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Refined palm oil fractions: Effect of skim milk powder and maltodextrin on emulsion properties and microencapsulation by spray drying

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ABSTRACT

The aim of this study was to investigate microencapsulation of palm oil fractions (palm olein (POL) and 90% palm olein+10% palm stearin (POS)) using skim milk powder (SMP) and maltodextrin (MD) by spray drying. Twenty-seven emulsions with POL were prepared to determine appropriate solid content (SC) and oil/coating material ratio (O/CM) of the emulsions to be fed into the spray dryer. Emulsion properties, such as viscosity and stability, were affected by SC and coating materials. The effects of coating materials used in microencapsulation of POL and POS were also tested by using different ratios of SMP and MD. The microencapsulation efficiency (69.28–84.97%), the microencapsulation yield (14.50–31.79%), and the peroxide value (4.12–7.07 meq O_2/kg oil) of the powders were affected by the coating materials (P < 0.05).

KEYWORDS

palm olein, palm stearin, microencapsulation efficiency, peroxide, viscosity

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1. INTRODUCTION

Palm oil (PO) is derived from the mesocarp of the palm fruit. One form is the liquid phase of PO, which is called palm olein (POL), and the second form is the solid phase of PO, which is called palm stearin (PS). These oils differ in terms of physicochemical properties such as fatty acid composition and melting point. PO is usually in solid form at room temperature due to having a melting temperature range of 32–40 °C (Mba et al., 2015; de Oliveira et al., 2015). It is melted by heating many times until arriving to its food industry destination. The heating process is an inevitable process in each step for the transportation of PO. When PO comes to Turkey, it must be refined in oil factories. After refining, it must be heated to move it from one tank to another. This heating process is repeated in the oil factory and during transfer to the transport tanker. As seen, the heating process is applied to PO several times until the final usage. These stages expose PO to oxygen during the transport processes. Because of lipid oxidation, the quality of PO is significantly reduced. PO needs to be protected against oxidation, for example by microencapsulation process (Tonon et al., 2011).

Since PO can be fractionated, its fatty acid composition varies depending on the fractionation process. In the literature, there are some studies on the microencapsulation of oil mixture (sunflower oil + palm oil) (Kelly et al., 2014) and crude palm oil (Rutz et al., 2017). However, it is not yet known, how fatty acid composition of the oil mixture and crude palm oil affect the emulsion properties and microencapsulation process. Refined PO is used in food industry as biscuit, cake, shortening, and margarine.

In the present study, refined PO fractions were microencapsulated by spray drying and using SMP and MD as coating materials. The use of SMP as coating material is unique for this treatment, since SMP is used together with PO in biscuit, cake, and cookie. The rheological properties of emulsions containing POL were determined. Microencapsulation yield, microencapsulation efficiency, peroxide value, moisture content, water activity, Carr index, and particle morphology of the powders were also evaluated.

2. MATERIALS AND METHODS

2.1. Materials

POL (C14:0, 1.01%; C16:0, 42.60%; C18:0, 4.51%; C18:1, 42.90%; C18:2, 8.98%) and PS (C14:0, 1.34%; C16:0, 65.88%; C18:0, 5.11%; C18:1, 23.66%; C18:2, 4.01%) were obtained from the Kücükbay Company (Izmir, Turkey). POS (C14:0, 1.05%; C16:0, 45.00%; C18:0, 4.56%; C18:1, 40.85%; C18:2, 8.54%) was prepared by the mixture of these oils (90% palm olein oil+10% palm stearin oil). SMP with 1% fat, provided by the Torku Company (Konya, Turkey), was used as a coating material. MD (DE 13-17), purchased from Sigma-Aldrich (Germany), was used as another coating material. Tween 20 (Merck, Germany) was used as emulsifier agent.

2.2. Emulsion preparation

The solid content (SC) and oil/coating material ratio (O/CM) of the emulsions to be fed into the spray dryer needed to be determined. Therefore, emulsions containing POL were prepared as indicated in Table 1. The emulsions were homogenised at 24,000 r.p.m. for 5 min.

Table 1. Solid content (SC) and oil/coating material (O/CM) ratio of emulsions with different coating material compositions (SMP – skim milk powder; MD – maltodextrin)

Emulsion number	SC (%)	O/CM	Coating materials SMP/MD
1	30	1/4	1/0
2	30	1/3	1/0
3	30	1/2	1/0
4	30	1/4	1/1
5	30	1/3	1/1
6	30	1/2	1/1
7	30	1/4	0/1
8	30	1/3	0/1
9	30	1/2	0/1
10	40	1/4	1/0
11	40	1/3	1/0
12	40	1/2	1/0
13	40	1/4	1/1
14	40	1/3	1/1
15	40	1/2	1/1
16	40	1/4	0/1
17	40	1/3	0/1
18	40	1/2	0/1
19	50	1/4	1/0
20	50	1/3	1/0
21	50	1/2	1/0
22	50	1/4	1/1
23	50	1/3	1/1
24	50	1/2	1/1
25	50	1/4	0/1
26	50	1/3	0/1
27	50	1/2	0/1

2.3. Emulsion analysis

2.3.1. Emulsion stability. After homogenisation, 10 mL aliquots of the emulsions were poured into a graduated cylindrical tube (15 mL), sealed with a plastic cap, and stored at 25 °C for 24 h. The emulsion separated into an upper layer (the cream) and bottom layer (the serum). The emulsion stability was expressed by ES% as Eq. (1) (Carneiro et al., 2013).

$$ES\,(\%) = \frac{\text{Upper phase height}}{\text{Emulsion inital height}}\,x\,100 \tag{1}$$

2.3.2. Emulsion viscosity. The emulsions containing POL were prepared as indicated in Table 1. Rheological parameters of the prepared emulsions were measured using a cylindrical type viscometer (Brookfield LVDV-II, USA). All measurements were performed at 25 °C. Shear rate, shear stress, % torque (T), and viscosity (cP) values were instantaneously recorded for each rotation speed (rpm).

Rheological models, Newtonian model (Eq. 2), Power law model (Eq. 3), Bingham model (Eq. 4), and Herschel–Bulkley model (Eq. 5), were studied to find the rheological model best fitting the experimental data. Apparent viscosity (μ_{app}) was calculated by using the power law model constants (Eq. 6).

$$\sigma = \eta \cdot \dot{\gamma} \tag{2}$$

$$\sigma = K \cdot (\dot{\gamma})^n \tag{3}$$

$$\sigma - \sigma_0 = K \cdot \dot{\gamma} \tag{4}$$

$$\sigma - \sigma_0 = K \cdot (\dot{\gamma})^n \tag{5}$$

$$\mu_{app} = K \cdot \dot{\gamma}^{n-1} \tag{6}$$

Where η is Newtonian viscosity (Pa.s), σ is the shear stress (Pa), $\dot{\gamma}$ is the shear rate (s^{-1}), K is the consistency coefficient ($Pa.s^n$), σ_0 is the yield stress (Pa), and n is the flow behaviour index (dimensionless).

2.4. Spray drying conditions and emulsion content

The emulsion was fed into a laboratory scale spray dryer (Buchi B-290, Switzerland) with a 2.8 mm nozzle atomiser. The SC and O/CM of the emulsions fed into the spray dryer were kept constant at 40% and 1/3, respectively. First the emulsions containing POL were prepared (Table 2). The emulsions' temperature was kept below 25 °C. Then the emulsions containing POS were prepared. The emulsions' temperature was kept below 35 °C in this treatment because of the high saturated fatty acid content of PS. Finally, the emulsions were fed into the spray dryer. Spray-drying processes were kept at constant at 8 mL min^{-1} feed rate, 600 L h^{-1} airflow rate, and 200 °C inlet temperature.

2.5. Analyses of microencapsulated oil powders

2.5.1. Microencapsulation efficiency (MEE). The total oil content was determined according to Domian and Wąsak (2008). The surface oil was determined according to Velasco et al. (2006). The MEE was calculated by Eq. (7) (Carneiro et al., 2013).

Table 2. Ratio of coating materials (SMP – skim milk powder; MD – maltodextrin) for the microencapsulation of palm olein oil (POL) and 90% palm olein oil+10% palm stearin oil (POS) emulsions by spray drying

Sample No	SMP/MD	Sample No	SMP/MD
POL1	1/0	POS1	1/0
POL2	3/1	POS2	3/1
POL3	1/1	POS3	1/1
POL4	1/3	POS4	1/3
POL5	0/1	POS5	0/1

$$MEE\,(\%) = \frac{Total\ \ oil - Surface\ \ oil}{Total\ \ oil} x\,100 \tag{7}$$

2.5.2. Microencapsulation yield (MEY). The MEY value was defined as the ratio of the powders collected in the collection vessel of the SC of the emulsion Eq. (8) (Kaushik et al., 2016).

$$MEY\,(\%) = \frac{Amount\ \ of\ \ microencapsulated\ \ powder}{Initial\ \ solid\ \ content\ \ of\ \ emulsion} x\,100 \tag{8}$$

2.5.3. Physicochemical analyses. Peroxide value (Cd 8-53, AOCS, 2005), colour properties, water activity (Başyiğit et al., 2020), and moisture content (Tatar and Kahyaoglu, 2014) of the powders were determined.

2.5.4. Scanning electron microscopy. The microstructural properties of the powders were observed using a scanning electron microscope (SEM) (Leo 404, England). Images of the powders were studied at 20 kV at 5,000× magnification.

2.5.5. Bulk density, tapped density, and carr index. Bulk density (ρ_b) was measured by dividing the mass of the powder by the volume occupied in the cylinder. The tapped density (ρ_t) was measured, then the cylinder was tapped by hand on a bench 180 times. The Carr index (CI) was calculated by Eq. (9) (Tatar and Kahyaoglu, 2014).

$$Carr\ \ index = \frac{Tapped\ \ density - Bulk\ \ density}{Tapped\ \ density} \tag{9}$$

2.6. Statistical analysis

Results were statistically evaluated by SPSS version 22.0 (IBM SPSS Inc. Chicago, USA). One-way variance analysis was used, and significant differences were determined by the Duncan multiple difference test. Significance was set at $P = 0.05$.

3. RESULTS AND DISCUSSION

3.1. Emulsion characterisation

3.1.1. Emulsion stability. There was no phase separation in the eighteen emulsions with SMP (Table 3). The emulsions containing only MD had phase separation and the emulsion stability values of these emulsions changed from 42 to 90%. It was thought to be caused by the poor emulsifying properties of MD. A similar finding has been reported by Shamaei et al. (2017), no phase separation was observed in the emulsions containing walnut oil with SMP, SMP+Tween 80, and SMP+MD. It was obvious that SMP possessed emulsifying properties. It is known that emulsion stability has an effect on microcapsules (Koç et al., 2015).

3.1.2. Emulsion viscosity. The emulsion viscosity decreased with high oil and low SC ratios (Table 3). It is generally known that emulsion viscosity is decreased by an increasing oil ratio in

Table 3. Rheological parameters for palm olein oil (POL) emulsions prepared with maltodextrin (MD) and skim milk powder (SMP)

Emulsion number	T_0 (Pa)	K (Pa.s^n)	n	R^2	CI (%)
1**	0	0.0054	1.0578	0.9927	n.d.
2***	0.1098	0.0053	1.5111	0.9970	n.d.
3**	0	0.0053	0.7406	0.9905	n.d.
4**	0	0.0058	0.7118	0.9985	n.d.
5**	0	0.0058	0.9520	0.9943	n.d.
6*	0.2538	0.0056	1	0.9925	n.d.
7***	0.2421	0.0077	1.2509	0.9980	90.56 ± 0.78
8***	0.1436	0.0071	1.2381	0.9905	88.59 ± 0.49
9*	0.0887	0.0065	1	0.9820	85.80 ± 1.70
10***	0.1853	0.0206	0.9820	0.9995	n.d.
11**	0	0.0184	0.8387	0.9973	n.d.
12***	0.3150	0.0172	1.0492	1.0000	n.d.
13***	0.0747	0.0206	0.7839	0.9995	n.d.
14***	0.1765	0.0186	1.0484	0.9990	n.d.
15***	0.3390	0.0164	0.9285	0.9997	n.d.
16**	0	0.0223	0.7646	0.9980	73.80 ± 0.65
17**	0	0.0215	0.7307	0.9973	71.98 ± 1.39
18***	0.2217	0.0215	0.8820	1.0000	68.98 ± 1.22
19***	0.1425	0.0793	0.8390	1.0000	n.d.
20**	0	0.0666	0.7688	0.9990	n.d.
21**	0	0.0388	1.1163	0.9980	n.d.
22**	0	0.1095	0.4918	0.9973	n.d.
23**	0	0.1063	0.4823	0.9953	n.d.
24***	0.8845	0.1082	0.7361	0.9990	n.d.
25**	0	0.1184	0.4701	1.0000	46.67 ± 1.34
26**	0	0.1133	0.4769	0.9930	44.46 ± 0.95
27***	1.0075	0.1293	0.6150	0.9990	42.43 ± 0.88

*Bingham flow model; **Exponential flow model; ***Herschel-Bulkley flow model; n.d.: not detected.

the emulsion (Tonon et al., 2012). In the present study, the viscosities of the emulsions containing only SMP were found lower than those containing only MD. Similar results were obtained by Bae and Lee (2008) during preparation of emulsion containing avocado oil, MD, and whey protein isolate. This is probably due to the fact that MD has some viscosity properties of starch.

3.2. Microcapsule characterisation

3.2.1. Microencapsulation efficiency (MEE). The powders for both microencapsulated POL (palm olein oil) (MEPOL) and microencapsulated POS (90% palm olein oil+10% palm stearin oil) (MEPOS) were produced by a spray dryer. The highest surface oil content and the lowest MEE of the powders were determined in MEPOL5 and MEPOS5 (without SMP) (Tables 4 and 5). Shamaei et al. (2017) found that the MEE of powders containing only SMP were significantly

Table 4. Total oil, surface oil, microencapsulation efficiency (MEE), microencapsulation yield (MEY), peroxide values (PV), colour values, moisture content, water activity, bulk density, tapped density, and Carr index for MEPOL samples

Sample No	Total oil (%)	Surface oil (%)	MEE (%)	MEY (%)	PV (meq O_2 kg^{-1})	*L**	*a**	*b**	Moisture content (%)	Water activity	Bulk density (g cm^{-3})	Tapped density (g cm^{-3})	Carr index
MEPOL1	23.44 ± 0.76^{b}	3.68 ± 0.21^{a}	84.32 ± 0.37^{b}	31.79 ± 2.11^{c}	4.12 ± 0.40^{a}	93.48 ± 1.28^{a}	-1.68 ± 0.05^{a}	10.84 ± 0.40^{e}	0.46 ± 0.12^{ab}	0.14 ± 0.00^{d}	0.28 ± 0.01^{a}	0.55 ± 0.04^{b}	0.49 ± 0.04^{c}
MEPOL2	22.32 ± 0.67^{ab}	3.35 ± 0.27^{a}	84.97 ± 1.37^{b}	29.20 ± 2.29^{bc}	4.46 ± 0.19^{ab}	93.46 ± 0.66^{a}	-1.4 ± 0.04^{b}	9.71 ± 0.31^{d}	0.45 ± 0.06^{ab}	0.12 ± 0.00^{a}	0.26 ± 0.00^{a}	0.47 ± 0.01^{a}	0.44 ± 0.01^{b}
MEPOL3	23.04 ± 1.52^{b}	3.51 ± 0.31^{a}	84.80 ± 0.43^{b}	30.84 ± 4.29^{c}	4.22 ± 0.22^{a}	93.54 ± 0.57^{a}	-1.26 ± 0.04^{c}	8.48 ± 0.12^{c}	0.40 ± 0.07^{ab}	0.13 ± 0.00^{b}	0.26 ± 0.02^{a}	0.45 ± 0.00^{a}	0.41 ± 0.03^{ab}
MEPOL4	20.94 ± 0.83^{a}	3.46 ± 0.44^{a}	83.48 ± 1.96^{b}	24.05 ± 2.94^{b}	4.89 ± 0.17^{bc}	93.97 ± 0.37^{a}	-0.90 ± 0.04^{d}	6.48 ± 0.31^{b}	0.38 ± 0.07^{a}	0.13 ± 0.00^{c}	0.27 ± 0.00^{a}	0.43 ± 0.01^{a}	0.38 ± 0.01^{a}
MEPOL5	22.97 ± 1.02^{b}	6.53 ± 0.15^{b}	71.54 ± 1.39^{a}	15.75 ± 2.95^{a}	5.05 ± 0.41^{c}	92.99 ± 0.31^{a}	-0.48 ± 0.03^{e}	3.83 ± 0.11^{a}	0.56 ± 0.08^{b}	0.13 ± 0.00^{b}	0.28 ± 0.00^{a}	0.44 ± 0.01^{a}	0.36 ± 0.03^{a}

[a, b, c, d, e] Different letters in the same column indicate significant difference at $P < 0.05$. MEPOS: microencapsulated POL (palm olein oil) powders. SMP: skim milk powder, MD: maltodextrin. MEPOL1 (1/0), MEPOL2 (3/1), MEPOL3 (1/1), MEPOL4 (1/3) and MEPOL5 (0/1); SMP/MD ratio as coating material.

Table 5. Total oil, surface oil, microencapsulation efficiency (MEE), microencapsulation yield (MEY), peroxide values (PV), colour values, moisture content, water activity, bulk density, tapped density, and Carr index for MEPOS powders

No	Total oil (%)	Surface oil (%)	MEE (%)	MEY (%)	PV (meq O_2 kg^{-1})	L^*	a^*	b^*	Moisture content (%)	Water activity	Bulk density (g cm^{-3})	Tapped density (g cm^{-3})	Carr index
MEPOS1	23.18 ± 0.92^{ab}	3.64 ± 0.26^{a}	84.28 ± 1.23^{c}	29.60 ± 1.26^{c}	6.07 ± 0.33^{a}	93.61 ± 0.14^{a}	−1.64 ± 0.04^{a}	13.56 ± 0.44^{e}	0.50 ± 0.13^{a}	0.14 ± 0.01^{a}	0.31 ± 0.01^{a}	0.51 ± 0.03^{b}	0.40 ± 0.02^{ab}
MEPOS2	24.15 ± 0.11^{b}	3.67 ± 0.35^{a}	84.82 ± 1.48^{c}	31.26 ± 2.02^{c}	6.04 ± 0.14^{a}	93.72 ± 0.62^{a}	−1.35 ± 0.03^{b}	10.71 ± 0.14^{d}	0.50 ± 0.15^{a}	0.13 ± 0.01^{a}	0.29 ± 0.01^{a}	0.45 ± 0.00^{a}	0.35 ± 0.02^{a}
MEPOS3	22.45 ± 1.20^{a}	3.99 ± 0.73^{a}	82.22 ± 3.01^{c}	29.68 ± 0.50^{c}	6.22 ± 0.52^{a}	94.51 ± 0.47^{bc}	−1.32 ± 0.04^{b}	8.22 ± 0.39^{c}	0.61 ± 0.06^{a}	0.14 ± 0.01^{ab}	0.28 ± 0.01^{a}	0.49 ± 0.04^{ab}	0.42 ± 0.04^{b}
MEPOS4	21.73 ± 0.60^{a}	5.66 ± 0.04^{b}	73.92 ± 0.62^{b}	19.35 ± 2.97^{b}	6.69 ± 0.37^{b}	94.13 ± 0.38^{ab}	−0.95 ± 0.01^{c}	7.19 ± 0.14^{b}	0.65 ± 0.11^{a}	0.15 ± 0.01^{b}	0.30 ± 0.03^{a}	0.49 ± 0.02^{ab}	0.38 ± 0.04^{ab}
MEPOS5	24.09 ± 0.95^{b}	7.40 ± 0.33^{c}	69.28 ± 1.10^{a}	14.50 ± 2.64^{a}	7.07 ± 0.13^{b}	94.81 ± 0.44^{c}	−0.53 ± 0.02^{d}	3.85 ± 0.13^{a}	0.50 ± 0.14^{a}	0.17 ± 0.01^{c}	0.30 ± 0.00^{a}	0.48 ± 0.01^{ab}	0.36 ± 0.01^{ab}

$^{a, b, c, d, e}$ Different letters in the same column indicate significant difference at $P < 0.05$. MEPOS: microencapsulated POS (90% palm olein oil+10% palm stearin oil) powders. SMP: skim milk powder, MD: maltodextrin. MEPOS1 (1/0), MEPOS2 (3/1), MEPOS3 (1/1), MEPOS4 (1/3) and MEPOS5 (0/1); SMP/MD ratio as coating material.

higher than those of powders containing SMP+MD ($P < 0.05$). The same researchers said that SMP as coating material was also very effective in the microencapsulation of walnut oil. These results are similar to the data in our study. Protein ratio decreases when the MD ratio increases in the emulsion, so the elasticity of the droplet surface of the powders may be reduced. With decreasing of elasticity on the droplet surface, the development of cracks and breaks in the membrane may cause oil leakage to the surface of the particles (see Figs 1 and 2). It is argued that lactose in SMP could have a positive effect on MEE. Lactose as a hydrophilic property significantly limited the diffusion of hydrophobic oil through the shell, therefore leading to high MEE values (Aghbashlo et al., 2013; Shamaei et al., 2017).

When the emulsion feed is stable, the MEE of powders will be high (Tonon et al., 2012; Carneiro et al., 2013). Looking at the results of emulsion stability (see Table 3), no phase separation was observed in the emulsions containing SMP. It is clearly showing that the emulsions to be fed into spray dryer influenced the final product.

3.2.2. Microencapsulation yield (MEY). High SMP ratio in the emulsion enhanced the MEY of the powders (14–31%). A possible reason may be that the surface oil values of the powders containing SMP were significantly lower than those without SMP. It is argued that the powders with high surface oil values adhere more to the interior surface of the drying cabinet, resulting in lower MEY. Close results (35–52%) were found by Kaushik et al. (2016) for microencapsulated flaxseed oil powders by spray drying. The same authors stated that the MEY decreased due to the increase in the surface oil ratio.

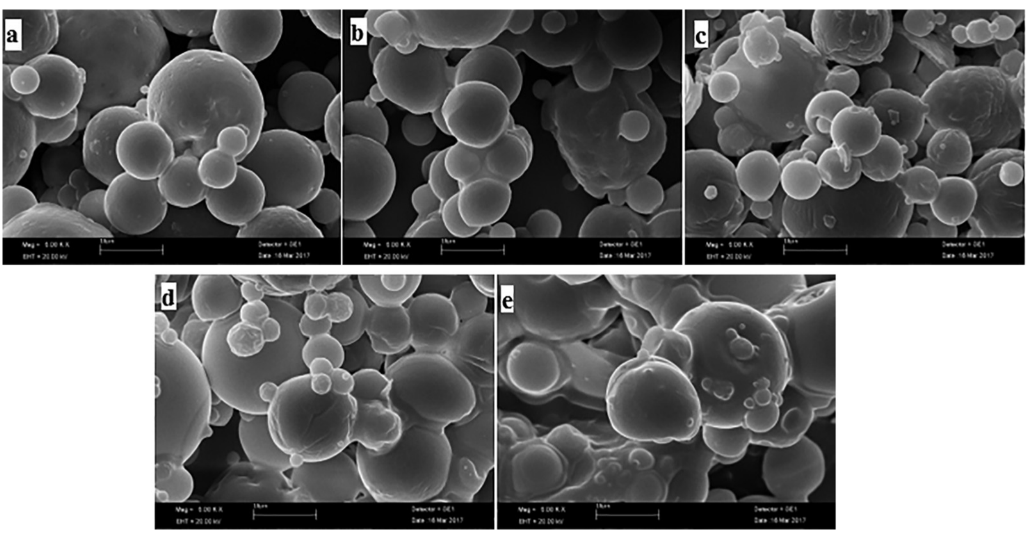

Fig. 1. Scanning electron microscope images of MEPOL powders (5,000 × zoom): a - MEPOL1, b - MEPOL2, c - MEPOL3, d - MEPOL4, e - MEPOL5. MEPOL: microencapsulated POL (palm olein oil) powders. SMP: skim milk powder, MD: maltodextrin. MEPOL1 (1/0), MEPOL2 (3/1), MEPOL3 (1/1), MEPOL4 (1/3) and MEPOL5 (0/1); SMP/MD ratio as coating material.

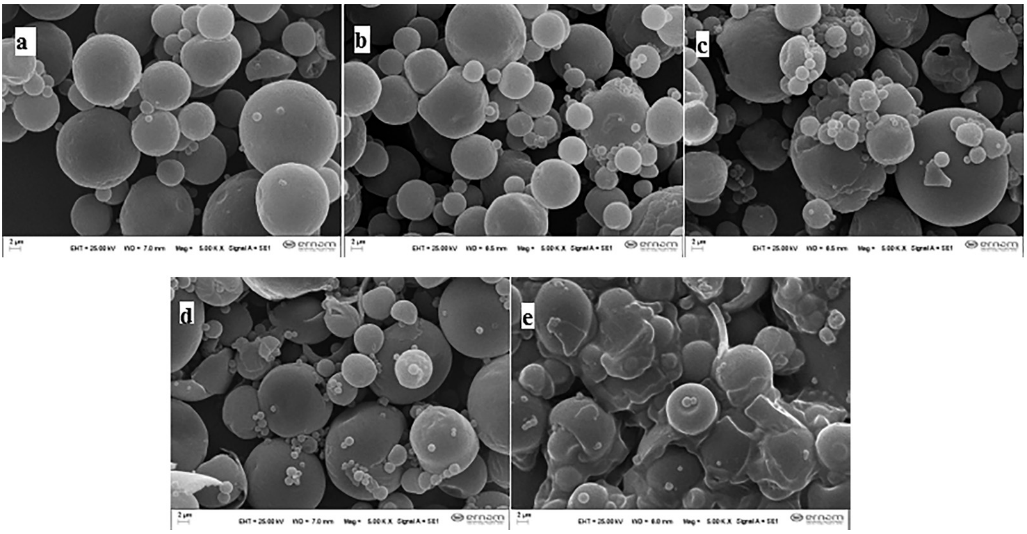

Fig. 2. Scanning electron microscope images of MEPOS powders (5,000 × zoom): a - MEPOS1, b - MEPOS2, c - MEPOS3, d - MEPOS4, e - MEPOS5. MEPOS: microencapsulated POS (90% palm olein oil+10% palm stearin oil) powders. SMP: skim milk powder, MD: maltodextrin. MEPOS1 (1/0), MEPOS2 (3/1), MEPOS3 (1/1), MEPOS4 (1/3) and MEPOS5 (0/1); SMP/MD ratio as coating material.

3.2.3. Peroxide value. The coating materials had significant effect on the PV of powders ($P < 0.05$) (Tables 4 and 5). The PV was positively affected by the increase of SMP ratio in the powders. Koç et al. (2015) reported that the PV of microencapsulated extra virgin olive oil powder was significantly influenced by coating material combination (MD and whey protein isolate). Aghbashlo et al. (2012) also reported that the PV of microencapsulated fish oil powder with only SMP was significantly higher than the PV of microencapsulated fish oil powder with 70% SMP+30% MD ($P < 0.05$). In the present study, PV appeared to be associated with surface oil. The residual oil (surface oil) of powders during drying is in direct contact with the oxygen of drying air. Because of this, the powders with high surface oil contents and low MEE values were also with high PV ($P < 0.05$).

3.2.4. Colour analyses, moisture content, water activity. As the SMP ratio decreased in the emulsion, L^* of MEPOS powders was affected ($P < 0.05$), but those of MEPOL powders were not ($P > 0.05$) (Table 4 and 5). Depending on the ratio of SMP/MD in the emulsion, a^* and b^* of powders were affected ($P < 0.05$). The powders became yellower as the SMP ratio increased in the emulsion.

The moisture content and the water activity values for the powders are given in Tables 4 and 5. The moisture content values of the powders were not generally affected by the composition of the coating material. In the present study, the moisture values of the powders were very low, because the inlet air temperature was very high (200 °C). Bae and Lee (2008) reported no effect of the coating material on the moisture content. The water activity values of MEPOL and MEPOS were determined as 0.12 to 0.17. The water activity values of the powders were low in accordance with the moisture content of powders.

3.2.5. Scanning electron microscope powder (SEM). The particle structures of MEPOL and MEPOS are shown in Figs 1 and 2. The particle structures of powders were significantly affected by coating materials. The particle structures of the powders with only SMP (MEPOL1 and MEPOS1) showed smooth surface with no breaks. However, the particle structures of the powders containing only MD (without SMP) showed more cracks and fissures. It is argued that this may contribute to diffusion of oil droplets to the powders' surface, because the surface oil values of the powders containing SMP were higher than those with only MD (without SMP).

Shamaei et al. (2017) reported that microencapsulated walnut oil powders containing SMP and SMP+Tween 80 had no cracks, agglomeration, or pores. It is argued that the surface oil could be associated with agglomeration, as agglomeration could be seen in the powders with high surface oil contents.

3.2.6. Bulk density, tapped density, Carr index. Bulk density values for MEPOL and MEPOS were from 0.26 to 0.31 ($g\,cm^{-3}$), and those were not significantly affected by the coating material ($P > 0.05$). As drying process temperature was fixed at constant 200 °C, similar moisture content and bulk density values of the powders were obtained ($P > 0.05$). Shamaei et al. (2017) reported that bulk density values of the powders with walnut oil+SMP and walnut oil+SMP+MD were found to be between 0.29 and 0.37 ($g\ cm^{-3}$). These results are close to our results. Carr indices were found from 0.35 to 0.49, and there were significant differences. The lowest Carr index was found in the powders containing only MD (without SMP) ($P < 0.05$). MD positively affected the flowability of powders.

4. CONCLUSIONS

In the present study, microencapsulation of refined palm oil fractions was successfully performed using SMP and MD as the coating material. The coating materials had significant effect on the powders. The highest MEE and MEY were found in powders without MD. The surface oil value and the PV of powders decreased with increasing SMP ratio in coating material. Furthermore, it is observed that no emulsions containing SMP showed phase separation. SMP could be a highly efficient, inexpensive, and easily accessible coating material for microencapsulation processes. Besides, SMP and refined palm oil fractions are widely used in food products such as cake, biscuit, and margarine. These ingredients (SMP and palm oil fractions) are separately used in production process. Microencapsulated oil powder (SMP + palm oil fractions) obtained by microencapsulation process of palm oil fractions using SMP can be used as a single product. It is argued that it will provide ease of use in food industry.

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