# Effect of cutting time and cooking temperature on physicochemical properties of chicken breast meat emulsion sausage with olive oil

Dong-Jin Shin ⓘ,*,[1] Dong-Gyun Yim ⓘ,*,[1] Jeong A. Kwon ⓘ,* Sung-Su Kim,* Hyun Jung Lee ⓘ,* and Cheorun Jo ⓘ*,†,[2]

*Department of Agricultural Biotechnology, Center for Food and Bioconvergence, and Research Institute of Agriculture and Life Science, Seoul National University, Seoul 08826, Republic of Korea; and †Institute of Green Bio Science and Technology, Seoul National University, Pyeongchang 25354, Korea

**ABSTRACT** This study aimed to optimize the emulsification of olive oil in chicken sausage production at varying cutting times (30, 45, and 60 s) and cooking temperatures (63, 73, and 83°C). Pork backfat sausages were prepared as controls, using the same variables. The quality attributes of the sausages were analyzed, and the distribution of lipid droplets was identified using confocal laser scanning microscopy. The combinations of cutting time and cooking temperature in olive oil sausages showed different emulsifying characteristics. Meat emulsion with olive oil at a cutting time of 60 s and cooking temperature of 73°C showed the highest emulsion stability with lowest water and lipid loss (2.49%, $P < 0.05$). The pH values were lower for olive oil samples than for the controls (5.9 vs. 6.2, $P < 0.05$). Cutting time of 60 s and cooking temperature of 73°C generated higher hardness, gumminess, and chewiness in olive oil sausages ($P < 0.05$). The replacement of pork backfat with olive oil resulted in a higher $b^*$, $C^*$, and h values, as well as lower lipid oxidation ($P < 0.05$). In addition, microstructural images exhibited a finer distribution of lipid droplets in olive oil sausages with a cutting time of 60 s. In conclusion, chicken sausage at a cooking temperature of 73°C and cutting time of 60 s was optimal for producing sausages with olive oil. Given the condition, the sausages produced from olive oil had better emulsion and oxidative stability than sausages produced from pork backfat.

Key words: olive oil, emulsification, cutting time, cooking temperature, chicken sausage

## INTRODUCTION

Chicken meat, one of the most representative white meat, is a valuable food source with high nutritional value. In addition to abundant amino acids, vitamins, minerals, and essential fatty acids, chicken meat has lower caloric value and saturated fatty acids than red meat (Kralik et al., 2018). Chicken meat has been associated with a lower risk of diseases related to the consumption of red meat, such as the incidence of cardiovascular disease and some cancers (Sinha et al., 2009; Marangoni et al., 2015). Thus, meat products based on chicken meat are appealing to health-conscious consumers.

Emulsion sausage is a major meat product, in which up to 30% of the total content is animal fat, emulsified with water and meat protein (Choi et al., 2013). However, high saturated fatty acid content in animal fats has been associated with obesity and coronary heart diseases (Siri-Tarino et al., 2010), and the substitution with plant oil has been highlighted by many scientists and industry. Owing to an abundance of unsaturated fatty acids and bioactive phytochemicals, plant oils can modify fatty acid composition and provide functionality in sausage (Kavuşan et al., 2020). However, since the fat in meat products contributes to the quality properties, including texture, oxidative stability, and sensory characteristics, its substitution should be performed carefully (Youssef and Barbut, 2011).

Olive oil is a promising lipid in the emulsification process as a fat substitute in meat products due to its superior sensory and functional properties (Rodriguez-Carpena et al., 2012; Shin et al., 2020). It contains high levels of monounsaturated fatty acids (oleic and eicosenoic acid) and antioxidant capacity (Rodriguez-Carpena et al., 2012). However, in previous studies, lower hardness and/or emulsion stability of beef (Bloukas et al., 1997), pork (Muguerza et al., 2001), and chicken meat sausages with olive oil (Shin et al., 2020)

compared with pork backfat controls were observed. Other reports suggested that chicken (Choi et al., 2009) or pork sausages with olive oil (Paneras et al., 1998) were firmer than sausages with pork backfat. The contradictory reports on the emulsion characteristics of sausages with olive oil suggest that certain factors need to be optimized in order to control its emulsification. Furthermore, few data has been reported on the use of olive oil in chicken meat sausages.

Some advanced processing techniques including pre-emulsification (Youssef and Barbut, 2011; Herrero et al., 2012; Kim et al., 2020) and double-layer emulsion (Cofrades et al., 2013; Kumar and Kumar, 2020) have been suggested to overcome such problems when plant oil is used in meat emulsions. However, these approaches require the use of additives or special technical steps. Furthermore, these methods could also create problems with consumer acceptance or increased production costs. Thus, a different approach for the emulsification of plant oils is needed.

On the processing of emulsion sausage, cutting, or comminution procedure is an influential factor for emulsification, as it not only imparts a change in temperature, but also changes the dispersion of fat particles (Tomas et al., 2007; Sun et al., 2015). Cooking temperature is also considered one of the most important factors influencing the gelation properties of myofibrillar proteins because cooking is required for denaturation and unfolding of protein molecules necessary for gel formation (Lesiów and Xiong, 2001). Although these factors could be crucial for emulsification of oils with meat protein, the combined effects of cutting time and cooking temperature on emulsification of chicken sausage with olive oil have not yet been elucidated. For these reasons, this study was conducted to investigate the impact of olive oil as a replacement for pork backfat in chicken sausages, and to optimize the physicochemical properties of chicken sausages by adjusting cutting time and cooking temperature.

## MATERIALS AND METHODS

### Raw Materials

Frozen broiler breasts were purchased from a local distributor (Maniker, Namyangju, Korea) and thawed at $4 \pm 1°C$ for 12 h prior to sausage manufacture. Pork backfat was purchased from a local butcher shop (Seoul, Korea), and extra virgin olive oil was purchased from a local market (CJ CheilJedang Corp., Seoul, Korea, 100% purity).

### Formulation and Processing of Sausages

Three batches of emulsion-type chicken sausages were prepared with 2 lipids types (pork backfat and olive oil), 3 cutting times (30, 45, and 60 s), and 3 cooking temperatures (63, 73, and 83°C). Cutting times and cooking temperatures were selected based on preliminary studies. Sausages were prepared

following a previously described method (Shin et al., 2020), with minor modifications, using 60% broiler breast meat, 20% lipid, and 20% iced water. As additives, 1.5% sodium chloride and 0.2% sodium triphosphate were added based on the total sample weight (w/w). The manufacturing process is illustrated in Figure 1. The meat was ground using a grinder (MG51, Kenwood, Hampshire, UK) equipped with a 5 mm plate. Six aliquots of raw materials (350 g for each meat batter) were prepared and emulsified in a bowl cutter at 2,200 rpm (C4W, Sirman, Padova, Italy). At final cutting, the batters were processed at different cutting times (30, 45, and 60 s). The temperature of the mixtures was monitored using a digital thermometer (TM-747DU, Tenmars Electronics Co., Ltd., Taipei, Taiwan) and maintained below 13°C during processing. Each emulsified meat batter was stuffed into a 25-mm diameter collagen casing (#240, NIPPI Inc., Tokyo, Japan). The batters were then steam-cooked in a smoke chamber (Bastra 851C, Bayha Strackbein GmbH, Arnsberg, Germany) at 75, 85, and 95°C until the core temperature reached 63, 73, and 83°C, respectively. The temperatures of the smoke chamber were set to compensate for the difference in the heating rate to achieve different core temperatures.
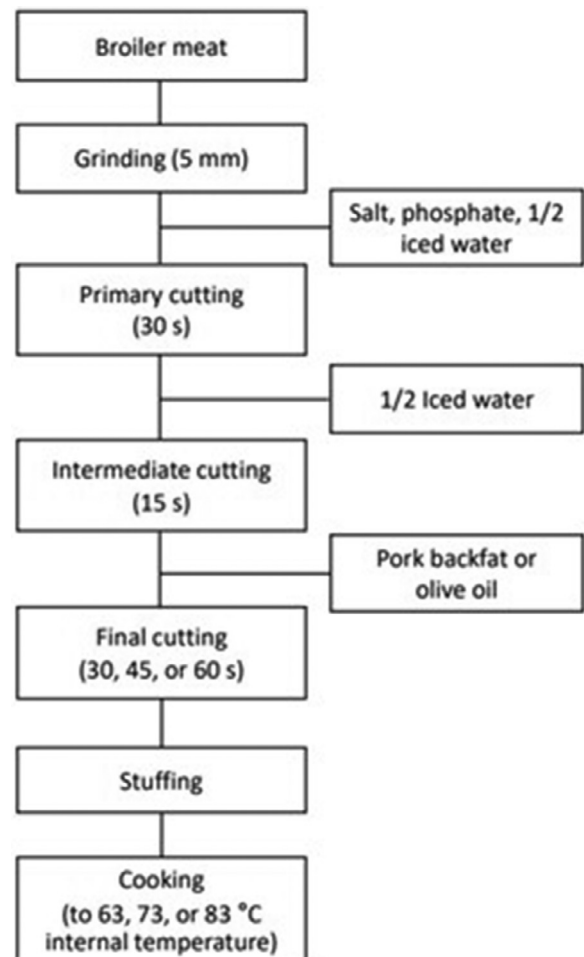


**Figure 1.** Flow diagram for manufacturing process of emulsion-type chicken sausages with pork backfat or olive oil with varying combinations of cooking temperature and cutting time.

## Emulsion Stability

The emulsion stability of the meat batters produced at different cutting times and cooking temperatures was determined by assessing water and lipid loss using a modified method based on Choi et al. (2009). Absorbent cotton was placed at the bottom of a 50 mL tube to absorb water and oil loss from the meat batter during cooking. A 5 × 5 cm, 25 mesh sieve was placed in the

$$Expressible\ fluid\ (\%) = \frac{Weight\ before\ centrifuging\ (g)\ -\ Weight\ after\ centrifuging\ (g)}{Weight\ before\ centrifuging\ (g)} \times\ 100$$

tube. Batter $(20 \pm 0.5\ g)$ was stuffed onto the mesh. The tube was loosely closed to avoid the possible effect of vapor pressure, then cooked to a core temperature of 63, 73, or 83°C using a water bath (WB-22, Daihan Scientific, Wanju, Korea) at 75, 85, or 95°C. Subsequently, the tube was cooled to room temperature $(20 \pm 2°C)$ for 12 h. The weight of cotton-absorbing water and lipid loss were then measured. To determine the water content, the cotton was dried in a drying oven at 105°C for 3 h (DS-520L, Daewon Science, Bucheon, Korea). The water and lipid loss from the batter was calculated as a percentage using the following equation:

$$Water\ loss\ (\%) = \frac{A\ -\ C}{Weight\ of\ batter\ (g)} \times\ 100$$

$Lipid\ loss\ (\%)$

$$= \frac{A\ -\ B}{Weight\ of\ batter\ (g)} \times\ 100\ -\ \textbf{\textit{water loss}}\ (\%)$$

where A is the weight of the cotton after cooking, B is the weight of cotton before cooking, and C is the weight of cotton after drying.

## pH Value

One gram of chopped sausage sample was diluted 10-fold with distilled water and homogenized for 30 s (T10 Basic, Ika Works, Staufen, Germany), and the pH of the homogenate was measured using a pH meter (SevenGo2, Mettler-Toledo International Inc., Schwerzenbach, Switzerland).

## Cooking Yield

The cooking yields were determined from the weight of the sausages before and after cooking.

$Cooking\ yield\ (\%)$

$$= \frac{Weight\ of\ cooked\ sample\ (g)}{Weight\ of\ raw\ sample\ (g)} \times\ 100$$

## Expressible Fluid

The centrifugation method was used to measure the expressible fluid of the cooked sausages (Shin et al., 2020). The sausage sample (5 g) was chopped and placed on a filter paper and centrifuged at $252 \times g$ for 10 min (Continent 512R, Hanil Co., Ltd., Incheon, Korea). The percentage of expressible fluid was calculated using the following formula:

## Water Content

The water content of the sausages was determined using the official methods of the AOAC International (Horwitz and Latimer, 2006). The ground sample (3 g) was weighed on an aluminum dish. The dish was placed in a drying oven at 105°C for 16 h (DS-520L, Daewon Science). The water content was calculated based on the weight loss from the sample after drying.

$Water\ content\ (\%)$

$$= \left(1 - \frac{Weight\ of\ sample\ after\ drying\ (g)}{Weight\ of\ sample\ (g)}\right) \times\ 100$$

## Lipid Content

Lipid content was analyzed by Soxhlet extraction (Horwitz and Latimer, 2006). Briefly, 1.5 g of ground sample was placed in a round filter paper and dried in a 105°C dry oven for 16 h (DS-520L, Daewon Science). The paper was then placed in a Soxhlet extractor to extract lipids from the sample. The extraction was performed for 12 h using ethyl ether, and the weight of the extracted lipid per total sample weight was presented as a percentage.

## 2-Thiobarbituric Acid Reactive Substances Value

Lipid oxidation was assessed by the 2-Thiobarbituric Acid Reactive Substances (**TBARS**) method (Kim et al., 2020). Five grams of the sample was blended for 30 s at 9,600 rpm using a homogenizer (T10 Basic, Ika Works, Staufen, Germany) with 15 mL distilled water and 50 $\mu$L of 7.2% (w/v) tert-butyl-4-hydroxyanisole ethanol solution. In a new tube, 2 mL of the homogenate was added to 4 mL of 0.02 M thiobarbituric acid in 15% (w/v) trichloroacetic acid. Tubes were capped and vortexed, heated in a 90°C water bath (WB-22, Daihan Scientific) for 30 min to develop the color, and cooled with tap water for 10 min. The absorbance of the reacted solution was measured at 532 nm using a UV/VIS spectrophotometer (X-ma 3100, Human Co. Ltd.,

Seoul, Korea). The TBARS value was expressed as mg of malondialdehyde (**MDA**)/kg sausage as follows:

$$TBARS \ (mg \ MDA/kg) =$$
$$(absorbance \ of \ sample \ - \ absorbance \ of \ blank \ sample)$$
$$\times 5.58$$

## Texture Profile Analysis

Sausage samples (ø 2.5 cm) were cut to a height of 2 cm and analyzed using a texture analyzer (TA1, AME-TEK Lloyd Instruments Ltd., Fareham, UK). With an attached ø 70 mm compression plate, the analyzer was subjected to compress the samples twice perpendicularly to 60% of their original height (test speed of 2.0 mm/s, trigger force of 0.1 newton). The acquired data were analyzed using the NexygenPlus software program (AME-TEK Lloyd Instruments Ltd.). The hardness (Newton, **N**), cohesiveness, springiness, chewiness (N), and gumminess (N) were recorded.

## Color Analysis

The color of the pork backfat, olive oil, and sausage surface was measured using a colorimeter (CM-5, Konica Minolta Co., Ltd., Osaka, Japan) with an 8-mm measuring area. Standard black and white calibration plates (CM-A210, Konica Minolta Co., Ltd.) were used for calibration. The lightness (L*; + brightness, − darkness), redness (a*; + redness, − greenness), and yellowness (b*; + yellowness, − blueness), chroma (C*), and hue angle (h) were recorded.

## Confocal Laser Scanning Microscopy

Confocal laser scanning microscopy (**CLSM**) was performed according to the method described by Liu et al. (2016). The cooked sausage specimen was prepared by slicing the sausage at a thickness of 3 mm using a razor blade. The fluorescent dye, 0.2% Nile blue A sulfate (w/v, certified by the Biological Stain Commission, Sigma-Aldrich, Saint Louis, MO) was prepared with deionized water and pipetted onto the specimen. It was allowed to be absorbed into the specimen at room temperature for 10 min. Micrographs of the samples were obtained using a confocal laser scanning microscope (SP8X, Leica, Wetzlar, Germany). The 488 nm and 633 nm lasers were used to excite in the lipid phase (green) and the protein phase (red), respectively. Emission spectra were collected from 500 to 650 nm for the lipid phase and 650 to 800 nm for the protein phase, and the images were overlaid.

## Statistical Analysis

All experiments were performed in triplicate with three separate batches of sausage manufacturing. Statistical analysis for the combined effect of cutting time and cooking temperature was performed using one-way analysis of variance (**ANOVA**), and significant differences were identified using the Student−Newman−Keuls multiple range test in the SAS statistical software program (SAS, Release 9.4; SAS Institute Inc., Cary, NC) with a significance level of $P < 0.05$. To identify significant differences ($P < 0.05$) between treatments, a $t$ test was performed using Excel 365 (Microsoft, Redmond, WA).

# RESULTS AND DISCUSSION

## Emulsion Stability

The stability of the meat emulsion to hold water and lipids in its matrix is one of the most important quality parameters for emulsion-type sausages. The emulsion stability of sausages formulated with pork backfat or olive oil with combinations of cutting time and cooking temperature is shown in Table 1. In the meat batters with pork backfat, emulsion stability tended to decrease with increasing cooking temperature ($P < 0.05$). However, no differences were found with respect to the cutting times.

Among the olive oil meat batters, the emulsion stability at cooking temperatures of 63 and 73°C significantly increased with increasing cutting time. At a cutting time of 60 s and cooking temperature of 73°C, the lowest percentage of water and lipid release was observed ($P < 0.05$). At a cutting time of 30 s, the lipid loss in the emulsion with olive oil was higher than that with pork backfat ($P < 0.05$). Usually, the optimal temperature for gelation of myofibrillar protein is reported to be between 70 and 80 °C (Wu et al., 2020). At this temperature, the protein is moderately denatured and forms a gel with the maximum capability of holding water. When the cooking temperature is above 80°C, the excessive denaturation and aggregation of myofibrillar protein results in a denser structure, which may lower the retention of water in the protein structure (Promeyrat et al., 2010). Also, the temperature-dependent increase in water loss during cooking due to shrinkage of the whole fiber has been reported (Tornberg, 2005). Consistent with these reports, the cooking temperature of olive oil meat batters at 83°C induced significantly higher water and lipid loss in the present study.

Several factors may have contributed to these results. 1) Different lipid characteristics: because the olive oil used had higher unsaturated fatty acids than did pork backfat, it was more fluid at room temperature. Youssef and Barbut (2010) reported that the hardness of fat plays an important role in emulsion stability. In their work, it was shown that sausages with solid animal fat had higher emulsion stability than those with fluidic plant oils. Therefore, the different phases of the lipids used could be a reason for the relatively higher lipid loss from olive oil sausages in the present study. In addition, the cell membrane of fat cells could be another factor for fat stabilization in meat products (Sun and Holley, 2011). 2) Fine dispersion of oil droplets: The CLSM images exhibited fine distribution of olive oil (Figure 3). According to Liu et al. (2016) and Youssef and Barbut (2010), evenly distributed small lipid droplets result in higher emulsion

**Table 1.** Emulsion stability of chicken meat emulsion with pork backfat or olive oil with varying combinations of cooking temperature and cutting time.

| Traits | Lipid type | Cutting time (s) | Cooking temperature (°C) | | | SEM[1] |
|---|---|---|---|---|---|---|
| | | | 63 | 73 | 83 | |
| Water and lipid loss (%) | Pork backfat | 30 | 3.73[c,y] | 8.11[b,x] | 10.02[a,y] | 0.407 |
| | | 45 | 3.14[b,y] | 8.85[a,x] | 10.50[a,y] | 0.565 |
| | | 60 | 2.69[b,y] | 9.00[a,x] | 10.16[a,y] | 0.358 |
| | Olive oil | 30 | 9.93[b,x] | 8.96[b,x] | 18.26[a,x] | 0.900 |
| | | 45 | 5.89[b,y] | 3.83[b,y] | 17.37[a,x] | 1.519 |
| | | 60 | 5.10[b,y] | 2.49[b,y] | 15.62[a,x] | 0.928 |
| | | SEM[2] | 1.482 | 0.953 | 0.709 | |
| Water loss (%) | Pork backfat | 30 | 3.28[c] | 7.46[b,x] | 9.43[a,y] | 0.378 |
| | | 45 | 2.98[b] | 8.24[a,x] | 9.75[a,y] | 0.492 |
| | | 60 | 2.52[b] | 8.29[a,x] | 9.52[a,y] | 0.358 |
| | Olive oil | 30 | 5.35[b] | 4.25[b,y] | 14.42[a,x] | 0.553 |
| | | 45 | 4.08[b] | 2.43[b,z] | 15.62[a,x] | 0.661 |
| | | 60 | 4.90[b] | 2.28[b,z] | 14.51[a,x] | 0.922 |
| | | SEM[2] | 0.999 | 0.419 | 0.516 | |
| Lipid loss (%) | Pork backfat | 30 | 0.46[y] | 0.65[y] | 0.59[y] | 0.089 |
| | | 45 | 0.16[b,y] | 0.61[a,y] | 0.75[a,y] | 0.083 |
| | | 60 | 0.17[b,y] | 0.71[a,y] | 0.64[a,y] | 0.060 |
| | Olive oil | 30 | 4.58[x] | 4.71[x] | 3.84[x] | 0.748 |
| | | 45 | 1.80[y] | 1.40[y] | 1.75[y] | 1.268 |
| | | 60 | 0.20[b,y] | 0.21[b,y] | 1.11[a,y] | 0.036 |
| | | SEM[2] | 1.160 | 0.784 | 0.326 | |

[a-c]Means within the same row with different superscripts differ significantly ($P < 0.05$).
[x-z]Means within the same column with different superscripts differ significantly ($P < 0.05$).
[1]Standard error of means (n = 9).
[2]Standard error of means (n = 18).

stability after cooking. They explained this phenomenon using the physical entrapment theory. That is, the fat cannot easily permeate the finely structured hydrophilic protein gel. Therefore, it can be held in meat emulsions. Similarly, Jiménez-Colmenero et al. (2010) found improvement in the emulsion stability of sausages by substituting pork backfat with a pre-emulsion of olive oil and various proteins. Moreover, the same authors noted the good thermal stability of these pre-emulsions, in which lipids are well incorporated into the protein matrix due to their smaller particles. 3) Higher emulsion stability in olive oil batters may be induced by increased hydrophobicity through moderate cooking temperature and prolonged cutting time. Liu et al. (2016) reported that

**Table 2.** The pH, cooking yield, and expressible fluid of emulsion-type chicken meat sausages with pork backfat or olive oil with varying combinations of cooking temperature and cutting time.

| Traits | Lipid type | Cutting time (s) | Cooking temperature (°C) | | | SEM[1] |
|---|---|---|---|---|---|---|
| | | | 63 | 73 | 83 | |
| pH | Pork backfat | 30 | 6.19[x] | 6.20[x] | 6.21[x] | 0.004 |
| | | 45 | 6.20[x] | 6.19[x] | 6.21[x] | 0.016 |
| | | 60 | 6.22[x] | 6.21[x] | 6.21[x] | 0.006 |
| | Olive oil | 30 | 5.92[y] | 5.97[y] | 5.91[y] | 0.020 |
| | | 45 | 5.92[y] | 5.94[y] | 5.96[y] | 0.025 |
| | | 60 | 5.94[y] | 5.94[y] | 5.88[y] | 0.037 |
| | | SEM[2] | 0.018 | 0.013 | 0.029 | |
| Cooking yield (%) | Pork backfat | 30 | 96.72[a,x] | 96.61[a,x] | 87.67[b] | 1.283 |
| | | 45 | 96.74[a,x] | 96.22[a,x] | 91.49[b] | 0.194 |
| | | 60 | 96.11[a,x] | 96.58[a,x] | 90.35[b] | 0.638 |
| | Olive oil | 30 | 94.30[y] | 91.39[y] | 87.75 | 2.820 |
| | | 45 | 93.80[b,y] | 96.90[a,x] | 87.25[c] | 0.251 |
| | | 60 | 93.01[a,y] | 94.45[a,x] | 86.81[b] | 0.733 |
| | | SEM[2] | 0.410 | 0.850 | 2.185 | |
| Expressible fluid (%) | Pork backfat | 30 | 17.07[y] | 17.63[y] | 14.52 | 1.268 |
| | | 45 | 17.84[y] | 17.27[y] | 14.39 | 1.661 |
| | | 60 | 15.41[y] | 17.01[y] | 14.50 | 1.380 |
| | Olive oil | 30 | 27.74[x] | 27.49[x] | 20.40 | 2.516 |
| | | 45 | 20.48[y] | 22.77[x,y] | 17.76 | 3.117 |
| | | 60 | 20.21[y] | 18.64[y] | 15.00 | 1.360 |
| | | SEM[2] | 2.031 | 2.728 | 2.301 | |

[a-c]Means within the same row with different superscripts differ significantly ($P < 0.05$).
[x,y]Means within the same column with different superscripts differ significantly ($P < 0.05$).
[1]Standard error of means (n = 9).
[2]Standard error of means (n = 18).

the hydrophobicity of meat proteins has an effect on the stabilization of hydrophobic lipids. The hydrophobicity can be changed according to the increase in temperature of the meat batter. Tornberg (2005) explained that the emulsifying and fat-binding properties of myofibrillar proteins are affected by cooking temperature. The functional properties of proteins can be improved by changing their hydrophobicity under moderate cooking (Tornberg, 2005). An increase in cutting time can also increase the temperature of the meat batter and induce a change in its hydrophobicity, along with a change in oil distribution (Tomas et al., 2007). It seemed that the combination of cutting time (60 s) and cooking temperature (73°C) resulted in optimal hydrophobicity and oil distribution for emulsification of olive oil. The hypothesis suggested here should be further studied by determining the detailed lipid structure and protein-lipid interactions in meat emulsions.

## pH, Cooking Yield, and Expressible Fluid

The pH value of the pork backfat sausages was higher than that of the olive oil sausages ($P < 0.05$, Table 2). While no differences among the combinations of processing conditions were observed in terms of pH. The decrease in pH due to replacement of pork backfat in sausage with olive oil has been previously reported by Utrilla et al. (2014). They reported that the acidity of olive oil could affect the pH of the sausages. In general, the pH value of meat products profoundly affects quality properties such as cooking yield, water holding capacity, and emulsion stability (Kuo and Chu, 2003). However,

the effect of pH on the quality properties of sausages was not obvious in this study. This means that the effect of cutting time and cooking temperature was likely more influential than pH. In the sausages with pork backfat, the cooking yields tended to decrease with increasing cooking temperature ($P < 0.05$). The sausage with olive oil at a cutting time of 60 s and cooking temperature of 73°C had similar cooking yields to those of the sausages with pork backfat.

As the oil was fluidic because of its high unsaturated fatty acid content, it was easily extracted from meat batter by centrifugation. An increase in cutting time reduced the expressible fluid in olive oil sausages. Especially, olive oil sausages with a cutting time of 60 s and cooking temperature of 73°C induced less expressible fluid among the olive oil sausages with the same cooking temperature. These values were similar to those of pork backfat sausages. The lower expressible fluid of olive oil sausages with a cutting time of 60 s and cooking temperature of 73°C can be explained with reference to the CLSM image (Figure 3). Under this condition, olive oil was finely incorporated into the protein gel matrix; in this way, the holding of water and oil within the structure of meat proteins can be achieved (Liu et al., 2016).

## Water Content, Lipid Content, and TBARS Value

As shown in Table 3, the water and lipid contents of the sausages appeared to be influenced by emulsion stability, as well as cooking yield (Tables 1 and 2). The water content of sausages with olive oil was lower at

**Table 3.** Water content, lipid content, and TBARS value of emulsion-type chicken sausages with pork backfat or olive oil with varying combinations of cooking temperature and cutting time.

| Traits | Lipid type | Cutting time (s) | Cooking temperature (°C) 63 | 73 | 83 | SEM[1] |
|---|---|---|---|---|---|---|
| Water content (%) | Pork backfat | 30 | 65.41[a] | 63.68[a,b,xyz] | 59.28[b,y] | 1.326 |
| | | 45 | 62.73 | 62.65[yz] | 62.50[x] | 0.559 |
| | | 60 | 65.23 | 65.90[x] | 65.54[x] | 1.027 |
| | Olive oil | 30 | 65.22 | 64.87[xy] | 62.53[x] | 0.745 |
| | | 45 | 60.91[a,b] | 61.77[a,z] | 59.02[b,y] | 0.604 |
| | | 60 | 61.69[a] | 60.76[a,z] | 58.77[b,y] | 0.427 |
| | | SEM[2] | 0.677 | 0.794 | 0.815 | |
| Lipid content (%) | Pork backfat | 30 | 12.54[xy] | 15.99 | 14.59 | 1.331 |
| | | 45 | 14.58[xy] | 11.93 | 14.13 | 2.051 |
| | | 60 | 11.59[xy] | 15.57 | 12.78 | 1.546 |
| | Olive oil | 30 | 9.15[y] | 9.64 | 9.34 | 1.407 |
| | | 45 | 13.09[xy] | 13.49 | 12.74 | 0.444 |
| | | 60 | 15.53[x] | 15.01 | 14.16 | 1.444 |
| | | SEM[2] | 1.233 | 1.399 | 1.685 | |
| TBARS (mg MDA/g sample)[3] | Pork backfat | 30 | 0.64[x] | 0.66[x] | 0.55[x] | 0.028 |
| | | 45 | 0.72[x] | 0.64[x] | 0.63[x] | 0.027 |
| | | 60 | 0.69[b,x] | 0.79[a,x] | 0.64[b,x] | 0.020 |
| | Olive oil | 30 | 0.18[y] | 0.16[y] | 0.19[y] | 0.044 |
| | | 45 | 0.18[a,y] | 0.15[b,y] | 0.18[a,y] | 0.034 |
| | | 60 | 0.16[a,y] | 0.18[b,y] | 0.17[a,y] | 0.044 |
| | | SEM | 0.026 | 0.046 | 0.027 | |

[a-c]Means within the same row with different superscripts differ significantly ($P < 0.05$).
[x-z]Means within the same column with different superscripts differ significantly ($P < 0.05$).
[1]Standard error of means (n = 9).
[2]Standard error of means (n = 18).
[3]MDA, malondialdehyde.

**Table 4.** Textural parameters of emulsion-type chicken sausages with pork backfat or olive oil with varying combinations of cooking temperature and cutting time.

| Traits | Lipid type | Cutting time (s) | Cooking temperature (°C) 63 | 73 | 83 | SEM[1] |
|---|---|---|---|---|---|---|
| Hardness (N) | Pork backfat | 30 | 24.25[z] | 26.51[y] | 30.35[xy] | 1.430 |
| | | 45 | 27.95[z] | 31.16[y] | 32.14[xy] | 1.001 |
| | | 60 | 26.78[z] | 29.17[y] | 33.61[xy] | 1.684 |
| | Olive oil | 30 | 22.68[b,z] | 28.27[a,y] | 26.92[a,y] | 0.807 |
| | | 45 | 40.55[x] | 46.08[x] | 39.16[xy] | 4.312 |
| | | 60 | 31.46[b,y] | 47.92[a,x] | 42.82[a,x] | 3.015 |
| | | SEM[2] | 1.835 | 3.044 | 2.889 | |
| Springiness | Pork backfat | 30 | 0.77 | 0.77[y] | 0.73 | 0.027 |
| | | 45 | 0.82 | 0.75[y] | 0.75 | 0.019 |
| | | 60 | 0.81 | 0.73[y] | 0.77 | 0.025 |
| | Olive oil | 30 | 0.75 | 0.87[x] | 0.69 | 0.071 |
| | | 45 | 0.73 | 0.78[y] | 0.71 | 0.033 |
| | | 60 | 0.68 | 0.85[x] | 0.76 | 0.039 |
| | | SEM[2] | 0.060 | 0.025 | 0.029 | |
| Gumminess (N) | Pork backfat | 30 | 6.16 | 6.96[yz] | 7.24[xy] | 0.504 |
| | | 45 | 8.03 | 8.70[xy] | 8.48[xy] | 0.398 |
| | | 60 | 8.24 | 8.00[yz] | 9.18[xy] | 0.884 |
| | Olive oil | 30 | 6.47 | 5.66[z] | 5.23[y] | 1.101 |
| | | 45 | 9.98 | 9.62[xy] | 8.92[xy] | 1.059 |
| | | 60 | 7.25[b] | 11.12[a,x] | 10.90[a,x] | 0.787 |
| | | SEM[2] | 0.933 | 0.745 | 0.891 | |
| Chewiness (N) | Pork backfat | 30 | 4.74 | 5.35[y] | 5.36[xy] | 0.529 |
| | | 45 | 6.60 | 6.52[y] | 6.35[xy] | 0.402 |
| | | 60 | 6.71 | 5.83[y] | 7.18[x] | 0.826 |
| | Olive oil | 30 | 5.25 | 4.99[y] | 3.67[y] | 1.399 |
| | | 45 | 7.35 | 7.48[xy] | 6.20[xy] | 0.863 |
| | | 60 | 5.04[b] | 9.39[a,x] | 8.29[a,x] | 0.785 |
| | | SEM[2] | 1.136 | 0.805 | 0.755 | |
| Cohesiveness | Pork backfat | 30 | 0.25[y] | 0.26[xy] | 0.24 | 0.015 |
| | | 45 | 0.29[xy] | 0.28[x] | 0.26 | 0.010 |
| | | 60 | 0.31[x] | 0.27[xy] | 0.27 | 0.019 |
| | Olive oil | 30 | 0.28 | 0.20[z] | 0.19 | 0.041 |
| | | 45 | 0.25 | 0.21[z] | 0.23 | 0.015 |
| | | 60 | 0.23 | 0.23[yz] | 0.26 | 0.014 |
| | | SEM[2] | 0.255 | 0.011 | 0.018 | |

N, Newton.
[a,b]Means within the same row with different superscripts differ significantly ($P < 0.05$).
[x-z]Means within the same column with different superscripts differ significantly ($P < 0.05$).
[1]Standard error of means (n = 9).
[2]Standard error of means (n = 18).

cutting times of 45 and 60 s than of 30 s in cooking temperature of 73°C. Because of the higher lipid content of these samples, their water content was determined to be proportionally lower (Okeudo and Moss, 2005). Conversely, the sausages with olive oil had a relatively lower lipid content and higher water content in the present study. The differences between the lipid types were not obvious.

The TBARS values, indicating the level of lipid oxidation, exhibited no clear tendency under different processing conditions (Table 3). All TBARS values of sausages were below 0.8 mg MDA/kg meat, which is the sensorial detection threshold for warmed-over flavor in chicken meat (Cortinas et al., 2005). However, it was clearly shown that the sausages with olive oil had lower TBARS values than those with pork backfat ($P < 0.05$, Table 3). The lower lipid oxidation of the olive oil sausages, even though olive oil has high oxidation-susceptible unsaturated fatty acid content, was due to the presence of natural antioxidants. An increase in the oxidative stability of meat products with olive oils has been reported in numerous studies

(Rodriguez-Carpena et al., 2012; Triki et al., 2013). This research explains that vitamin E, vitamin K, carotenoids, and various polyphenols in olive oil have antioxidant effects.

## *Textural Properties*

Hardness tended to increase with increasing cutting time in the sausages with olive oil at cooking temperatures of 73 and 83°C (Table 4). Regardless of the cooking temperature, the hardness at cutting times of 45 and 60 s was higher than that at 30 s in olive oil sausages. This is a good indication for a well-formed emulsion, as the emulsion stability and cooking yield in olive oil sausage were also higher with higher hardness (Tables 1 and 2). Youssef and Barbut (2010) reported the same phenomenon: a well-emulsified canola oil sausage with higher emulsion stability resulted in higher hardness. In the present study, the hardness values of the sausages with olive oil at cutting times of 45 and 60 s at cooking temperature of 73°C were higher than those of sausages with

**Table 5.** Color parameters of emulsion-type chicken sausages with pork backfat or olive oil with varying combinations of cooking temperature and cutting time.

| Traits | Lipid type | Cutting time (s) | Cooking temperature (°C) 63 | 73 | 83 | SEM[1] |
|---|---|---|---|---|---|---|
| $L^*$ | Pork backfat | 30 | 82.99[b,x] | 83.66[a,x] | 83.48[ab,x] | 0.142 |
| | | 45 | 83.34[b,x] | 84.34[a,x] | 84.10[a,x] | 0.158 |
| | | 60 | 83.78[b,x] | 84.31[ab,x] | 84.81[a,x] | 0.209 |
| | Olive oil | 30 | 76.99[z] | 77.01[z] | 76.16[z] | 0.444 |
| | | 45 | 81.70[xy] | 80.27[y] | 79.39[y] | 0.846 |
| | | 60 | 80.25[y] | 81.78[y] | 80.65[y] | 0.647 |
| | | SEM[2] | 0.698 | 0.535 | 0.545 | |
| $a^*$ | Pork backfat | 30 | 1.03[c,x] | 1.17[b,x] | 1.50[a,xy] | 0.023 |
| | | 45 | 1.08[b,x] | 1.13[b,x] | 1.66[a,x] | 0.045 |
| | | 60 | 0.92[b,x] | 1.10[b,x] | 1.43[a,xy] | 0.061 |
| | Olive oil | 30 | 1.20[b,x] | 1.28[b,x] | 1.68[a,x] | 0.092 |
| | | 45 | 0.34[b,y] | 0.64[ab,y] | 1.13[a,y] | 0.182 |
| | | 60 | 0.60[y] | 0.35[y] | 0.77[z] | 0.125 |
| | | SEM[2] | 0.136 | 0.128 | 0.111 | |
| $b^*$ | Pork backfat | 30 | 14.41[a,y] | 13.91[b,z] | 13.60[c,z] | 0.073 |
| | | 45 | 14.22[y] | 13.89[z] | 13.57[z] | 0.152 |
| | | 60 | 13.99[a,y] | 13.59[b,z] | 13.29[c,z] | 0.057 |
| | Olive oil | 30 | 19.39[x] | 20.45[x] | 20.77[x] | 0.067 |
| | | 45 | 17.68[x] | 18.84[xy] | 17.44[y] | 0.851 |
| | | 60 | 18.09[a,x] | 17.51[ab,y] | 16.42[b,y] | 0.378 |
| | | SEM[2] | 0.657 | 0.547 | 0.559 | |
| $C^*$ | Pork backfat | 30 | 14.45[a,y] | 13.96[b,z] | 13.68[c,z] | 0.072 |
| | | 45 | 14.26[xy] | 13.94[z] | 13.67[z] | 0.151 |
| | | 60 | 14.02[a,y] | 13.64[b,z] | 13.37[c,z] | 0.057 |
| | Olive oil | 30 | 19.43[x] | 20.50[x] | 20.84[x] | 0.688 |
| | | 45 | 17.68[x] | 18.85[xy] | 17.48[y] | 0.858 |
| | | 60 | 18.11[a,x] | 17.51[ab,y] | 16.44[b,y] | 0.380 |
| | | SEM[2] | 0.658 | 0.551 | 0.563 | |
| H | Pork backfat | 30 | 85.92[y] | 85.17[z] | 83.72[z] | 0.112 |
| | | 45 | 85.68[a,y] | 85.36[a,yz] | 83.03[b,z] | 0.209 |
| | | 60 | 86.25[a,y] | 85.39[a,yz] | 83.85[b,z] | 0.258 |
| | Olive oil | 30 | 86.43[a,y] | 86.42[a,y] | 85.38[b,y] | 0.231 |
| | | 45 | 88.91[a,x] | 88.10[a,x] | 86.34[b,y] | 0.433 |
| | | 60 | 88.13[x] | 88.85[x] | 87.30[x] | 0.384 |
| | | SEM[2] | 0.407 | 0.317 | 0.298 | |

[a-c]Means within the same row with different superscripts differ significantly ($P < 0.05$).
[x-z]Means within the same column with different superscripts differ significantly ($P < 0.05$).
[1]Standard error of means (n = 9).
[2]Standard error of means (n = 18).

pork backfat ($P < 0.05$). These were comparable to sausages made with transglutaminase (Lee et al., 2019), an enzyme added to increase hardness.

Meanwhile, gumminess and chewiness presented the same trend as hardness, because gumminess was calculated as hardness × cohesiveness, and chewiness as hardness × cohesiveness × springiness. The higher gumminess and chewiness show the capability of the meat protein gel to store energy upon mechanical deformation (Petridis et al., 2010). In line with the hardness value, olive oil treatments at cutting times of 45 and 60 s at cooking temperature of 73°C also had similar gumminess and chewiness compared with the fat treatments. This can be explained by the stronger and more elaborate bonds among the meat proteins in the emulsion. Wu et al. (2020) reported that the texture of meat products is affected by the retention of water and lipids within such products. In the present study, treatments that exhibited low water and fat content on emulsion stability had higher hardness (Tables 1 and 4). Moreover, finely distributed small lipid droplets (Figure 3) can affect the formation of texture. Liu et al. (2016) reported that small lipid droplets are favorable for forming a strong interfacial protein film of meat protein around each fat.

## Color

The color values were significantly different for both lipid types and processing conditions (Table 5). Generally, these differences are based on the indigenous colors of raw materials. The utilized fat had white-pink color ($L^*$, 75.85; $a^*$, 1.78; $b^*$, 11.47; $C^*$, 11.61; h 81.21) and olive oil had its own yellow-gold color ($L^*$, 35.07; $a^*$, - 1.92; $b^*$, 31.47; $C^*$, 31.53; h, 93.49). Thus, the produced olive oil sausages generally had lower $L^*$ and $a^*$ values and higher $b^*$, $C^*$, and h values than the pork backfat sausages. In previous studies, lower $a^*$ and/or $L^*$ values and higher $b^*$ values of olive oil sausages than those of pork backfat sausages have been reported (Choi et al., 2009; Shin et al., 2020).

The $a^*$ values of olive oil sausages differed significantly according to the processing conditions. It has been reported that emulsion stability can affect meat color (Jeong and Han, 2019). In the present study, treatments with higher emulsion stability generally had lower $a^*$ values. Therefore, the olive oil sausage with a cutting time of 60 s and cooking temperature of 73°C also had a relatively low $a^*$ value among olive oil treatments. This might be due to the negative $a^*$ value of olive oil used.
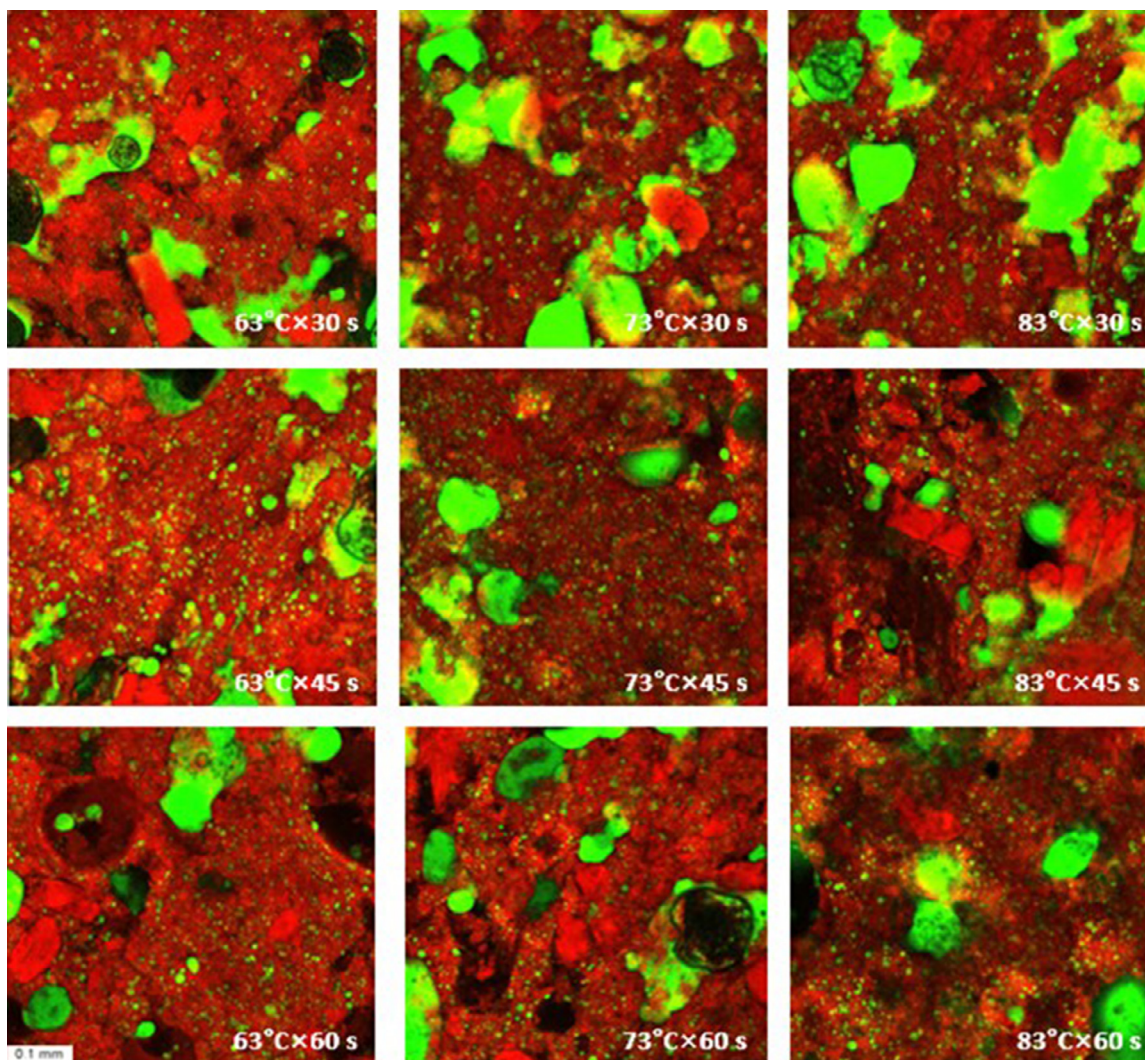
**Figure 2.** CLSM images of chicken sausages with pork backfat with varying combinations of cooking temperature and cutting time. Bar, 0.1 mm. Lipid phase, green; protein phase, red. Abbreviation: CLSM, confocal laser scanning microscopy.

Usually, the development of red color in meat products is important, because consumers expect a red color in conventional meat products (Yong et al., 2019). However, the concept of weisswurst, white sausages, seems feasible based on the white color of cooked chicken meat and olive oil, as well as the additive-free trend.

## CLSM

The CLSM images of the sausages exhibited different distributions of lipid (green) and protein (red) phases according to the combinations of cutting time and cooking temperature (Figures 2 and 3). In the pork backfat sausage, structural changes due to cooking temperature were not observed. While a change attributable to cutting time was observed. As the cutting time increased, the number of large fat droplets decreased. Regarding olive oil treatments, the same tendency by the cutting time was shown more clearly. At 30 s of low cutting time, larger and irregularly shaped lipid droplets were observed. These structures caused inferior quality properties, such as high loss of

water and oil, as well as lower cooking yield (Liu et al., 2016). With the increase in cutting time, the lipid droplets of olive oil were distributed well in a globular shape. Olive oil sausages with cutting times of 45 and 60 s had smaller and more regular oil distribution than that of sausages cut for 30 s, except for the sausage with a cutting time of 45 s and cooking temperature of 63°C. The formation of this difference in structure could be affected by the cooking temperature. Increased cooking temperature can increase the hydrophobicity of chicken meat proteins (Lesiów and Xiong, 2001). Thus, higher temperature could result in a favorable condition, allowing incorporation of the oil into the meat structure by protein-lipid interactions with hydrophobic olive oil treatments at cooking temperatures of 73 and 83°C. However, an excessive increase in cooking temperature could induce more denaturation and aggregation of myofibrillar proteins, producing a denser structure that may lower the retention of water in the protein structure (Promeyrat et al., 2010). As the emulsion stability and cooking yield were significantly lower at a cooking temperature of 83°C,
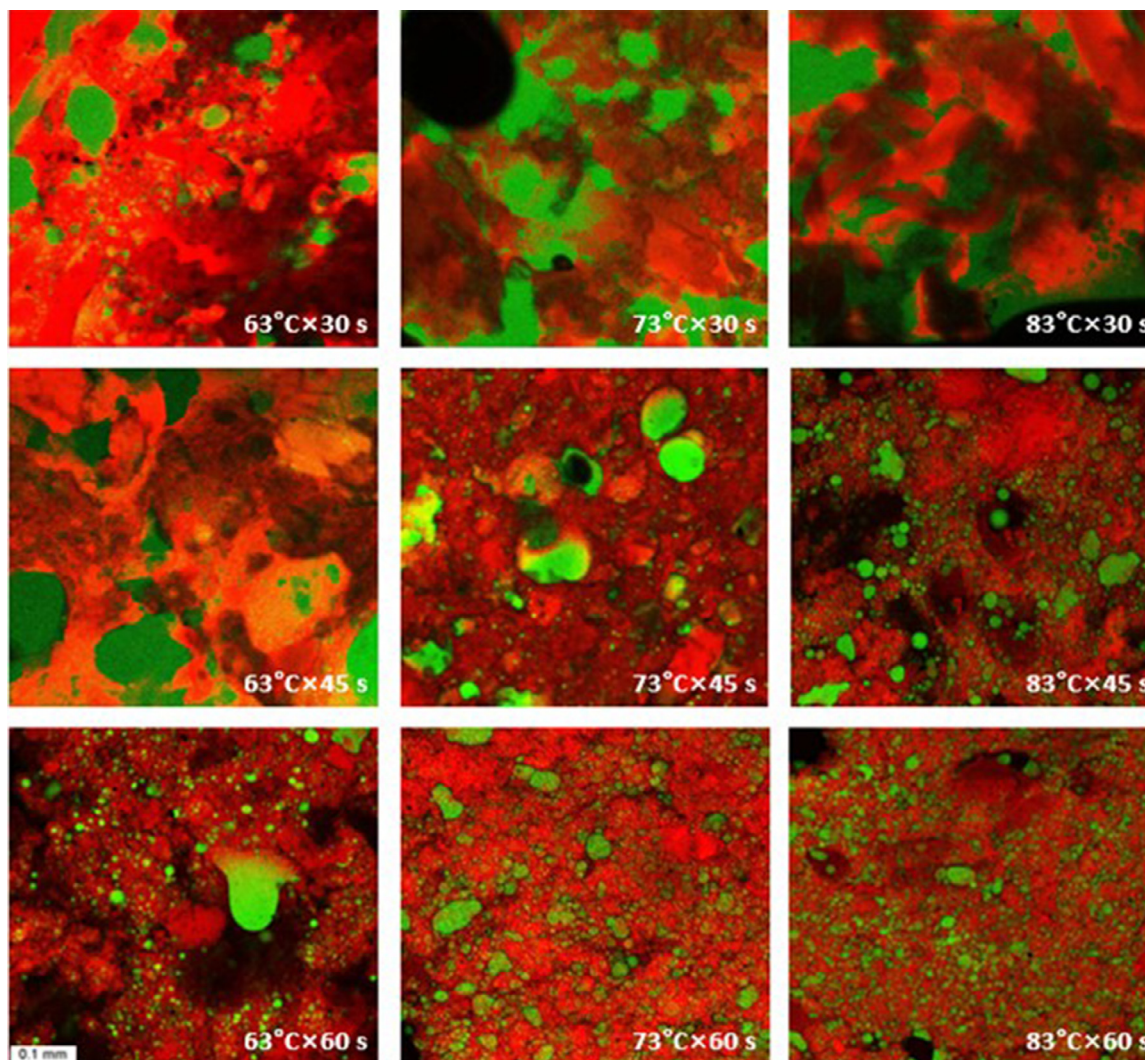
**Figure 3.** CLSM images of chicken sausages with olive oil with varying combinations of cooking temperature and cutting time. Bar, 0.1 mm. Lipid phase, green; protein phase, red. Abbreviation: CLSM, confocal laser scanning microscopy.

this condition could be considered inappropriate, although it exhibited a well-emulsified structure.

## CONCLUSIONS

Combinations of different cutting times and cooking temperatures significantly influenced the physicochemical properties of chicken sausages with olive oil. The olive oil sausage with a cutting time of 60 s and cooking temperature of 73°C had better or similar results to the pork backfat sausage in terms of emulsion stability, cooking yield, expressible fluid, and texture. This may be due to changes in lipid-droplet distribution and protein-lipid interactions. Olive oil sausages showed better stability, in terms of lipid oxidation, than did fat sausages. For the production of high-quality chicken sausage with olive oil, an elongated cutting time of 60 s and a cooking temperature of 73°C are recommended. Further experiments to prove the proposed hypothesis for protein-lipid interactions and evaluate the sensory quality of the products are worth pursuing.

## DISCLOSURES

The authors declared that there is no conflict of interest.

## REFERENCES

Bloukas, J., E. Paneras, and G. Fournitzis. 1997. Effect of replacing pork backfat with olive oil on processing and quality characteristics of fermented sausages. Meat Sci. 45:133–144.

Choi, Y. S., K. S. Park, H. W. Kim, K. E. Hwang, D. H. Song, M. S. Choi, S. Y. Lee, H. D. Paik, and C. J. Kim. 2013. Quality characteristics of reduced-fat frankfurters with pork fat replaced

by sunflower seed oils and dietary fiber extracted from *makgeolli* lees. Meat Sci. 93:652–658.

Choi, Y. S., J. H. Choi, D. J. Han, H. Y. Kim, M. A. Lee, H. W. Kim, J. Y. Jeong, and C. J. Kim. 2009. Characteristics of low-fat meat emulsion systems with pork fat replaced by vegetable oils and rice bran fiber. Meat Sci. 82:266–271.

Cofrades, S., I. Antoniou, M. T. Solas, A. M. Herrero, and F. Jiménez-Colmenero. 2013. Preparation and impact of multiple (water-in-oil-in-water) emulsions in meat systems. Food Chem. 141:338–346.

Cortinas, L., A. Barroeta, C. Villaverde, J. Galobart, F. Guardiola, and M. D. Baucells. 2005. Influence of the dietary polyunsaturation level on chicken meat quality: lipid oxidation. Poultry Sci. 84:48–55.

Herrero, A. M., P. Carmona, T. Pintado, F. Jiménez-Colmenero, and C. Ruiz-Capillas. 2012. Lipid and protein structure analysis of frankfurters formulated with olive oil-in-water emulsion as animal fat replacer. Food Chem. 135:133–139.

Horwitz, W., and G. Latimer. 2006. Official Methods of Analysis of AOAC International. . 18th AOAC international, Gaithersburg, MA.

Jeong, Y., and Y. Han. 2019. Effect on the Emulsification stability and quality of emulsified sausages added with Wanggasi-Chunnyuncho (*Opuntia humifusa* f. *jeollaensi*s) fruit powders. Food Sci. Anim. Resour. 39:953–965.

Jimenez-colmenero, F., A. Herrero, T. Pintado, M. T. Solas, and C. Ruiz-capillas. 2010. Influence of emulsified olive oil stabilizing system used for pork backfat replacement in frankfurters. Food Res. Int. 43:2068–2076.

Kavuşan, H. S., M. Serdaroğlu, B. Nacak, and G. İpek. 2020. An approach to manufacture of fresh chicken sausages incorporated with black cumin and flaxseed oil in water gelled emulsion. Food Sci. Anim. Resour. 40:426.

Kim, H. J., H. J. Kim, J. Jeon, K. C. Nam, K. S. Shim, J. H. Jung, K. S. Kim, Y. Choi, S. H. Kim, and A. Jang. 2020. Comparison of the quality characteristics of chicken breast meat from conventional and animal welfare farms under refrigerated storage. Poultry Sci. 99:1788–1796.

Kralik, G., Z. Kralik, M. Grčević, and D. Hanžek. 2018. Quality of chicken meat. Pages 63-94 in Animal Husbandry and Nutrition. B. Yucel and T. Taskin, eds. IntechOpen, London, UK.

Kumar, Y., and V. Kumar. 2020. Effects of double emulsion (W1/O/W2) containing encapsulated *Murraya koenigii* berries extract on quality characteristics of reduced-fat meat batter with high oxidative stability. LWT Food Sci. Technol. 127:109365.

Kuo, C., and C. Chu. 2003. Quality characteristics of Chinese sausages made from PSE pork. Meat Sci. 64:441–449.

Lee, S. H., J. Choe, D. J. Shin, H. I. Yong, Y. Choi, Y. Yoon, and C. Jo. 2019. Combined effect of high pressure and vinegar addition on the control of *Clostridium perfringens* and quality in nitrite-free emulsion-type sausage. Innov. Food Sci. Emerg. Technol. 52:429–437.

Lesiów, T., and Y. L. Xiong. 2001. Mechanism of rheological changes in poultry myofibrillar proteins during gelation. Avian. Poult. Biol. Rev. 12:137–149.

Liu, W. J., T. C. Lanier, and J. A. Osborne. 2016. Capillarity proposed as the predominant mechanism of water and fat stabilization in cooked comminuted meat batters. Meat Sci. 111:67–77.

Marangoni, F., G. Corsello, C. Cricelli, N. Ferrara, A. Ghiselli, L. Lucchin, and A. Poli. 2015. Role of poultry meat in a balanced diet aimed at maintaining health and wellbeing: an Italian consensus document. Food Nutr. Res. 59:27606.

Muguerza, E., O. Gimeno, D. Ansorena, J. Bloukas, and I. Astiasarán. 2001. Effect of replacing pork backfat with pre-

emulsified olive oil on lipid fraction and sensory quality of Chorizo de Pamplona—a traditional Spanish fermented sausage. Meat Sci. 59:251–258.

Okeudo, N. J., and B. W. Moss. 2005. Interrelationships amongst carcass and meat quality characteristics of sheep. Meat Sci. 69:1–8.

Paneras, E., J. Bloukas, and D. Filis. 1998. Production of low-fat frankfurters with vegetable oils following the dietary guidelines for fatty acids. J. Muscle Foods 9:111–126.

Petridis, D., E. Vlazakis, I. Tzivanos, E. Derlikis, and C. Ritzoulis. 2010. Effects of selected ingredients and fat content on the sensory and mechanical properties of frankfurter-type sausages. J. Texture Stud. 41:880–898.

Promeyrat, A., M. L. Bax, S. Traore, L. Aubry, V. Sante-Lhoutelher, and P. Gatellier. 2010. Changed dynamics in myofibrillar protein aggregation as a consequence of heating time and temperature. Meat Sci. 85:625–631.

Rodriguez-Carpena, J. G., D. Morcuende, and M. Estevez. 2012. Avocado, sunflower and olive oils as replacers of pork back-fat in burger patties: Effect on lipid composition, oxidative stability and quality traits. Meat Sci. 90:106–115.

Shin, D. J., H. J. Lee, D. Lee, C. Jo, and J. Choe. 2020. Fat replacement in chicken sausages manufactured with broiler and old laying hens by different vegetable oils. Poult. Sci. 99:2811–2818.

Sinha, R., A. J. Cross, B. I. Graubard, M. F. Leitzmann, and A. Schatzkin. 2009. Meat intake and mortality: a prospective study of over half a million people. Arch. Intern. Med. 169:562–571.

Siri-Tarino, P. W., Q. Sun, F. B. Hu, and R. M. Krauss. 2010. Saturated fatty acids and risk of coronary heart disease: modulation by replacement nutrients. Curr. Atheroscler. Rep. 12:384–390.

Sun, C., T. Wu, R. Liu, B. Liang, Z. Tian, E. Zhang, and M. Zhang. 2015. Effects of superfine grinding and microparticulation on the surface hydrophobicity of whey protein concentrate and its relation to emulsions stability. Food Hydrocoll 51:512–518.

Sun, X. D., and R. A. Holley. 2011. Factors influencing gel formation by myofibrillar proteins in muscle foods. Compr. Rev. Food Sci. Food Saf. 10:33–51.

Thomas, R., A. S. R. Anjaneyulu, Y. P. Gadekar, H. Pragati, and N. Kondaiah. 2007. Effect of comminution temperature on the quality and shelf life of buffalo meat nuggets. Food Chem. 103:787–794.

Tornberg, E. 2005. Effects of heat on meat proteins - Implications on structure and quality of meat products. Meat Sci. 70:493–508.

Triki, M., A. M. Herrero, F. Jimenez-Colmenero, and C. Ruiz-Capillas. 2013. Effect of preformed konjac gels, with and without olive oil, on the technological attributes and storage stability of merguez sausage. Meat Sci. 93:351–360.

Utrilla, M. C., A. G. Ruiz, and A. Soriano. 2014. Effect of partial replacement of pork meat with an olive oil organogel on the physicochemical and sensory quality of dry-ripened venison sausages. Meat Sci. 97:575–582.

Wu, M., J. Wang, J. Hu, Z. Li, R. Liu, Y. Liu, Y. Cao, Q. Ge, and H. Yu. 2020. Effect of typical starch on the rheological properties and NMR characterization of myofibrillar protein gel. J. Sci. Food Agric. 100:258–267.

Yong, H. I., S. H. Lee, S. Y. Kim, S. Park, J. Park, W. Choe, and C. Jo. 2019. Color development, physiochemical properties, and microbiological safety of pork jerky processed with atmospheric pressure plasma. Innov. Food Sci. Emerg. Technol. 53:78–84.

Youssef, M., and S. Barbut. 2011. Fat reduction in comminuted meat products-effects of beef fat, regular and pre-emulsified canola oil. Meat Sci. 87:356–360.

Youssef, M. K., and S. Barbut. 2010. Physicochemical effects of the lipid phase and protein level on meat emulsion stability, texture, and microstructure. J. Food Sci. 75:S108–S114.