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Improved physicochemical properties of pork patty supplemented with oil-in-water nanoemulsion

Abstract

This study aimed to investigate the effect of nanoemulsion on the physicochemical and sensory characteristics of pork patty to improve texture for elderly members of the population. Hence, we prepared pork patties supplemented with different of liquid materials: water; oil and water; oil, water, and surfactants; and nanoemulsion. The emulsion itself was characterized and the physicochemical properties of the pork patties, including pH, water content, cooking loss, thawing loss, liquid holding capacity, color, and texture, were analyzed. The size of NEM was 165.70±9.32 nm and NEM had high ζ-potential value indicating that it is stable. NEM patties had the lowest cooking and thawing losses, and the highest liquid retention, all of which affected the tenderness of the patties. Color of the patty was also affected by the addition of NEM. The highest lightness and yellowness and the lowest redness were observed (p<0.05). NEM patties had the lowest values for all texture attributes indicating improved tenderness. Our results demonstrate that NEM has positive effects on pork patties and can help to tenderize food products designed for the elderly. With further study, NEM could be a candidate tenderization agent in the meat industry.

Keywords: nanoemulsion, pork patty, tenderness

Introduction

Restructured meat products such as patties and sausages are an important part of both the meat product and fast-food industries. Recently, the demand for healthier meat and processed meat products has increased (Hoffman and Mellett, 2003; Baek et al., 2016; Ahn et al., 2019). An excessive intake of animal fat can cause cardiovascular disease, high cholesterol, obesity, and chronic diseases (Hur et al., 2008; Serdaroğlu et al., 2017). However, fat is an important factor in enhancing stability, improving flavor and sensory parameters such as texture, viscosity, juiciness, and mouth feel of various meat products (Hur et al., 2008). Therefore, two strategies have contributed to develop novel supplementation approaches to improve these qualities in pork patty products while reducing animal fat content (Choi et al., 2012; Jung and Joo, 2013). The first strategy has employed various vegetable oils to meat products. Liu et al. (1991) reported that ground beef patties prepared with hydrogenated corn or palm oil had similar values for factors affecting overall acceptability to patties produced using beef fat, including low cooking loss, and they were eventually deemed an acceptable beef fat substitution. However, meat products supplemented with only alternative vegetable oils revealed the reduced elasticity resulting in the impaired texture, and the added oil accelerated oxidation within the product resulting in a reduction in shelf life and a loss of nutritional property (Paglarinia et al., 2019). The second strategy has used different types of emulsions to meat products. Kim et al. (2018) reported that reduced-fat chicken patties supplemented with an emulsion containing 10% collagen and 10% wheat sprout fiber exhibited improved quality characteristics such as pH, yellowness, protein solubility, and overall acceptability. When oil-in-water emulsion was applied to meat products as a fat substitute, it improved the lipid composition, water retention, oxidation stability and sensory characteristics of meat products (Alejandre et al., 2016; Alejandre et al., 2017; Paglarini et al., 2018; Robert et al., 2019). Therefore, this study focused on applying the oil-in-water emulsion strategy to develop restructured pork patty.

In the food technology industry, micro and nanoemulsions can be used to reduce fat consumption, enhance organoleptic and physicochemical qualities, and provide healthier essential oil alternatives (Giametti et al., 2015). Oil-in-water emulsions include an oil phase within the water phase and surfactants to improve emulsion stability (McClements et al., 2007). In this study, canola oil emulsion was prepared with tween 80 and lecithin which were used as surfactants. Canola oil has lower values of saturated fatty acid and linolenic acid than other conventional vegetable oils, and has a positive effect on reduced fat level with restoring textural properties in comminuted meat products prepared with reduced fat levels (Giese, 1996; Youssef and Barbut, 2009). Appropriate choice of surfactant is important in producing successful stable emulsion over a variety range of external conditions (Kim et al., 2017). Tween 80 and lecithin are nature origin and nontoxic, and have been widely used in food and pharmaceutical industries (Gosenca et al., 2013; Riehm et al., 2017). In addition, usage of both tween 80 and lecithin is known to contribute to improving the emulsion stability (Gosenca et al., 2013; Riehm et al., 2017).

Nanoemulsions generally have very small particle sizes, in the range of 20-200 nm, and generate a suitable and stable carrier system as a result of their high surface area and free energy (Gharehbeglou et al., 2019). There have been relatively few studies that compare the physicochemical properties of micro and nanoemulsions in the generation of pork patties.

According to WHO (2019) reports, the elderly people, over 80 years old, is the fastest growing section of the population with the number of people in this age range expected to triple, from 143 million to 426 million, by 2050. The elderly people start to have three major eating disorders such as mastication, swallowing, and digestion disorders. This means that the texture of food products is important in elderly people who have dietary limitations (Nishinari, 2009) as increases in texture attributes such as hardness, chewiness, and gumminess can result in people being reluctant to eat these foods (Kohyama et al., 2002). Funami (2016) reported that digestion of food and absorption of mineral and nutrients from food is enhanced by modifications in their textural properties. Therefore, the improvement of texture is a major challenge in producing food for elderly populations, especially where they have developed various eating dysfunctions.

Thus, this study aimed to evaluate the effect of using a nanoemulsion in the production of tendered pork patty without the quality deterioration. To this end, we evaluated the physicochemical properties and sensory attributes of pork patties supplemented with our nanoemulsion.

Materials and Methods

Materials

Fresh ground ham (hind leg) and canola oil (Sajo Haepyo, Seoul, Korea) were purchased from a local market. Tween® 80, a nonionic and aliphatic surfactant derived from oleic acid, was purchased form Daejung (Siheung, Korea). Lecithin, from soybean, was purchased from Samchun (Pyongtack, Korea). Sodium chloride was purchased from Daejung (Siheung, Korea). Phosphotungstic acid was purchased from Hayashi Pure Chemical Industry (Osaka, Japan).

Preparation and properties of nanoemulsion

Oil-in-water nanoemulsions (NEM) were prepared by mixing 70 g aqueous solution (3.5% tween 80) and 30 g canola oil solution (1% lecithin) with a high-speed homogenizer (IKAT25 digital ULTRA-TURRAX®, Staufen, Germany) at 15,000 rpm for 3 min. To prepare the nanoemulsion (NEM), emulsion mixture was homogenized using a high-pressure homogenizer (microfluidizer; MN400, Micronox, Inc., Seongnam, Korea) up to 3 times at a pressure of 150 MPa (22,000 psi) in order to reduce droplet size and polydispersity index (PdI). After emulsions were diluted approximately 1:100 with distilled water. The droplet size and ζ-potential were measured using a Zetasizer (Nano ZS90; Malvern Ins., Worcestershire, UK).

Transmission electron microscopy (TEM)

The morphology of each emulsion was imaged using a TEM (JEM-1010; Jeol Ltd., Tokyo, Japan) operated at 63 kV. Samples were diluted approximately 1:200 with distilled water and 10 μL of this diluted sample was placed on a copper grid. After 30 s, any excess solution was removed, and the grid was dried in the desiccator at ambient temperature before loading on the microscope.

Preparation of pork patties

The pork patties were prepared as indicated in Table 1. Ground meat, salt, and five different sources of liquid were mixed a mixer (Model 5K5SS; Kitchen aid, St. Joseph, MI, USA) for 3 min. These mixtures were then cut into 95 g of pieces and placed in the metallic mold (d, 9.5 cm; h, 1 cm) to form. After pork patties were formed, they were cooked in an oven at 180 ℃ for 12 min (until core temperature reached 70 ℃). Pork patties were then cooled to room temperature, and their physicochemical properties were analyzed.

pH and water content measurement

To measure the pH, pork patties (5 g) were homogenized with distilled water (45 mL) for 1 min. The pH values were then measured on a pH meter (S-220, Mettler Toledo Co., Zurich, Switzerland). Each reading was performed in triplicate for each sample. Water content of the patties was determined using the heating/drying method (AOAC, 2012). Samples were weighed and dried at 105 ℃ using a dry-oven (OF-105; Daihan Scientific Co., Ltd., Wonju, Korea) until they reached a constant weight. Water content was then calculated using the following formula:

$$\text{Water content (\%)} = [(W_1 - W_2)/ W_1] \times 100$$

where W_1 and W_1 are the initial and final weights of samples, respectively.

Cooking loss

Each patty was weighed before and after cooking and the cooking loss was calculated using the following formula:

$$\text{Cooking loss (\%)} = [(W_1 - W_2)/ W_1] \times 100$$

where W_1 and W_2 is the weight of before and after cooking, respectively.

Thawing loss

Pork patty samples were frozen (24 h, -18 ℃) and the thawing was completed when the internal temperature of the samples reached 25 ℃. Thawing loss of each pork patty was measured as the difference between the initial weight (before freezing) and the final weight (after thawing) and was expressed as a percentage.

$$\text{Thawing loss (\%)} = [(W_1 - W_2)/ W_1] \times 100$$

where W_1 and W_2 is the weight of patty before freezing and after thawing, respectively.

Liquid holding capacity (LHC)

The ability of pork patty product to retain moisture was evaluated using the Choi et al. (2018) method with minor modifications. Briefly, approximately 1 g of minced pork patty was placed in a 15 mL centrifuge tube and centrifuged at 3,000 ×*g* for 10 min at 4 ℃. The LHC was then calculated using the following formula:

$$\text{LHC (\%)} = (L_2/L_1) \times 100$$

where L_1 is initial weight of the sample, and L_2 is the weight of the sample after centrifugation.

Color profile analysis

Color values for each of the different pork patties were measured using a color reader (CR-10; Konica Minolta Sensing Inc., Tokyo, Japan) calibrated using a white standard plate (L*, lightness, 97.83; a*, redness, 0.43; b*, yellowness, 1.98). The instrument was placed on different sections of the pork patty surface during analysis.

Texture profile analysis (TPA)

TPA was measured using a texture analyzer (CT3; Brookfield Engineering Laboratories, Stoughton, MA, USA). Samples (1 × 1 × 1 cm) were taken and compressed to 50% of their original height at 1 mm/s and 100 g trigger pressure using a circular plate probe (TA4/1000; 38.1 mm in diameter). Force and time curves were then used to calculate hardness, adhesiveness, cohesiveness, springiness, gumminess, and chewiness.

Sensory evaluation

A twelve-member sensory panel was selected and trained. Pork patties from each treatment were cooked and cut into 2 × 2 × 1 cm pieces. The sample order was randomized, and samples were evaluated for the intensity and preference of color, meat flavor, tenderness, springiness, juiciness, compactness, fattiness and overall acceptability, using a 7-point scale (7=intensity or like extremely; 1=weakness or dislike extremely). This study was approved by the institutional review board (IRB) at Konkuk University (IRB approval number: 7001355-201905-HR-310).

Statistical analysis

All experimental values were measured in at least triplicate and results are presented as mean ± standard deviation. Means within groups were compared using one-way ANOVA followed by Duncan's multiple range test (p<0.05). Theses statistical analysis was performed using SPSS 20.0 software (SPSS, 2011). Principal component analysis (PCA) was performed using XLSTAT (ver. 2016.02.28540; Addinsoft, New York, NY, USA).

Results and Discussion

Emulsion properties

NEM was characterized before use as a supplement in the pork patty (Table 2). The particle size for NEM was 165.70±9.32 nm. This was consistent with the TEM image taken to allow visual characterization of the emulsion, each packed with Tween 80 and lecithin in a monolayer at the oil-water interface (Fig. 1). TEM image revealed that spheres in the emulsions were relatively evenly distributed, and the diameters for these spheres in NEM were nano ranged. ζ-potential of NEM was -29.17±0.45 mV. Emulsion with an ζ-potential value 30 mV have an energy barrier, caused by repulsive force, which prevents coagulation (Miller and Abbott, 2012). Thus, less than -30.00 mV or greater than +30.00 mV is generally considered as the basic criterion for the assess of emulsion stability (Jo et al., 2015). Since ζ-potential of NEM produced in this study was close to 30.00 mV, NEM could be considered stable. PdI value ≤0.30 is considered to be acceptable and indicates a mono-distribution of emulsion suspension, while the value >0.30 indicates a poly-distribution suspension (Du et al., 2014). Since PdI value of NEM was 0.26±0.03, these results suggested that NEM tended to form uniform particles. The L*, a*, and b* values of NEM were 87.58±0.14, -1.53±0.01, and 2.89±0.01, respectively. The L* value of NEM was high. This result is seemed to be caused by white color of NEM and the small particle size, which affects the light scattering properties of the emulsion (McClements and Rao, 2011).

pH and water content of pork patties

pH and water content of pork patties supplemented with different liquids was analyzed (Table 3). Pork patties supplemented with nanoemulsion (6.72±0.01) showed higher pH values compared to other patties, while the OWS patty (emulsion control) showed the lowest pH value (6.63±0.01, $p<0.05$). However, pH values of all pork patties were similar, even though there were significant differences among the values. No trend of pH changes was shown among all patties, regarding the effects of surfactant and emulsion. Different pHs in each sample was seemed to be directly caused by different pork patties themselves.

As expected, the W patty had a significantly higher moisture retention value, 71.57±0.63%, than the other samples which showed similar values ($p<0.05$). This result is probably because W patties had 30% more water than the other patties which all had similar moisture retention values (63.20-63.75%).

Cooking and thawing loss measurements of pork patties

Cooking and thawing loss values for the pork patties are recorded in Table 3. Of all the samples, the NEM patty had the lowest cooking loss value, whereas the OWS patties had the highest value at 32.51±6.39% ($p>0.05$). When we compared the W and OW patties, we observed a slight reduction in cooking loss values for the OW patties. This result was consistent with a previous study, where a meat analog supplemented with MCT oil showed a 50% reduction in cooking loss when compared with the same meat analog supplemented with water (Kim et al., 2019). In the comparison of the OW and OWS patties, a significant increase in cooking loss value for the OWS patty was observed which was caused by surfactants added to the patty ($p<0.05$). This result could be explained that the phosphorus ionic group of the hydrophilic group in lecithin maybe strongly attracted the water molecules, resulting in exposure and collection of free water. Then, this embedded water by lecithin could be easily released during cooking process. Whereas, the NEM patty had lower cooking loss values, 12.17±0.86%, than the OWS patties (emulsion control, 32.51±6.39%), the nanoemulsion seemed to have a positive effect on the cooking loss value. This result can be hypothesized that the nanosized and uniformed nanoemulsions can surround the inherent water inside pork such as "Pickering" formation during blending in the patty protein matrix, resulting in being stable against thermal process (Sharma et al., 2015). It was attributed that the hydrophilic head group of lecithin layer of nanoemulsion might be combined to the inherent water in pork or the added water.

In the thawing loss analysis, pork patties supplemented with the nanoemulsion showed lower thawing loss values than other patties. NEM patties had significantly lower thawing loss values than OWS patties (emulsion control) which had the highest loss values out of all the samples ($p<0.05$). This result was seemed to be caused by the stable NEM holding water during the freezing process. When we compared water and oil effects, there were no significant differences between W and OW patties. In the comparison of the OW and OWS patties, a slight increase in thawing loss value for the OWS patty was observed which was caused by surfactants added to the patty ($p>0.05$) as previously mentioned.

Liquid holding capacity

In this study, LHC was used as a measure of total water and oil content lost from the pork patty. NEM patty (79.70±1.10%, $p<0.05$) showed higher liquid retention than OWS patty (emulsion control, 66.82±0.63%). When we compared W and OW patties, the OW patty had significantly higher liquid retention (75.52±1.02%) than the W patty (69.92±1.43%, $p<0.05$). This result was consistent with a previous study that a meat analog added with MCT oil revealed a 21.9% increment in cooking loss, compared with the same meat analog added with water (Kim et al., 2019). The NEM patty had the highest retention values 79.70±1.10% ($p<0.05$), which possibly indicates a positive effect on the tenderness of the pork patties. Lee et al. (2008) reported that the loss of water holding capacity of the muscle caused toughening of texture due to muscle shrinking by moisture reduction. Cofrades et al. (2013) reported that binding of water and fat in post-rigor raw pork was improved as a result of the high thermal stability of their emulsion. Serdaroğlu et al. (2016) also demonstrated that emulsion improved the liquid retention capacity in post-rigor lean beef.

Color measurement

Color changes in the pork patties supplemented with the different liquids evaluated in this study are recorded in Table 4. NEM patty had the highest L* and b* values, 70.07±0.65 and 12.97±0.43 respectively, and the lowest a* value, 1.23±0.24. The highest L* and lowest a* values of NEM patty were seemed to be clearly caused by the white color of NEM used in the patty. OWS (61.06±0.63) patty showed significantly lower values compared to other patties ($p<0.05$) because of the high cooking losses in the samples, which lost a large amount of their liquid contents. Yellow-brownish lecithin and yellow tween 80 could be another reason for a decrease in L* value of OWS. In the a* measurement, W patty had the highest value (3.39±0.14, $p>0.05$), and this result was seemed be caused by colorless water added in the patty. NEM patty had the lowest a* value, 1.23±0.24, which was seemed to be clearly caused by the white color of NEM used in the patty. This result was consistent with a previous study that lean shoulder blade beef meat supplemented with pre-emulsified oil presented significantly reduced redness compared with the meat supplemented with canola oil (Youssef and Barbut, 2011). In the b* measurement, W patty had the significant lower value, 8.21±0.21 than OW patty (10.74±0.36, $p<0.05$), which contained light yellow canola oil. OW patty showed a significantly lower value, 10.65±0.30, compared to OWS patty (12.03±0.22, $p<0.05$). This result was seemed be caused by yellow-brownish lecithin and yellow tween 80 used in the patty as surfactants.

Texture profile analysis

Table 5. represents the texture profile analysis of pork patties supplemented with various liquids. Hardness analysis revealed that the patties supplemented with the nanoemulsion had lower value (5.24±0.32 g) than the other patties ($p<0.05$). OWS and NEM patties, which contain surfactants, have significantly lower hardness values than W and OW patties ($p<0.05$). Surfactants have the potential to influence the tenderness of pork patties. Xia et al. (2018) have reported that lecithin may weaken the cross-linking of proteins, resulting in decreasing texture value such as hardness. Texture parameters including cohesiveness, springiness, gumminess, and chewiness represented the lowest values for NEM patty and the highest values for OW patty, which was the same trend as the hardness ($p<0.05$). However, there was no statistically significant difference in the adhesiveness values from all patties. All texture parameters were lowest in the NEM patties, suggesting a positive effect on the tenderness of the pork patties.

Sensory evaluation

The sensory evaluation results were presented in Fig. 2. As expected, NEM patty showed the highest intensity values for tenderness, juiciness, meat flavor, and fattiness, while it showed the lowest intensity values for springiness and compactness. Kim et al. (2019) reported that meat analog mixed with emulsion as an animal fat substitute showed high tenderness and juiciness in sensory test. Pietrasik et al. (2013) have demonstrated that most consumers consider the tenderness of meat to be an important criterion for determining the quality and overall acceptability of meat. Intensity values of tenderness and juiciness in all patties were seemed to be caused by texture values of hardness and cooking loss respectively, and they were inversely proportional. Intensity values of springiness in all patties were related and proportional to texture values of springiness.

In the preference analysis, NEM patty presented the highest values of tenderness, juiciness, and overall acceptability which were preferred sensory attributes, while the values of pork patties were very close each other. Kim et al. (2019) also demonstrated that meat analog added with MCT oil emulsion revealed high overall acceptability. Especially, the results of intensity and preference analyses of NEM patty showed the same patterns in tenderness and juiciness. NEM and OW patties showed higher overall acceptability values than W and OWS patties, which was seemed to be related to high preference values of tenderness and juiciness. Other preference results didn’t show any noticeable pattern, however, OWS and W patties had the lowest values in all preference analyses.

Conclusion

In this study, we evaluated the application of nanoemulsion in pork patty to improve their suitability for the elderly. Oil-in-water emulsion prepared with canola oil (as lipid phase) presented good stability for use as a food ingredient in product reformulation. NEM affected the physicochemical properties (liquid binding properties, texture, color) of pork patty. This is the first result which suggests the feasibility of using NEM as a technological strategy for the development of elderly meat products. NEM was an effective additive in pork patties, showing textural advantages and judged acceptable by panels. Using these results, we could conclude that NEM can be used to manufacture acceptable food products for the elderly. This study also investigated the potential for improving organoleptic qualities such as tenderness and juiciness, in the pork patty industry.

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Table 1. Pork patty ingredients

	Ingredient percentages (%)						
	Meat	Water	Tween 80	Oil	Lecithin	Salt	Total
W[1)]	73.00	25.00	-	-	-	2.00	100.00
OW[2)]	73.00	17.50	-	7.50	-	2.00	100.00
OWS[3)]	73.00	16.90	0.60	6.80	0.70	2.00	100.00
NEM[4)]	73.00	16.90	0.60	6.80	0.70	2.00	100.00

Pork patties supplemented with different liquids: [1)] W, water; [2)] OW, oil and water; [3)] OWS, oil (1% lecithin) and water (3.5% tween 80); [4)] NEM, nanoemulsion, oil (1% lecithin) and water (3.5% tween 80), which were processed using a high speed homogenizer and microfluidizer.

Table 2. Characterization of NEM

	NEM[1]
Particle size (nm)	165.70±9.32
ζ-potential (mV)	-29.17±0.45
PdI[2]	0.26±0.03
L*	87.58±0.14
a*	-1.53±0.01
b*	2.89±0.01

[1] NEM, nanoemulsion; [2] PdI, polydispersity index, L*, lightness; a*, redness; b*, yellowness.

Table 3. Physicochemical analysis of pork patties supplemented with various liquids

	pH	Water content (%)	Cooking loss (%)	Thawing loss (%)	Liquid holding capacity (%)
W[1)]	6.69 ± 0.01^{b}	71.57 ± 0.63^{a}	15.31 ± 2.00^{b}	1.02 ± 0.14^{ab}	69.92 ± 1.43^{c}
OW[2)]	6.67 ± 0.01^{c}	63.20 ± 2.96^{b}	12.46 ± 0.33^{b}	1.05 ± 0.15^{ab}	75.52 ± 1.02^{b}
OWS[3)]	6.63 ± 0.01^{d}	64.79 ± 0.87^{b}	32.51 ± 6.39^{a}	1.13 ± 0.24^{a}	66.82 ± 0.63^{d}
NEM[5)]	6.72 ± 0.01^{a}	63.75 ± 0.55^{b}	12.17 ± 0.86^{b}	0.75 ± 0.16^{b}	79.70 ± 1.10^{a}

Pork patties supplemented with different liquids: [1)] W, water; [2)] OW, oil and water; [3)] OWS, oil (1% lecithin) and water (3.5% tween 80); [4)] NEM, nanoemulsion, oil (1% lecithin) and water (3.5% tween 80), which were processed using high a speed homogenizer and microfluidizer. Table provides mean values ± standard deviation. $^{a-e}$ Values with different letters in a column are significantly different (p<0.05).

Table 4. Colorimetric analysis of pork patties supplemented with various liquids

	L*	a*	b*
W[1)]	64.23 ± 0.23^{b}	3.39 ± 0.14^{a}	8.21 ± 0.21^{d}
OW[2)]	63.16 ± 1.09^{b}	3.14 ± 0.15^{a}	10.74 ± 0.36^{c}
OWS[3)]	61.06 ± 0.63^{c}	2.12 ± 0.24^{b}	12.03 ± 0.22^{b}
NEM[5)]	70.07 ± 0.65^{a}	1.23 ± 0.24^{c}	12.74 ± 0.21^{a}

Pork patties supplemented with different liquids: [1)] W, water; [2)] OW, oil and water; [3)] OWS, oil (1% lecithin) and water (3.5% tween 80); [4)] NEM, nanoemulsion, oil (1% lecithin), and water (3.5% tween 80), which were processed using a high speed homogenizer and microfluidizer. Table presents mean values ± standard deviation. $^{a-d}$ Values with different letters in a column are significantly different (p<0.05).

Table 5. Texture analysis of pork patties supplemented with various liquids

	Hardness (N)	Adhesiveness (mJ)	Cohesiveness	Springiness (mm)	Gumminess (g)	Chewiness (mJ)
W[1)]	6.34 ± 0.37^{b}	0.17 ± 0.10^{a}	0.55 ± 0.02^{b}	2.55 ± 0.11^{bc}	356.00 ± 27.14^{b}	8.94 ± 1.01^{c}
OW[2)]	7.70 ± 0.41^{a}	0.14 ± 0.09^{a}	0.70 ± 0.02^{a}	3.05 ± 0.07^{a}	553.78 ± 26.93^{a}	16.54 ± 0.97^{a}
OWS[3)]	5.89 ± 0.21^{c}	0.17 ± 0.05^{a}	0.69 ± 0.07^{a}	2.89 ± 0.43^{ab}	418.00 ± 57.92^{b}	12.05 ± 3.77^{b}
NEM[5)]	5.24 ± 0.32^{d}	0.06 ± 0.06^{a}	0.54 ± 0.26^{b}	2.12 ± 0.89^{c}	285.50 ± 136.91^{c}	6.80 ± 4.40^{cd}

Pork patties supplemented with different liquids: [1)] W, water; [2)] OW, oil and water; [3)] OWS, oil (1% lecithin) and water (3.5% tween 80); [4)] NEM, nanoemulsion, oil (1% lecithin), and water (3.5% tween 80), which were processed using a high speed homogenizer and microfluidizer. Table presents mean values ± standard deviation. $^{a-d}$ Values with different letters in the same column are significantly different (p<0.05).

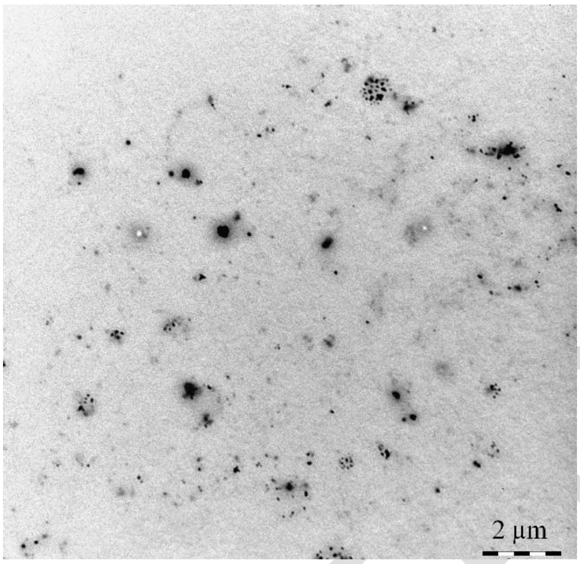


Fig 1. Transmission electron microscopy image of nanoemulsions at 10,000 × magnification. Scale bar is 2 µm.

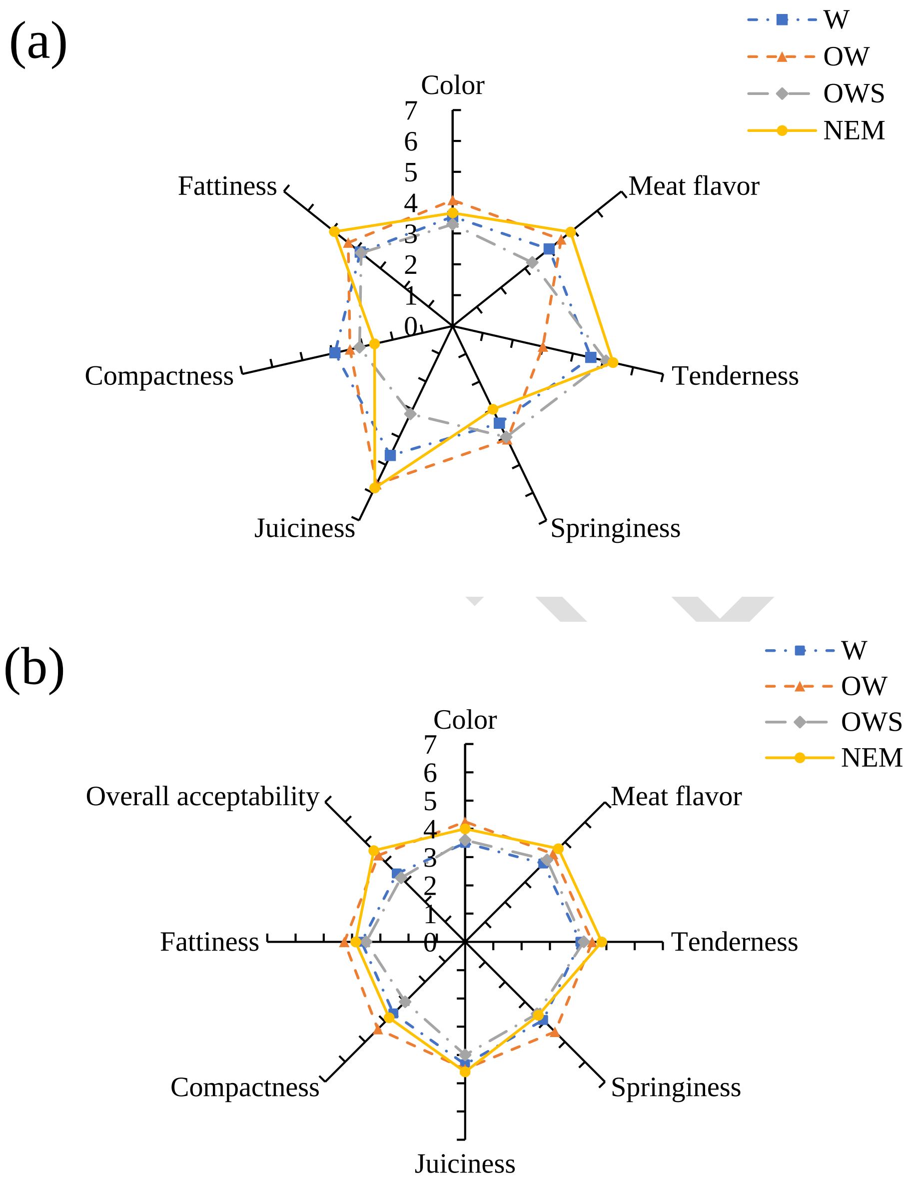
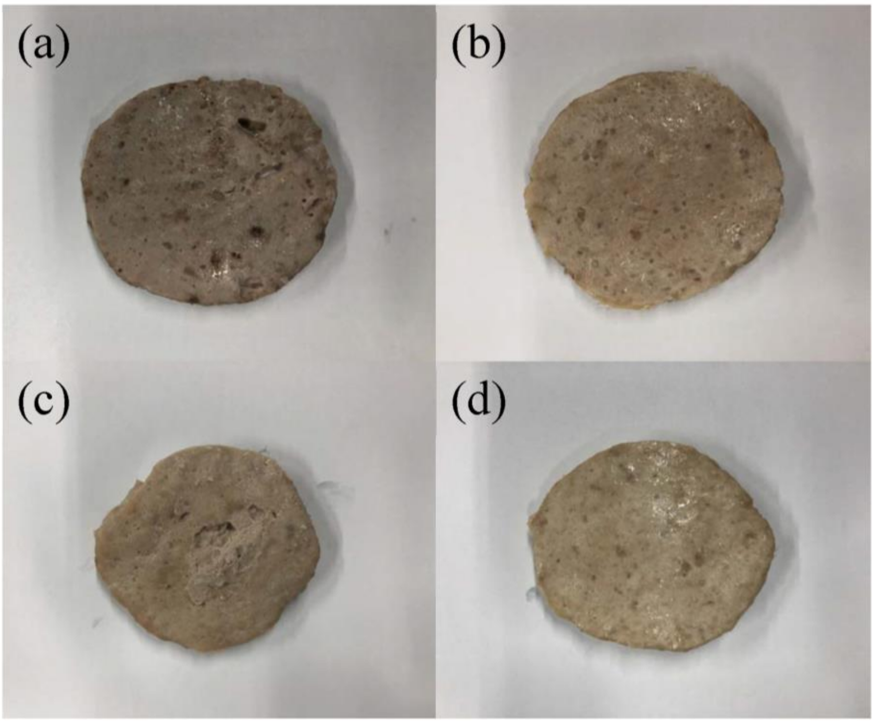


Fig. 2. Changes of intensity (a) and preference (b) in sensory evaluation of pork patties supplemented with various liquids. W, water; OW, oil and water; OWS, oil (1% lecithin) and water (3.5% tween 80); MEM, microemulsion, oil (1% lecithin), and water (3.5% tween 80), which were homogenized using a high speed homogenizer; NEM, nano emulsion, oil (1% lecithin), and water (3.5% tween 80), which were processed using a high speed homogenizer and microfluidizer.



Supplemental data 1. Cooked pork patties supplemented with different emulsions. Pork patties supplemented with different liquids: (a) W, water; (b) OW, oil, and water; (c) OWS, oil (1% lecithin), and water (3.5% tween 80); (d) NEM, nanoemulsion, oil (1% lecithin) and water (3.5% Tween 80), which were homogenized using a high speed homogenizer and microfluidizer.