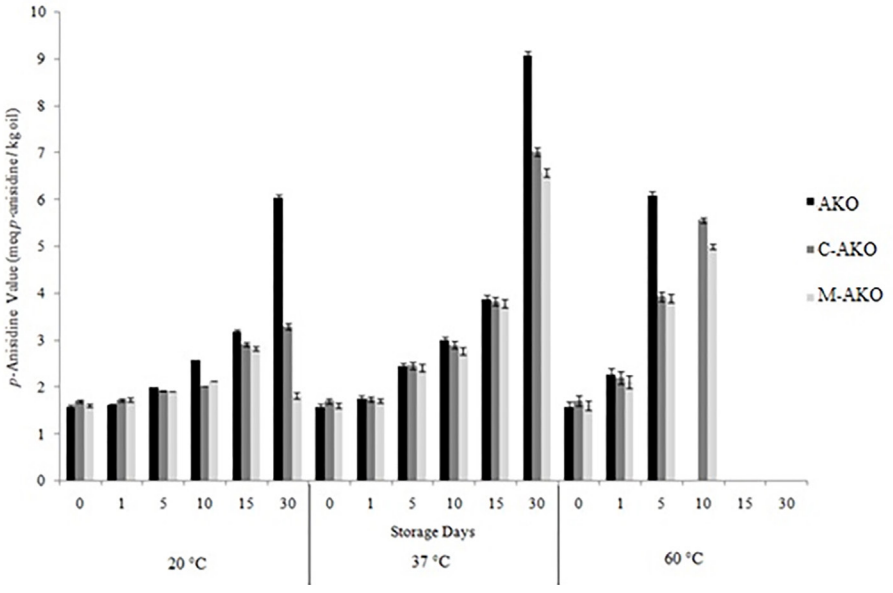

Figure 5. p-Anisidine values of AKO and AKO powders produced with control (C-AKO) and mushroom by-product (M-AKO) emulsions.

Table IV. Dien (K_{232}) and Trien (K_{270}) values of AKO and AKO powders.

		Dien (K_{232})			Trien (K_{270})		
T (°C)	**Days**	**AKO**	**C-AKO**	**M-AKO**	**AKO**	**C-AKO**	**M-AKO**
20 °C	0	1.43^{Ce}±0.03	1.45^{Ad}±0.02	1.44^{Bc}±0.04	0.02^{Be}±0.00	0.02^{Bd}±0.00	0.03^{Ad}±0.01
	1	1.46^{Bd}±0.04	1.47^{Ac}±0.01	1.47^{Ab}±0.00	0.04^{Ad}±0.01	0.03^{Bc}±0.01	0.04^{Ac}±0.00
	5	1.45^{Bd}±0.00	1.47^{Ac}±0.01	1.47^{Ab}±0.01	0.04^{Ad}±0.02	0.04^{Ac}±0.02	0.03^{Bd}±0.00
	10	1.48^{Ac}±0.01	1.48^{Ac}±0.00	1.48^{Ab}±0.02	0.06^{Ac}±0.01	0.05^{Bb}±0.02	0.04^{Cc}±0.01
	15	1.51^{Ab}±0.05	1.50^{Bb}±0.03	1.49^{Cb}±0.06	0.08^{Ab}±0.00	0.05^{Bb}±0.00	0.05^{Bb}±0.00
	30	1.61^{Aa}±0.03	1.54^{Ba}±0.04	1.52^{Ca}±0.06	0.10^{Aa}±0.02	0.08^{Ba}±0.00	0.07^{Ca}±0.02
37 °C	0	1.43^{Cf}±0.03	1.45^{Ae}±0.02	1.44^{Be}±0.04	0.02^{Bf}±0.00	0.02^{Be}±0.00	0.03^{Ad}±0.01
	1	1.47^{Ae}±0.01	1.47^{Ad}±0.04	1.47^{Ad}±0.00	0.06^{Ae}±0.02	0.04^{Bd}±0.00	0.04^{Bd}±0.02
	5	1.49^{Ad}±0.07	1.48^{Bd}±0.05	1.48^{Bd}±0.00	0.08^{Ad}±0.02	0.05^{Bd}±0.01	0.05^{Bc}±0.01
	10	1.53^{Ac}±0.04	1.50^{Bc}±0.00	1.50^{Bc}±0.00	0.10^{Ac}±0.01	0.08^{Bc}±0.01	0.07^{Cb}±0.01
	15	1.60^{Ab}±0.00	1.54^{Bb}±0.01	1.52^{Cb}±0.04	0.13^{Ab}±0.03	0.10^{Bb}±0.02	0.08^{Cb}±0.00
	30	1.74^{Aa}±0.01	1.60^{Ba}±0.00	1.57^{Ca}±0.03	0.17^{Aa}±0.02	0.14^{Ba}±0.03	0.11^{Ca}±0.01
60 °C	0	1.43^{Cf}±0.03	1.45^{Af}±0.02	1.44^{Bf}±0.04	0.02^{Bf}±0.00	0.02^{Bf}±0.00	0.03^{Af}±0.01
	1	1.58^{Ae}±0.03	1.50^{Be}±0.03	1.49^{Be}±0.05	0.07^{Ae}±0.00	0.05^{Be}±0.01	0.05^{Be}±0.00
	5	1.67^{Ad}±0.02	1.62^{Bd}±0.02	1.60^{Bd}±0.00	0.11^{Ad}±0.00	0.09^{Bd}±0.03	0.07^{Cd}±0.02
	10	1.76^{Ac}±0.00	1.70^{Bc}±0.01	1.68^{Cc}±0.01	0.17^{Ac}±0.01	0.13^{Bc}±0.02	0.10^{Cc}±0.03
	15	1.88^{Ab}±0.00	1.81^{Bb}±0.03	1.79^{Cb}±0.01	0.22^{Ab}±0.01	0.16^{Bb}±0.00	0.14^{Cb}±0.02
	30	2.01^{Aa}±0.05	1.93^{Ba}±0.04	1.90^{Ca}±0.03	0.30^{Aa}±0.03	0.21^{Ba}±0.00	0.19^{Ca}±0.01

Results are mean±standard error. * A–C Values in the same row at the same storage temperature with different letters are significantly different (p < 0.05). ** a–c Values in the same column with different letters are significantly different (p < 0.05). * AKO: Apricot kernel oil, C-AKO: AKO powder produced with control emulsion, M-AKO: AKO powder produced with mushroom by-product emulsion.**

also been determined that it can be blended and used with combined coating materials in oil microencapsulation. For this reason, it has been predicted that mushroom by-products, primarily composed of polysaccharides and proteins, could be used as a healthy alternative in the microencapsulation process. In future studies, testing the combinations of mushroom by-products with different coating materials, mixing ratios, and oils to be microencapsulated will expand the possibilities of using mushroom by-products.

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