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Effect of pre-emulsified sesame oil on physical-chemical and rheological properties of pork batters

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Abstract

Physical-chemical and rheological properties of pork batters as affected by replacing pork back-fat with pre-emulsified sesame oil were investigated. Replacement of pork back-fat with pre-emulsified sesame oil, improved L* value, moisture and protein content, hardness, cohesiveness, and chewiness, declined a* value, fat content and energy, but not affect cooking yield. When used pre-emulsified sesame oil to replace pork back-fat 50%, the sample had the highest L* value and texture. According to the results of dynamic rheological, replaced pork back-fat by pre-emulsified sesame oil increased the storage modulus (G') values at 80 °C, and formed firm gel. The result of Low-field nuclear magnetic resonance (LF-NMR) shown that the batters with pre-emulsified sesame oil had higher water holding capacity than the control. Overall, the batters with pre-emulsified sesame oil enabled lowering of fat and energy contents, making the pork batter had better texture.

Keywords: pre-emulsified sesame oil; physical-chemical properties; pork; dynamic rheological; LF-NMR.

Practical Application: The batters with pre-emulsified sesame oil should be adopted for lowering of fat and energy contents in meat processing industry.

1 Introduction

Emulsion meat products are a type of frequently consumed meat products, they have enjoy widely consumer acceptance in certain sections of the global population (Delgado-Pando et al., 2010). Tradition emulsion meat products had high animal fat (> 25%), that is related with an increased risk of cardiovascular disease (Jeon et al., 2015; McNeill & Van Elswyk, 2012), some cancers risk (Ferguson, 2010). For declining the animal fat content of emulsion meat products, some studies have demonstrated the possible utilization of food materials, such as food hydrocolloids (Wu & Lin, 2011; Hsu & Chung, 2001), different type plant oils (Hsu & Yu, 2002), fiber (Zhuang et al., 2016), and non-meat proteins (Youssef & Barbut, 2011). Compared with various technological methods for replacement of animal fat, pre-emulsion technology has been reported to be useful as a means of stabilizing the non-meat fats used for incorporation in meat matrix (Jimenez-Colmenero, 2007). Some studies have been reported that replacement pork back-fat by different pre-emulsified plants oil in emulsion meat products (Delgado-Pando et al., 2011; Youssef et al., 2011; Salcedo-Sandoval et al., 2013).

Sesame oil having a characteristic flavour is very popular as a source of health oils in many Asian and European countries and widely used in food industry (Sowmya et al., 2009). It has high polyunsaturated fat content, abound lignans compounds and α-tocopherol. The fatty acid composition includes 43% oleic and linoleic each, 9% palmitic fatty acids, and 4% stearic. Sesame oil intake is related with a decreased risk of hypertensive and cardiovascular disease (Wu et al., 2009a), partial adhesive small bowel obstruction (Hsu et al., 2016), cypermethrin induced brain toxicity (Hussien et al., 2013), and it has positive effects on type 2 diabetes mellitus (Sankar et al., 2011), cough in children (Saab et al., 2006). On the other hand, sesame oil has beneficial effects on anticancer (Salerno & Smith, 1991), anti-inflammatory and antibacterial (Hsu et al., 2008). But few researchers reported that used pre-emulsified sesame oil to product lower fat emulsion meat products. The aim of this work was thus to evaluate the physical-chemical and rheological properties of pork batters, which produced by the beating process with 1% NaCl, as affected by substituting pork back-fat by pre-emulsified sesame oil.

2 Materials and methods

2.1 Preparation of pre-emulsified sesame oil

Sesame oil (Kerry Grain and Oil (Shenzhen) co., Ltd, China) was purchased from a local market (Nianjing, China). Soy protein isolated (91.50% protein) was provided by Linyi Shansong Biological Products Co., Ltd (China). Preparation of pre-emulsified sesame oil was based on the procedure of Hoogenkamp (1989). Briefly, the ratio of soy protein isolate: sesame oil: water was 1: 16: 16, respectively. Water was heated to 60~65 °C and homogenized with the soy protein isolate in a homogenizer (Omnimixer, Omni International, INC, USA). The mixture was cooled to 5 °C and placed in a chilled bowl cutter (2 °C) (StephanUMC-5C, Germany). After homogenizing for 1 min, the sesame oil was added slowly while homogenization

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continued. Finally, the mixture was homogenized for an additional 3 min and poured into double plastic (nylon/PE) bags. These were stored at 2 ± 2 °C overnight before product manufacture.

2.2 Preparation of pork batters

Fresh post-rigor pork leg meat (20.47%, 7.14%, 71.18% protein, fat and moisture contents respectively) and back-fat (1.68%, 8.30%, 89.82% protein, moisture and fat contents respectively, Association of Official Agricultural Chemists, 2000) were obtained from a local market (Nanjing, China). All visible connective tissue and fat were trimmed from the meat. The meat and fat were separately mixed and passed through a grinder (MM-12, Guangdong, China) fitted a plate having 6 mm diameter holes. The ground meat (1.0 kg each) was packaged in double plastic (nylon/PE) bags and store -20 °C until use within 2 weeks. The batters of T1 was prepared with pork meat 1000 g, back-fat 250 g, sodium tripolyphosphate 4 g, salt 12.5 g; T2 was prepared with pork meat 1000 g, backfat 125 g, pre-emulsified sesame oil 125 g, sodium tripolyphosphate 4 g, salt 12.5 g; T3 was prepared with pork meat 1000 g, pre-emulsified sesame oil 250 g, sodium tripolyphosphate 4 g, salt 12.5 g. Pork meat were thawed (overnight at 4 °C) prior to use. The thawed ground meat was processed using a beating machine (MC-6, Shandong, China) according to the processing below (Kang et al., 2014a): the meat was beaten with salt and sodium tripolyphosphate for 10 min (200 rpm), followed by addition of pork back-fat and/or pre-emulsified sesame oil, and mixed (200 rpm) to a batter for 5 min (final temperature less than 10 °C). Then the prepared meat batter was shaped into meatballs of 30 mm diameter, and cooked for 80 °C water for 20 min and cooled to room temperature, packed in laminated film (Nylon/PE) bags and storage at -20 °C. The processing conditions used were equivalent to those of a commercial operation.

2.3 Proximate analysis

Moisture and ash contents were determined according to the Association of Official Analytical Chemists methods (Association of Official Agricultural Chemists, 2000). Protein content was estimated by multiplying by 6.25 the total Kjeldahl nitrogen, an automatic digestion system (Kjelect-TM, Danish) was used. Total fat content was determined by Sohxlet extraction with diethylether. Each product was analyzed in representative triplicate samples. The energy content of the meatballs were determined based on 17 kJ/g for protein, 37 kJ/g for fat, and 16 kJ/g for carbohydrate.

2.4 Color measurement

The color of each raw and cooked batter was measured using a Minolta chromameter (CR-40, Minolta Camera Co., Japan), calibrated with a white plate (L*, 97.75, a*, 0.08, b*, 1.49). A mean of eight measurements was taken for each L* value (lightness), a* value (redness), b* value (yellowness).

2.5 Cooking yieldP

Cooking yields were calculated using the Formula 1:

$$\textit{Cooking yield}\% = \frac{\text{Wight of batter after cooking}}{\text{Wight of batter before cooking}} \times 100 \quad (1)$$

2.6 Texture profile analysis (TPA)

After cooling at 2 °C overnight, the cooked batters were stay at room temperature for 2 h. The TPA attributes of the cooked batters was determined using a texture analyzer (TA-XT. plus, Stable Micro system Ltd., Surry, UK). The conditions were as follows: test speed 2.0 mm/s, strain 50% and trigger force 5 g. The cooked batters were cut in two to obtain a 20 mm depth, 25 mm diameter strip. The cylinder probe (P/50, 50 mm stainless cylinder) of the texture analyzer mould was used. Attributes were calculated as follows: Values for hardness, springiness, cohesiveness, and chewiness was determined as described by Bourne (1978).

2.7 Dynamic rheological measurement

Dynamic rheological studies were performed on a MCR301 dynamic rheometer (Auton. Paar. Ltd, Austria). A 50 mm parallel steel plate geometry with a 0.5 mm gap was used. The raw batter was placed between the flat parallel plates with its perimeter coated with a thin layer of silicone oil to prevent dehydration. Samples were heated at a rate 2 °C/min from 20 °C to 80 °C. During this heating process, the sample was continuously sheared in an oscillatory mode at a fixed frequency of 0.1 Hz. Changes of the storage modulus (G') was measured during the heating. Each sample was measured in triplicate.

2.8 LF-NMR measurements

NMR relaxation measurements were performed according to the method of Han et al. with slight modification. Approximately 2 g of the cooked batter was placed in a 15 mm glass tube and inserted in the NMR probe of a PQ001 Niumag Pulsed NMR analyzer (Niumag Electric Corporation, Shanghai, China). The analyzer was operated at resonance frequency of 22.6 MHz at 32 °C. Spin-spin relaxation time (T_2) was measured using the Carr–Purcell–Meiboom–Gill sequence. T2 was measured made a τ-value of 350 μs. Data from 10,000 echoes were acquired as 32 scan repetitions. The repetition time between subsequent scans was 8000 ms. Post processing of NMR T2 data distributed exponential fitting of CPMG (Carr-Purcell-Meiboom-Gill) decay curves were performed by Multi-Exp Inv Analysis software (Niumag Electric Corp., Shanghai, China). Each measurement was performed at least triplicate.

2.9 Statistical analysis

The experiment was designed with four replications. The data was analyzed using the one-way ANOVA program. The difference between means was considered significant at $p < 0.05$. Significant differences between means were identified by the LSD procedure using the statistical software package SPSS v.18.0 (SPSS Inc., USA).

3 Result and discussion

3.1 Proximate composition

The proximate composition of the cooked batters formulated with various amounts of pork back-fat and pre-emulsified sesame oil are given in Table 1. Due to fat has more energy than protein and water at the same weight, the energy was decreased from 1009.08 kJ/100 g to 807.06 kJ/100 g with pre-emulsified sesame oil content increasing and total replaced pork back-fat by pre-emulsified sesame oil. There were differences significant ($p < 0.05$) in the moisture, fat and protein content of the different formulations. T3 had the highest moisture, protein content, and the lowest energy, fat content. T1 had the highest energy and fat content. The protein and moisture content increased with pre-emulsified sesame oil levels increasing, oppose to energy and fat content. Jimenez-Colmenero et al. (2010) reported when pork back-fat was totally replaced by oil-in-water emulsion, the moisture and protein content increased, and the energy and fat content declined. It was due to the different proximate composition between pork back-fat and oil-in-water emulsion. Lurueña-Martínez et al. (2004) showed that reduced fat levels together with olive oil increasing moisture in the beef low-fat frankfurters. Josquin et al. (2012) found that replacement of animal fat with pre-emulsified fish oil could increase moisture and protein content and lower total fat content. Muguerza et al. (2001) reported that partial replacement of pork back-fat with pre-emulsified olive oil resulted in a reduction of total added fat, and protein content only showed a significant increase firstly noticed from sausage with 25% of substitution as a consequence of the addition of soy protein isolate. The ash content was similar as samples at the same salt level. This was agreed with Paneras & Bloukas (1994) who found vegetable oil replaced pork back fat in low-fat frankfurters ware no significant difference in ash contents.

3.2 Colour

The color parameters of the raw and cooked batters formulated with various ratios of pork back-fat and pre-emulsified sesame oil are presented in Table 2. There were significant ($p < 0.05$) differences in L* value, a* value and b* value of the raw and cooked batters which containing the different contents of pre-emulsified sesame oil. The highest L* value was found in raw and cooked batters for formulation the samples which contained pre-emulsified sesame oil. The result was observed by Cáceres et al. (2008) who used pre-emulsified fish oil replaced pork fat in bologna-type sausages. In contrast, the treatments which contained pre-emulsified sesame oil had lower a*-value than T1. Hsu & Yu (2002) found that decreasing fat addition level and adding water generally decreased meatballs' red and yellow color. This might be due to decreasing the concentration of the myoglobin by adding pre-emulsified sesame oil to the low-fat treatments and much smaller sesame oil globules which reflect lighter than the larger pork back-fat fat globules. Similar results reported by Youssef & Barbut (2011), when used pre-emulsified olive oil with soy protein isolate partly replaced beef fat in the comminuted beef meat emulsions had higher L* value and lower a*-value. Bishop et al. (1993) also showed that increased pre-emulsified corn oil contents in bologna resulted in higher L* value compared to low fat bologna. López-López et al. (2009) found that the replacement of the pork back-fat by olive oil reduced a*-value of the frankfurters. The b* value of raw batters with pre-emulsified sesame oil were lower than T1, and all cooked batters had similar b* value. The similar result was found in the low-fat frankfurters prepared by partial replacement of pork back-fat with olive oil-in-water emulsion (Salcedo-Sandoval et al., 2013).

3.3 Cooking yield

Replacement of pork back-fat by pre-emulsified sesame oil had no effected ($p > 0.05$) on cooking yield in the different batters (Table 2). Due to T2 and T3 had higher moisture content, the result indicated the samples made with the different pre-emulsified sesame oil content presented good water and fat binding properties, and had good thermal behaviour. Jimenez-Colmenero et al. (2010) reported that used emulsified olive oil with soy protein isolate replaced pork back-fat in frankfurters and control had same cooking loss. When sesame oil was pre-emulsified by soy protein isolate it actually helped to stabilize the products and

Table 1. Proximate analysis (%) and cooking yield (%) of pork batters made with various amounts of pork back-fat and pre-emulsified sesame oil.

Sample	Energy (kJ/100g)	Protein (%)	Fat (%)	Moisture (%)	Ash (%)	Cooking yield (%)
T1	1009.39 ± 10.32[a]	14.59 ± 0.21[c]	19.28 ± 0.05[a]	59.63 ± 0.42[c]	1.90 ± 0.02[a]	99.81 ± 0.51[a]
T2	911.34 ± 11.05[b]	15.33 ± 0.06[b]	16.29 ± 0.09[b]	62.67 ± 0.26[b]	1.92 ± 0.02[a]	99.84 ± 0.19[a]
T3	807.06 ± 12.12[c]	15.70 ± 0.06[a]	13.30 ± 0.05[c]	64.27 ± 0.29[a]	1.91 ± 0.01[a]	99.99 ± 0.26[a]

Each value represents the mean ± standard deviation. T1: 100% pork back-fat; T2: 50% pre-emulsified sesame oil and 50% pork back-fat; T3: 100% pre-emulsified sesame oil; [a-c]Different parameter superscripts in the same column indicate significant differences ($p < 0.05$).

Table 2. Effect on color (L*, a*, b* value) of raw and cooked pork batters made with various amounts of pork back-fat and pre-emulsified sesame oil.

Sample	Raw batters			Cooked batters		
	L* value	a* value	b* value	L* value	a* value	b* value
T1	57.83 ± 1.79[c]	13.24 ± 0.82[a]	7.74 ± 0.55[c]	68.63 ± 0.98[c]	4.64 ± 0.48[a]	8.22 ± 0.39[c]
T2	70.12 ± 1.02[a]	11.47 ± 0.90[b]	11.18 ± 0.45[a]	72.54 ± 0.56[a]	3.69 ± 0.36[b]	8.67 ± 0.24[b]
T3	70.54 ± 0.62[a]	10.76 ± 0.46[c]	11.46 ± 0.32[a]	73.67 ± 0.84[a]	3.28 ± 0.37[c]	8.94 ± 0.23[a]

Each value represents the mean ± standard deviation. T1: 100% pork back-fat; T2: 50% pre-emulsified sesame oil and 50% pork back-fat; T3: 100% pre-emulsified sesame oil; [a-c]Different parameter superscripts in the same column indicate significant differences ($p < 0.05$).

resulted in lower cooking loss. Because of different processing and formulations, Su et al. (2000) reported that used pre-emulsified fat as pork back-fat replacement in low-fat frankfurters could improve cooking yield.

3.4 TPA

Textural properties of cooked batters were affected by replacement of pork back-fat with pre-emulsified sesame oil in the formulation (Table 3). All the TPA parameter of T1 was lower ($p < 0.05$) than T2 and T3. The cooked batters added pre-emulsified sesame oil replaced pork back-fat had higher hardness, springiness, cohesiveness and chewiness. Bloukas et al. (1997) reported that incorporation of pre-emulsified olive oil with soy protein isolate in fermented sausage, resulted in harder texture than the control. Park et al. (1989) showed that hardness, cohesiveness, and chewiness values were higher in low-fat sausages made with high-oleic sunflower oil than in regular beef fat (30%) frankfurters. In the present study, the results were agreement with Youssef & Barbut (2011), who reported that replacing beef fat with pre-emulsified canola oil significantly increased hardness values, when pre-emulsified canola oil contents were 10% and 17.5%, and the treatment of 17.5% pre-emulsified canola oil contents had a better texture than the 10%. T2 had the best texture, which due to the higher emulsifying capacity of soy protein isolate, add pre-emulsified sesame oil could decrease meat protein use to encapsulate fat, so had more meat protein used in meat matrix and formed good texture. Soy protein isolate also could better interact with the meat proteins during heating process and enhanced the gel (Ramirez-Suárez & Xiong, 2003). T3 had lower texture than T2, it was probably that added over 50% pre-emulsified sesame oil increased the moisture of cooked batters, thus formed soft texture. The results indicated that pre-emulsified sesame oil contents were the major factor affecting meatballs texture.

3.5 Dynamic rheological measurement

The effects of pre-emulsified sesame oil on raw meat batters the changes in G' during the heating process were determined (Figure 1). T1 had typical dynamic rheological curve of raw pork batters (Kang et al., 2014b). When heated from 20 °C to 41 °C, G' decreased slowly, and then at a slightly increase from 41 °C to 50 °C, because the meat protein denaturation occurred, and gelation at 45-50 °C was initiated after protein-protein interaction had taken place (Xiong & Brekke; 1990). Due to the denaturation of the myosin tails, and this changes could disruption of the protein network that had previously formed at lower temperatures, G' had a moderate decline from 53 °C to 56 °C (Wu et al., 2009b; Álvarez et al., 2012). This was immediately followed by a phase where a rapid increase in G' occurred as the temperature approached 80 °C, because of the transformation of the viscous sol into an elastic gel network (Álvarez, 2012). T2 and T3 had similar heating curves, there also involved three phases during the heating process. In the first phase, G' exhibited a slightly decrease as the temperature increased from 20 °C to 42 °C, then G' exhibited a slightly increase as the temperature increased from 43 °C to 52 °C. In the second phase, because of the denaturation of the myosin tails, G' showed a slightly decrease as the temperature increased from 53 °C to 55 °C. A rapid increase in G' occurred at approximately 56 °C as the temperature approached 80 °C. G' of T2 (21.97 KPa) had higher than T1 (19.81 KPa) and T3 (20.57 KPa), indicated T2 had a denser protein network and better texture (Table 3) (Sun et al., 2012).

3.6 LF-NMR measurement

Table 4 shows the distribution of NMR T_2 measurements after multi-exponential fitting of cooked pork batters. T_{2b} is assigned to water tightly associated to protein and macromolecular constituents, and represents about 1-4% of the total water in the meat system, the relaxation population centered at approximately 0-10 ms (Allais et al., 2004). T_{21} is a major component and considered to intra-myofibrillar water and water within the protein structure, T_{22} was possibly corresponds to extra-myofibrillar water. There are centered at approximately 30-60 ms, 100-400 ms, respectively (Li et al., 2012; Sánchez-Alonso et al., 2012). In the T1, the initial relaxation times of T_{2b} were quicker ($p < 0.05$) than T2 and T3, the result indicated that pork batters made with various amounts of

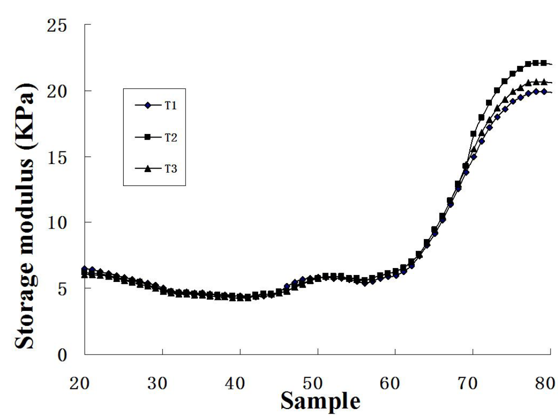

Figure 1. Changes in dynamic storage modulus (G', KPa) with temperature (*T*, °C) for each of pork batters made with various amounts of pork back-fat and pre-emulsified sesame oil.

Table 3. Texture profile analysis of pork batters made with various amounts of pork back-fat and pre-emulsified sesame oil.

Sample	Hardness (N)	Springiness	Adhesiveness	Chewiness (N mm)
T1	65.06 ± 0.55^c	0.903 ± 0.002^c	0.711 ± 0.002^c	41.82 ± 0.48^b
T2	68.20 ± 1.35^a	0.933 ± 0.003^a	0.752 ± 0.003^a	45.58 ± 1.05^a
T3	67.76 ± 1.02^b	0.925 ± 0.005^b	0.729 ± 0.005^b	46.34 ± 1.14^a

Each value represents the mean ± standard deviation. T1: 100% pork back-fat; T2: 50% pre-emulsified sesame oil and 50% pork back-fat; T3: 100% pre-emulsified sesame oil; $^{a-c}$Different parameter superscripts in the same column indicate significant differences ($p < 0.05$).

Table 4. Effect on relaxation time (ms) and peak ration (%) of of pork batters made with various amounts of pork back-fat and pre-emulsified sesame oil.

Sample	Relaxation time			Peak ration (%)		
	T_{2b} (ms)	T_{21} (ms)	T_{22} (ms)	T_{2b} (%)	T_{21} (%)	T_{22} (%)
T1	0.57 ± 0.05^{c}	60.32 ± 1.51^{b}	329.31 ± 10.12^{a}	4.33 ± 0.3^{2a}	86.67 ± 0.52^{c}	9.35 ± 0.20^{a}
T2	0.76 ± 0.03^{b}	68.25 ± 1.48^{a}	295.18 ± 11.05^{b}	2.93 ± 0.28^{b}	88.21 ± 0.60^{b}	8.87 ± 0.18^{b}
T3	0.89 ± 0.04^{a}	69.47 ± 1.64^{a}	262.44 ± 10.85^{c}	2.05 ± 0.31^{c}	89.81 ± 0.56^{a}	8.03 ± 0.22^{c}

Each value represents the mean ± standard deviation. T1: 100% pork back-fat; T2: 50% pre-emulsified sesame oil and 50% pork back-fat; T3: 100% pre-emulsified sesame oil; $^{a-c}$Different parameter superscripts in the same column indicate significant differences ($p < 0.05$).

pork back-fat and pre-emulsified sesame oil produced different effects of the meat protein (Kang et al., 2016). The initial relaxation times of T_{21} in T2 and T3 were quicker than T1, indicated T2 and T3 had better gel network than T1. Because of soy protein isolate had excellent gelling and structuring behaviour, the batters which contented pre-emulsified sesame oil had better texture (Berghout et al., 2015). Han et al. (2009) reported the pork gels with various amounts of microbial transglutaminase had quicker initial relaxation times of T_2, because the changes of fast relaxing protein and slowly relaxing water protons. The results also were accordance with the changes of texture (Table 3) and dynamic rheological (Figure 1). The initial relaxation times of T_{22} in T2 and T3 were quicker, which indicated T2 and T3 had less water out the cooked batters with pre-emulsified sesame oil (Ruiz-Cabrera et al., 2004). T1 had the smallest peak ration (%) of T_{2b} and T_{22}, and had the largest peak ration (%) of T_{21}, and T3 had the smallest peak ration (%) of T_{21}, and had the largest peak ration (%) of T_{2b} and T_{22}, one reason was that added pre-emulsified sesame oil could improve protein content, and cause the water which tightly associated to protein and macromolecular constituents decreased. The other reason was when oil/fat is pre-emulsified with a non-meat protein, more meat proteins can become available for gel formation of the meat matrix (Wu et al., 2011). Due to T3 had the greatest peak ration (%) of T_{21} and the highest moisture content in cooked batter (Table 1), the texture was lowered. Therefore, the used of LF-NMR could determine water holding capacity, and other physical-chemistry properties in the emulsion meat products.

4 Conclusion

The study showed that the use of pre-emulsified sesame oil replacement pork back-fat significantly influenced the Physical-chemical and rheological properties of pork batters. Replacement of pork back-fat by pre-emulsified sesame oil was not effect on ($p > 0.05$) cooking yield, and improved lightness, texture and protein content, decreased redness, fat content, and energy of cooked batters. The sample replaced pork back-fat with 50% pre-emulsified sesame oil (T2) had higher L*-values and TPA than the 100%. T2 also had the highest G' value at 80 °C, implied had a better texture. The results of LF-NMR indicated that used the LF-NMR could determine the physical-chemistry properties in the pork cooked batters. The results showed that by adding pre-emulsified sesame oil it was possible to produce low fat meat batter and having desired qualities.

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