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Compositional Differences Among Types of Mechanically Separated Chicken and Their Influence on Physicochemical Attributes of Frankfurter-Type Sausages[1]

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Abstract: Mechanically separated chicken (MSC) from 2 different separation methods (MSC1, Beehive separator, aged bones [Provisur Technologies, Mokena, IL]; MSC2, Poss separator, fresh bones [Poss Design Limited, Oakville, Ontario, Canada]) and chicken breast trim (CBT) were used as raw materials in frankfurters. Texture, color, and lipid oxidation were measured over a refrigerated storage period of 98 d. Both MSC were higher in fat and lower in moisture than CBT. MSC frankfurters had lower L^* and higher a^* values than CBT frankfurters, with MSC2 frankfurters having the lowest L^* and highest a^* ($P < 0.05$). Thiobarbituric acid-reactive substances values were higher in MSC1 frankfurters ($P < 0.05$) than in CBT and MSC2 frankfurters. Texture Profile Analysis hardness, cohesiveness, resilience, and chewiness were highest in MSC2 frankfurters. Differences among MSC resulted in detectable differences in finished product attributes, with MSC2 frankfurters being darker and redder and having lower levels of lipid oxidation than MSC1 frankfurters, underscoring the importance of understanding the specific functional attributes of MSC obtained by different processes prior to product formulation and manufacturing.

Key words: mechanically separated chicken, mechanically separated poultry, frankfurters, sausage
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Introduction

Mechanically separated chicken (MSC) is a widely used formulation raw material in mixed-species frankfurters and bologna, as well as many ground poultry meat products such as chicken nuggets and patties. Despite its popularity, however, it has been established that the use of mechanically separated meat or poultry in further-processed meat and poultry products can lead to textural softness, grittiness, off-flavor development, and increased redness (Froning and Johnson, 1973; Daros et al., 2005; Horita et al., 2014; Paulsen and Nagy, 2014). These adverse effects on product quality have been attributed to lower protein functionality and lack of muscle structure that result from the high pressures used in their obtainment, and they limit the extent of commercial utilization of these materials.

Mechanically separated meat and poultry materials are generated by forcing bones—after whole-muscle removal—through a sieve or similar device under high pressure to separate any remaining soft meat material from bone residue. Although the mechanical separation process recovers high amounts of nutritionally valuable protein, it has been well documented to reduce protein functionality and hence detrimentally affect the quality characteristics of finished products. The addition of MSC to processed meat products impacts final product color, texture, and oxidative stability

(Paulsen and Nagy, 2014). It has been reported to have a negative impact on the eating quality of processed products by modifying texture, introducing grittiness, increasing off-flavors, and increasing redness (Froning and Johnson, 1973; Daros et al., 2005; Horita et al., 2014; Paulsen and Nagy, 2014). In one study, compressive and tensile strength of comminuted sausages was significantly reduced when MSC replaced more than 40% of beef and pork raw materials (Daros et al., 2005).

The known variability of mechanically separated meat and poultry materials, which is caused primarily by differences in mechanical separation systems and in source materials (Crosland et al., 1995), has the potential to introduce differences in raw material performance and, therefore, quality attributes of finished meat and poultry products. Little modern literature has looked at the quality of differing MSC types and compared them with each other and with whole-muscle chicken. In this study, two different processing methods used to produce MSC (MSC1: Beehive separator, aged bones [Provisur Technologies, Mokena, IL]; MSC2: Poss separator, fresh bones [Poss Design Limited, Oakville, Ontario, Canada]) were compared with each other and with a whole-muscle chicken breast meat raw material. The aim was to assess the compositional differences among the two MSC and chicken breast trim (CBT) and to evaluate their effects on the physicochemical properties of frankfurter-type sausages, when used as the sole source of meat. We hypothesized that the two MSC raw materials would behave differently in a frankfurter system. Due to the freshness of bones and reduced processing speed, we also hypothesized that the MSC2 raw material would behave more similarly to CBT.

Materials and Methods

Raw materials

Three different chicken raw materials were sourced from commercial broiler chickens (*Gallus domesticus*) approximately 42 d of age at time of harvest, each from a different commercial facility. They consisted of two types of MSC (MSC1 and MSC2) processed under different processing conditions and chicken breast meat (*pectoralis major*, CBT). MSC1 originated from broiler frames and was produced 3–5 d following breast meat removal on a Beehive S88 mechanical separator (Provisur Technologies) with sieve sizes of 1.5, 9.9, and 7.4 mm, and MSC2 was produced from frames of broiler carcasses separated immediately following breast meat removal on a Poss separator (Poss Design Limited). MSC1 and MSC2 were each sampled from 3 production lots produced on 3 consecutive days. CBT was obtained from commercial broilers and sourced from one production lot to reduce variation in poultry fat content. All materials were packaged in 18.2-kg boxes, frozen at −44.4°C for 72 h, and held for 19, 18, and 17 d, respectively, at −17.7°C to −23.3°C before overnight shipping to our laboratory. Upon receipt, they were immediately sampled and analyzed as described subsequently (2.4 proximate composition and pH) and stored at −20°C. Pork backfat (86.6 g/100 g lipid; 11.5 g/100 g moisture; 0.9 g/100 g protein) was sourced from the Iowa State University Meat Laboratory, frozen on day 7 postmortem at −20°C and used within 10 d. All raw materials were thawed at 0°C for 3 d and stored at 4°C for 2 d before processing.

Frankfurter manufacture

Frankfurter formulations are shown in Table 1. All treatments were formulated to a target theoretical final product lipid content of approximately 23%. Frankfurter treatments were designated by "F-" preceding the chicken raw material utilized in its manufacture (i.e., F-CBT, F-MSC1, F-MSC2). Batch sizes were adjusted to 11.36 kg on a total-meat basis. On the day of manufacturing, CBT and pork backfat were

Table 1. Formulations of frankfurters[1] manufactured with different sources of chicken raw materials (values expressed as g/100 g)

Raw material/ingredient	F-CBT	F-MSC1	F-MSC2
CBT[2]	47.30	-	-
MSC1[3]	-	69.46	-
MSC2[4]	-	-	79.78
Pork backfat	22.59	9.72	12.63
Salt	1.46	1.46	1.46
Corn syrup solids	3.50	3.50	3.50
Spices[5]	1.27	1.27	1.27
Dextrose	0.76	0.76	0.76
Sodium tripolyphosphate	0.40	0.40	0.40
Curing salt (6.25% $NaNO_2$)	0.17	0.17	0.17
Sodium erythorbate	0.03	0.03	0.03
Water	22.52	13.23	0.00

[1]Frankfurter treatments designated by "F-" preceding the raw material utilized in its manufacture.

[2]Chicken breast trim.

[3]Mechanically separated chicken obtained from bones 3–5 d of age using Beehive separator (Provisur Technologies, Mokena, IL).

[4]Mechanically separated chicken obtained from fresh bones using Poss separator (Poss Design Limited, Oakville, Ontario, Canada).

[5]Blend of mustard, black pepper, coriander, garlic powder, and red pepper.

ground through a 12.7-mm plate (grinder model 7542; Biro Manufacturing Co., Marblehead, Ohio). Chicken raw material (MSC1, MSC2, or CBT) was added to a 30-L bowl chopper (KILIA-Fleischerei-und Spezial Maschinen-Fabrik GmbH, Neumünster, Germany) along with half of the water/ice, salt, and all other dry ingredients. Batters were chopped at 4,500 rpm under vacuum to 8.3°C, after which the fat and remainder of water/ice were added. Chopping under vacuum at 4,500 rpm continued to a temperature of 12.7°C. Batters were then stuffed into 25-mm cellulose sausage casings (Viscofan, Danville, Illinois) to a target volume of 56 cm^3 per link using a vacuum stuffer and automatic linker (Handtmann VF 608 Plus, Albert Handtmann Maschinenfabrik GmbH & Co. KG, Riss, Germany). Frankfurter links were weighed, hung on stainless steel dowels, and thermally processed in a single-truck Alkar oven (DEC International, Inc., Lodi, WI), following the cycle shown in Table 2, to a final internal temperature of 79.4°C. Smoking was achieved using hickory chips (Chips n' Chunks Hickory All-Natural Wood Chips; Smokehouse Products LLC, Hood River, OR) pyrolyzed by a smoke generator (Alkar Smokemaster, DEC International, Inc.). Product internal temperatures were monitored by calibrated temperature probes built into the oven. Treatment processing order and oven location were randomized.

After thermal processing, frankfurters were transferred to a −1.1°C cooler for approximately 18 h, after which they were weighed and casings removed using an automatic frankfurter peeler (Townsend 2600; Townsend Engineering, Des Moines, IA). Frankfurters were randomized by mixing in a plastic tub, packaged (4 links per package) in 10.16 cm × 25.4 cm plastic bags (oxygen transmission rate of 3–6 cm^3/m^2/24 h at 23°C, 0% relative humidity; Cryovac Sealed Air Corp., Duncan, SC), and vacuum sealed (Ultravac UV 2100; UltraSource LLC, Kansas City, MO). Packages were shrink-wrapped by dipping for 2 s in water at 195°C, placed in cardboard boxes, and stored at 1.1°C under 3,500 K fluorescent display lights (2,300 lux) (Sylvania, Danvers, MA) to simulate retail display, for up to 98 d. Packages were placed in a random arrangement approximately 305 mm from the light source and were repositioned once a week in a random pattern to reduce the effect of location.

Table 2. Thermal processing cycle for frankfurters

	Step time (min)	Dry bulb temperature (°C)	Wet bulb temperature (°C)	Relative humidity (%)	Exhaust fan
Cook	10	43.3	40.5	84	Off
Cook	20	54.4	0	0	On
Smoke	15	54.4	0	0	Off
Smoke	30	62.8	57.2	75	Off
Cook	30	68.3	0	0	On
Cook	15	74.0	62.8	59	On
Steam cook	10	79.4	79.4	100	On
Cold shower	30	10	0	0	On

Batter stability

Batter stability was tested on the day of manufacture following the method of Rongey (1965). Briefly, approximately 25 g of raw batter was inserted into Wierbicki tubes (Wierbicki et al., 1957), placed in a water bath at 71°C for 30 min, allowed to cool at room temperature for 3 min, and centrifuged at 310 × *g* for 10 min. Water (bottom) and lipid (top) layers were read from the graduated part of each tube, and fluid separation was calculated as follows:

$$\%\,Water\ separation = \frac{water\ volume\,(mL)}{sample\ weight\,(g)} \times 100$$

$$\%\,Lipid\ separation = \frac{lipid\ volume\,(mL)}{sample\ weight\,(g)} \times 100$$

Two samples per treatment were analyzed each sampling day, and the results were averaged.

Proximate composition and pH

Proximate composition was determined on all meat raw materials, raw batters, and finished products. Samples were homogenized using a food processor (model KFP715WH2; KitchenAid, St. Joseph, MI). Protein content was determined by the CEM Sprint Rapid Protein Analyzer (AOAC Official Method 2011.04), moisture content by the CEM Smart 6 system (AOAC Official Method 2008.06), and fat content by the CEM ORACLE system (AOAC Official Method 2008.06) (CEM Corporation, Mathews, NC). All analyses were done in duplicate and averaged.

For pH measurement, 90 mL of distilled, deionized water was added to 10 g of ground sample and mixed vigorously with a glass stirring rod for 30 s, and the mixture was filtered through 11-µm–filter paper (Whatman Grade 1; GE Healthcare Life Sciences, Pittsburgh, PA). The pH of the filtrate was measured using a SevenMulti pH meter equipped with an InLab Solids Pro-ISM electrode (Mettler Toledo, Columbus, OH). Each sample pH was measured in duplicate.

Hydroxyproline

Poultry raw materials were analyzed for hydroxyproline content by NP Analytical Laboratories (St. Louis, MO; internal method code HPHV). Briefly, 250 mg of sample was mixed with 6 N HCl in a modified Kjeldahl flask. After oxygen was removed by pulling a vacuum and repeated freezing and thawing, the flask was sealed and placed in a 110°C oven for 24 h to allow for protein hydrolysis. After cooling, an internal standard was mixed, pH was adjusted to 2.2, and hydroxyproline and internal standard were separated on a sodium cation exchange column by pH gradient elution with a temperature gradient of 53°C to 90°C. The separated amino acids were subsequently reacted with ninhydrin and measured spectrophotometrically, after which fractions were injected into a Biochrom amino acid analyzer (Cambridge, UK), and the concentration of hydroxyproline was determined by comparing with a standard solution of known concentration (Lee et al., 1978; Lin, 1982). Measurements were done in triplicate.

Calcium and iron

Poultry raw materials were analyzed for calcium and iron content by NP Analytical Laboratories (St. Louis, MO; internal method codes CAF and FEF, respectively). Briefly, 10 g of sample was ashed in a muffle furnace and analyzed by atomic absorption spectroscopy. Absorbance of test samples was compared with that of iron and calcium to determine concentration. Measurements were done in triplicate.

Lipid oxidation

On days 0, 14, 28, 42, 56, 70, 84, and 98 of storage, 3 frankfurters from one randomly selected package of each treatment were homogenized in a food processor (KFP715WH2; KitchenAid, St. Joseph, MI) and analyzed by the modified 2-thiobarbituric acid method for meat products containing sodium nitrite (Zipser and Watts, 1962). A DU 640 spectrophotometer (model 4320940; Beckman Instruments, Inc., Fullerton, CA) was used to measure absorbance at 532 nm. Analyses were performed in duplicate, and results were averaged.

Color

Color was evaluated at days 0, 14, 28, 42, 56, 70, 84, and 98 of storage. Three frankfurters from one randomly selected package of each treatment were scanned by a LabScan XE colorimeter (model LS 1500; Hunter Associated Laboratories, Inc., Reston, VA) using illuminant D65 (daylight at 6,500 K), 10° observer angle and set to the Commission Internationale de l´Eclairage (CIE; "International Commission on Illumination") L^*, a^*, b^* color space. External color was measured in 2 different locations on each frankfurter's light-exposed surface using a 3.3-mm aperture. For internal color, frankfurters were sliced in half lengthwise, and 2 measurements were taken in the center with a 6.35-mm aperture. Measurements from the same package were averaged.

Texture Profile Analysis

Texture Profile Analysis (TPA) was performed on storage days 0, 14, 28, 42, 56, 70, 84, and 98 using a TA-XT2i Texture Analyser (Texture Technologies, Inc., Scarsdale, NY) equipped with a 30-kg load cell. One randomly selected package of frankfurters from each treatment group was analyzed each sampling day. After equilibration to room temperature for a minimum of 5 h, a 2.54-cm-long section was cut from the center of each frankfurter, positioned on a flat end and compressed twice to 50% of its original height with a 5.08 cm (diameter) × 20 mm (height) aluminum probe (TA-25; Texture Technologies, Inc., Scarsdale, NY) at a test speed of 5.0 mm s^{-1}. The TPA parameters measured were hardness, cohesiveness, chewiness, springiness, and resilience. Three measurements were taken from each package and averaged.

Experimental design and statistical analysis

The experiment was designed as a randomized complete block design replicated 3 times, with each replication corresponding to a frankfurter manufacturing day. MSC materials for each replication were sourced from separate production lots, and CBT material was sourced from one production lot. Data were analyzed using PROC MIXED of SAS version 9.4 (SAS Institute, Inc., Cary, NC). Treatment (MSC1, MSC2, CBT), day of storage, and their interaction were treated as fixed factors and replication as a random factor. The multiple time point measurements were corrected with a Tukey's adjustment and an autoregressive order 1 covariate. Significance was determined at $P < 0.05$.

Results and Discussion

Composition of chicken raw materials

The composition of MSC can vary and is different than that of chicken whole muscle (Satterlee et al., 1971; Ang and Hamm, 1982; Hamm and Young, 1983; Paulsen and Nagy, 2014). The composition of

both MSC types and of the breast trim material (Table 3) were similar to that previously reported for similar materials (Ang and Hamm, 1982; Perlo et al., 2006; Li et al., 2015; Soglia et al., 2016). Moisture content was different ($P < 0.05$) among all materials (CBT > MSC2 > MSC1). Protein content was significantly higher ($P < 0.05$), and fat content was lower ($P < 0.05$), in CBT than in both MSC raw materials. MSC2 was higher ($P < 0.05$) in moisture and lower ($P < 0.05$) in fat than MSC1. Although their protein contents do not differ, hydroxyproline content was higher ($P < 0.05$) in MSC1 (Table 3), indicating higher collagen content, possibly as a result of more bone matter incorporation during mechanical recovery.

Calcium content was very low in CBT (0.01 g/100 g) and higher in both MSC materials, not surprising considering its common use as an indicator of bone matter content in mechanically recovered meat and poultry (Field, 1988). The calcium content of MSC2 (0.09 g/100 g) was lower ($P < 0.05$) than that of MSC1 (0.25 g/100 g) and 64% lower than the US regulatory limit of 0.235% (9 C.F.R. § 381.173, 2020) established for mechanically separated poultry, which suggests less bone crushing—and subsequent lower incorporation into the final material—during its obtainment process. Iron content for both MSC was 2.5 to 3 times higher than for CBT, which is consistent with reports in the literature (Field, 1988; Koolmees et al., 1986; Henckel et al., 2004), but still slightly higher ($P < 0.05$) in MSC2 than in MSC1. The relative differences in calcium content (higher in MSC1) and iron content (higher in MSC2) among the two MSC suggests differential incorporation of bone matter and bone marrow into materials from the two separation processes. In a previous study, Crosland et al. (1995) compared MSC obtained by 2 different deboning machine types and observed a higher calcium content in one despite small differences in iron content among them. Subsequently, Field (1999) noted that the calcium content of mechanically recovered products is not a good estimator of the amount of marrow present and suggested that it should not be used for that purpose.

There were significant ($P < 0.05$) differences in pH among the chicken materials (Table 3). The pH of CBT (5.88) was comparable to that of normal chicken breast reported recently (Li et al., 2015). The pH of MSC is known to be higher due to its bone marrow content (Field, 1988), and in this study, the pH of MSC2 was lower than that of MSC1, which was similar to that reported by Rivera et al. (2000).

Overall, the compositional differences among the two MSC indicate that the MSC2 obtainment process is gentler and results in less incorporation of bone material but probably equivalent amounts of bone marrow.

Composition of raw batters and cooked frankfurters

Although frankfurter treatments were formulated to similar compositional targets, there were differences ($P < 0.05$) both in the raw batters and in the finished cooked products (Table 4). Larger than expected differences among treatments were observed in the cooked frankfurters, which suggests differences in the stability of the product matrix. F-MSC2, in particular, had a lower moisture content and higher fat content, suggesting greater moisture loss during cooking. These differences, however, were not borne out by the calculated yield values.

Batter stability, pH, and cook/chill yields

For batter stability (Table 4), treatment effects were significant only for water separation, which was greater ($P < 0.05$) in F-MSC1 than in F-MSC2. The fact that this difference did not manifest itself in product composition suggests that, although the MSC2 raw batter

Table 3. Composition of chicken raw materials

Raw material[1]	Moisture (g/100 g)	Fat (g/100 g)	Protein (g/100 g)	pH	Hydroxyproline (g/100 g)	Calcium (g/100 g)	Iron (ppm)
CBT	74.41[a]	2.40[c]	23.48[a]	5.88[c]	0.08[c]	0.010[c]	5.75[c]
MSC1	68.35[c]	16.17[a]	14.40[b]	6.82[a]	0.21[a]	0.248[a]	16.57[b]
MSC2	71.00[b]	14.83[b]	14.00[b]	6.70[b]	0.14[b]	0.086[b]	18.67[a]
SEM	0.34	0.16	0.14	<0.01	0.01	0.023	0.52

[1]CBT = chicken breast trim; MSC1 = mechanically separated chicken obtained from bones 3–5 d of age using Beehive separator (Provisur Technologies, Mokena, IL); MSC2 = mechanically separated chicken obtained from fresh bones using Poss separator (Poss Design Limited, Oakville, Ontario, Canada).

[a,b,c]Means in the same column with different superscripts are significantly different ($P < 0.05$).

SEM = standard error of the mean.

Table 4. Least-squares means[1] for main effect of chicken raw material on proximate composition, pH, batter stability, and cook/chill yield of frankfurters

	Raw batter			Cooked				Batter stability (% separation)		
Treatment[2]	Moisture (g/100 g)	Lipid (g/100 g)	Protein (g/100 g)	Moisture (g/100 g)	Lipid (g/100 g)	Protein (g/100 g)	pH	Water	Lipid	Yield (%)
F-CB	61.8^{b}	21.1^{a}	11.5^{a}	57.2^{b}	24.0^{b}	12.5^{a}	6.25^{c}	5.9^{ab}	0.5^{a}	87.1^{c}
F-MSC1	62.9^{a}	20.1^{b}	10.2^{c}	58.3^{a}	22.8^{c}	11.2^{c}	6.69^{a}	9.4^{a}	0.9^{a}	87.3^{b}
F-MSC2	61.0^{c}	21.3^{a}	11.1^{b}	55.4^{c}	25.4^{a}	11.8^{b}	6.59^{b}	3.8^{b}	0.3^{a}	87.8^{a}
SEM	0.24	0.30	0.09	0.26	0.26	0.12	0.02	1.02	0.44	0.38

[1]Means of 3 replications.

[2]F-CBT = frankfurters made with chicken breast trim; F-MSC1 = frankfurters made with mechanically separated chicken obtained from bones 3–5 d of age using Beehive separator (Provisur Technologies, Mokena, IL); F-MSC2 = frankfurters made with mechanically separated chicken obtained from fresh bones using Poss separator (Poss Design Limited, Oakville, Ontario, Canada).

[a,b,c]Means in the same column with different letters are significantly different ($P < 0.05$).

SEM = standard error of the mean.

was more unstable, it did not detrimentally affect yield and product composition. Yields were unaffected by type of raw material ($P > 0.05$). Cooked product pH values were different from each other ($P < 0.05$) and followed the same trend as for their constituent raw materials (F-MSC1 > F-MSC2 > F-CBT) (Table 3).

Texture Profile Analysis

Treatment effects for all TPA attributes were significant ($P < 0.05$), but storage time and treatment × storage time interaction were not. Therefore, only means averaged across all sampling time points are reported (Table 5). F-MSC2 was harder ($P < 0.05$) than both F-MSC1 and F-CBT, which were not different from each other ($P > 0.05$). These results are in contrast with previous literature, which shows a decrease in compressive strength with the addition of MSC (Daros et al., 2005; Massingue et al., 2018). In a companion study to this one (Miller et al., 2020), it was observed that the rheological behavior of myofibrillar extracts of these two MSC was similar, despite differences in proximate composition and collagen content. However, due to these compositional differences (Table 3) and the goal of targeting the same compositional values in all 3 treatments, the frankfurter formulations (Table 1) differed in significant ways, specifically (i) how moisture and fat were incorporated (i.e., as moisture present in the meat or water added to the batch), (ii) the proportion of chicken fat and pork fat present, and (iii) protein quality (i.e., more intact fibers from CBT, more damaged fibers from MSC2). In addition, moisture content was lower in the final F-MSC2. There were, therefore, several confounding factors, which this study could not elucidate, that could account for its greater hardness, such that definitive conclusions will require further research. Daros et al. (2005) reported that addition of MSC as a replacement for beef, pork, and pork fat beyond 60% resulted in reduced compressive and tensile strength, and Massingue et al. (2018) reported decreased hardness

Table 5. Least-squares means[1] for main effect of chicken raw material on texture profile analysis values of frankfurters, averaged across all storage time sampling points[2]

Treatment[3]	Hardness (N)	Resilience (%)	Cohesiveness	Chewiness (N mm)	Springiness (%)
F-CBT	46.02^{b}	36.66^{c}	0.69^{b}	30.18^{b}	95.40^{c}
F-MSC1	44.15^{b}	38.45^{b}	0.67^{c}	29.84^{b}	97.98^{a}
F-MSC2	54.82^{a}	41.50^{a}	0.72^{a}	38.34^{a}	96.68^{b}
SEM	1.68	0.95	<0.01	1.33	0.31

[1]Means of 3 replications.

[2]Days 0, 14, 28, 42, 56, 70, 84, and 98.

[3]F-CBT = frankfurters made with chicken breast trim; F-MSC1 = frankfurters made with mechanically separated chicken obtained from bones 3–5 d of age using Beehive separator (Provisur Technologies, Mokena, IL); F-MSC2 = frankfurters made with mechanically separated chicken obtained from fresh bones using Poss separator (Poss Design Limited, Oakville, Ontario, Canada).

[a,b,c]Means in the same column with different superscripts are significantly different ($P < 0.05$).

SEM = standard error of the mean.

with increasing levels of MSC in mutton and lamb sausages. However, neither of these studies attempted to target the same final product proximate composition at every level of MSC addition, thus making it impossible to rule out the effects of product composition on textural attributes. TPA parameters of resilience, cohesiveness, and chewiness were also highest in F-MSC2, whereas F-MSC1 was more resilient and cohesive than F-CBT ($P < 0.05$). Both MSC-containing frankfurters had higher springiness than F-CBT, which agrees with Massingue et al. (2018), who found an increase in springiness with an increase in the addition of MSC to lamb sausages.

Color

Color data over the 98-d storage period are shown in Table 6. For internal color, treatment effects for all color parameters (L^*, a^*, b^*) were significant ($P < 0.05$), but storage time and treatment × storage time interactions were not. L^* values followed the progression F-CBT > F-MSC1 > F-MSC2 at all sampling time points, except at day 98, when the MSC-containing treatments were not different. a^* values followed the progression F-MSC2 > F-MSC-1 > F-CBT ($P < 0.05$), except at day 98, when there was no difference among F-MSC1 and F-MSC2. There were no differences in b^* values among the 3 treatments, except at day 0, when F-CBT was lower than F-MSC1 and F-MSC2. The differences in L^* and a^* values could be attributed, to some degree, to higher bone marrow content, as suggested by the iron content of the 3 materials (F-MSC2 > F-MSC-1 > F-CBT) (Table 3). These results agree with those of previous studies that have found that increased myoglobin and hemoglobin content in mechanically separated meats cause both higher a/a^* values and lower L/L^* values in processed meat products (Froning and Johnson, 1973; Mielnik et al., 2002).

For external color, treatment and storage time effects for all color parameters (L^*, a^*, b^*) were significant ($P < 0.05$), but treatment × storage time interactions were not. L^* values were higher for F-CBT than for F-MSC1 and F-MSC2 at all time points, and the latter two did not differ except at days 56 and 70 (Table 6). L^* values increased significantly at day 28 in F-CBT and at day 14 in F-MSC1 and F-MSC2 and continued to trend upward, though not significantly, thereafter. a^* values were always lower

Table 6. Least-squares means[1] of color values of frankfurters stored under light display at 1.1°C

Color value	Sampling location	Treatment[2]	Storage time (d)							
			0	14	28	42	56	70	84	98
L^*	External	F-CBT	54.97^{ay}	58.16^{axy}	59.14^{ax}	60.69^{ax}	59.99^{ax}	60.19^{ax}	60.77^{ax}	61.00^{ax}
		F-MSC1	42.30^{by}	46.04^{bx}	46.21^{bx}	47.18^{bx}	46.31^{bx}	48.07^{bx}	48.08^{bx}	47.63^{bx}
		F-MSC2	38.73^{by}	42.92^{x}	43.76^{bx}	44.54^{bx}	42.56^{cx}	44.42^{cx}	44.56^{bx}	45.16^{bx}
	Internal	F-CBT	81.33^{ax}	80.76^{ay}	81.05^{ay}	81.03^{ay}	80.60^{ay}	80.72^{ay}	81.27^{ay}	81.44^{ay}
		F-MSC1	63.43^{bx}	63.32^{bx}	63.31^{bx}	63.79^{bx}	63.74^{bx}	63.83^{bx}	63.68^{bx}	63.07^{bx}
		F-MSC2	60.47^{cx}	60.47^{cx}	60.54^{cx}	60.51^{cx}	60.38^{cx}	60.29^{cx}	61.04^{cx}	62.05^{bx}
a^*	External	F-CBT	13.03^{bx}	11.76^{bxy}	11.14^{bxy}	9.92^{by}	10.31^{cy}	10.31^{cy}	10.33^{by}	9.82^{by}
		F-MSC1	18.63^{ax}	15.89^{ay}	15.69^{ay}	15.56^{ay}	15.71^{by}	15.07^{by}	14.91^{ay}	14.88^{ay}
		F-MSC2	20.91^{ax}	18.27^{ay}	17.84^{ay}	17.70^{ay}	19.33^{axy}	17.57^{ay}	17.30^{ay}	16.21^{ay}
	Internal	F-CBT	3.22^{cx}	3.63^{cx}	3.60^{cx}	3.87^{cx}	3.90^{cx}	3.89^{cx}	3.77^{cx}	4.81^{bx}
		F-MSC1	10.88^{bx}	11.10^{bx}	11.40^{bx}	11.35^{bx}	11.37^{bx}	11.22^{bx}	11.29^{bx}	12.13^{ax}
		F-MSC2	13.98^{ax}	14.16^{ax}	14.16^{ax}	14.28^{ax}	14.27^{ax}	14.13^{ax}	13.92^{ax}	12.80^{ax}
b^*	External	F-CBT	41.86^{ax}	40.35^{axy}	38.32^{axyz}	36.37^{az}	37.11^{ayz}	37.18^{ayz}	37.59^{ayz}	34.98^{az}
		F-MSC1	32.14^{bx}	31.07^{bxy}	29.33^{bxy}	29.32^{bxy}	29.77^{bxy}	29.31^{bxy}	29.11^{bxy}	27.86^{by}
		F-MSC2	29.37^{bxy}	29.24^{bxy}	27.70^{bxy}	27.68^{bxy}	29.90^{bx}	28.05^{bxy}	28.02^{bxy}	26.24^{by}
	Internal	F-CBT	14.12^{by}	15.18^{axy}	15.59^{axy}	15.22^{axy}	15.23^{axy}	15.08^{axy}	14.92^{axy}	16.19^{ax}
		F-MSC1	16.05^{ax}	15.97^{ax}	16.30^{ax}	15.88^{ax}	15.87^{ax}	15.66^{ax}	15.76^{ax}	15.39^{ax}
		F-MSC2	15.19^{abx}	15.64^{ax}	15.48^{ax}	15.34^{ax}	15.22^{ax}	15.08^{ax}	15.04^{ax}	15.48^{ax}

Standard errors of the mean: L^* external = 1.75; L^* internal = 0.38; a^* external = 0.85; a^* internal = 0.36; b^* external = 1.22; b^* internal = 0.31.

[1]Means of 3 replications.

[2]F-CBT = frankfurters made with chicken breast trim; F-MSC1 = frankfurters made with mechanically separated chicken obtained from bones 3–5 d of age using Beehive separator (Provisur Technologies, Mokena, IL); F-MSC2 = frankfurters made with mechanically separated chicken obtained from fresh bones using Poss separator (Poss Design Limited, Oakville, Ontario, Canada).

[a-c]Within color value and sampling location, means in the same column with different superscripts are significantly different ($P < 0.05$).

[x-z]Within color value and sampling location, means in the same row with different superscripts are significantly different ($P < 0.05$).

in F-CBT than in the MSC-containing treatments—which did not differ from each other except at days 56 and 70—and decreased significantly starting at day 42 in F-CBT and at day 14 in F-MSC1 and F-MSC2. These changes in L^* and a^* over time during display lighting conditions indicate light-induced color fading in all 3 treatments and suggest that the pigments were more unstable in the MSC-containing samples. b^* values in F-CBT were always higher than in the MSC-containing treatments and decreased significantly from day 0 at day 42 and beyond, whereas in the latter, they remained constant throughout the storage period. Previous studies in other processed meat products have also reported reduced a^* and increased L^* values over time (Yen et al., 1988; Møller et al., 2003; Nannerup et al., 2004).

Lipid oxidation

Results are shown in Figure 1. There were no significant effects of storage time on thiobarbituric acid-reactive substances (TBARS) values for all treatments over the entire 98-d storage period ($P < 0.05$), which is not surprising given the known antioxidant activity of sodium nitrite and oxidative stability of vacuum-packaged products. There were, however, significant raw material treatment effects ($P \geq 0.05$). TBARS values were significantly higher ($P < 0.05$) in F-MSC1 than in both F-CBT and F-MSC2 frankfurters for the duration of the study, indicating that the MSC1 raw material had elevated levels of rancidity at the time of product manufacturing. Although it is standard industry practice to break and grind mechanically separated poultry materials in frozen form to minimize lipid oxidation, in this study they were allowed to thaw completely (3 d at 0°C followed by 2 d at 4°C) in order to better assess their stability relative to each other. TBARS values in F-MSC2 were lower than in F-MSC1, despite its higher lipid content (Table 4) and the higher iron content of its chicken meat raw material, MSC2 (Table 3). Increased lipid oxidation of MSC compared with intact muscle chicken is well-documented (Baker and Kline, 1984; Mielnik et al., 2002; Olsen et al., 2005; Paulsen and Nagy, 2014), given the favorable conditions for lipid oxidation promoted by the poultry mechanical separation process, such as increased iron content, greater surface area (which allows for greater exposure to oxygen), and increased temperature. The higher TBARS values of F-MSC1, when compared with F-MSC2, can be attributed to factors such as longer bone holding time before mechanical separation (3–5 d for MSC1 as opposed to 0 d for MSC2), a more aggressive separation process, and/or the fact that the materials were generated in different manufacturing facilities. Given that the 3 chicken raw materials utilized were readily available commercial materials, it is evident that the extended thawing time to which they were subjected in this study accelerated lipid oxidation in an MSC1 material that was already more susceptible to lipid oxidation.

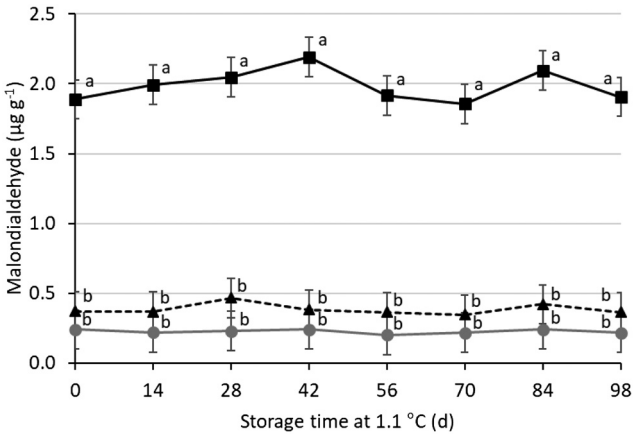

Figure 1. Least-squares means for main effect of chicken raw material on TBARS values of frankfurters stored under light display at 1.1°C. Error bars indicate ± SEM (=0.014). F-CBT (•); F-MSC1 (■); F-MSC2 (▲). [a,b]Means with different superscripts are significantly different ($P < 0.05$). F-CBT = frankfurters made with chicken breast trim; F-MSC1 = frankfurters made with mechanically separated chicken obtained from bones 3–5 d of age using Beehive separator (Provisur Technologies, Mokena, IL); F-MSC2 = frankfurters made with mechanically separated chicken obtained from fresh bones using Poss separator (Poss Design Limited, Oakville, Ontario, Canada); TBARS, thiobarbituric acid-reactive substances.

Conclusions

Although previous studies have generally reported lower quality in products made with MSC than with whole-muscle materials, this study found the functional properties of 2 different types of MSC to be different. Frankfurters produced with MSC2 exhibited equal or better performance in all textural characteristics and in lipo-oxidative stability than those made with MSC1 or the more intact CBT. Both MSC frankfurters were darker and redder than CBT frankfurters, but MSC2 frankfurters were darker and redder than MSC1 frankfurters. Our results demonstrate that the compositional and functional properties of MSC raw materials are variable and dependent to a great degree on their obtainment process and that this variability can, in turn, affect finished product quality attributes. Further research is needed to elucidate with more specificity the degree to which specific mechanical separation process variables (e.g., type of

process, bone source and age, freezing and thawing conditions) impact the functional quality of the resulting MSC materials.

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