



Effect of Salt Inclusion Level on Commercial Bacon Processing and Slicing Yields

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Abstract: The objectives were to determine effects of salt inclusion on production yields, commercial slicing yields, sensory characteristics, and lipid oxidation of bacon. A total of 144 bellies that ranged in weight from 5.8 to 6.6 kg were selected from 2 different suppliers. Fresh bellies were weighed to determine an initial weight (green weight). Then, bellies were randomly assigned to salt levels of 1.2, 1.5, or 1.8% in the final product and manufactured into bacon. Bacon was stored frozen, in aerobic packages, for approximately 0 d, 30 d, 60 d, or 90 d and analyzed for lipid oxidation. Sensory analysis was conducted approximately 14 d after slicing and again 90 d later. Cook yield was increased ($P \leq 0.05$) in 1.2% bacon compared with 1.5 and 1.8% bacon, but slicing yield was 1% unit greater ($P \leq 0.05$) in 1.8% bacon compared with 1.2% bacon. Increasing salt content from 1.5 to 1.8% increased the number of bacon slices generated from a slab of bacon by 12 slices and by nearly 16 slices when compared with the 1.2% treatment. Sensory saltiness increased ($P \leq 0.05$) as intended salt level increased. Lipid oxidation and oxidized odor and flavor intensity was not different among salt treatment levels within any storage period. Reducing salt from 1.8 to 1.2% in bacon can adversely affect slicing yield, but was not detrimental to cook yield and did not reduce the rate of lipid oxidation of bacon.

Keywords: bacon, lipid oxidation, low sodium, salt

Meat and Muscle Biology 1:8–17 (2017)

doi:10.22175/mmb2016.11.0005

Submitted 11 November 2016

Accepted 29 March 2017

Introduction

Increased intake of dietary sodium has been linked to hypertension and increased risk of heart disease. Therefore, public health officials are recommending reduced dietary intake of salt (Desmond, 2006). In the U.S., meat products contribute approximately 21% of the sodium intake of adults, and salt content of processed meats has become a major issue for the meat industry (Desmond, 2006). However, because of the functionality of salt in processed meats, reduction of salt in these products can adversely affect production yield (pump uptake, cook yield, slicing yield and slice count in bacon), flavor, shelf life, and food safety (Aaslyng et al., 2014).

Reducing salt in cooked sausage from 1.95 to 1.20% negatively affected consumer preference (Aaslyng et al., 2014; Ruusunen et al., 1999). Added salt decreased

water activity in fresh products such as ground beef and further processed products such as hot dogs, reducing moisture of the meat (Sofos, 2008) and limiting the ability of bacterial organisms to grow and reproduce (Scott, 1957). Though salt imparts several positive functional qualities, it can also be detrimental to shelf life. Salt expedites lipid oxidation by accelerating activity of lipoxygenase present in the muscle, contributing to the development of rancidity (Jin et al., 2011). Flavor is one of the most important quality attributes for pork and an increase in off-flavors and rancidity can decrease consumer preference (Gandemer, 2002). Greater levels of salt, in ground pork patties, increased lipid oxidation over time and the increase in lipid oxidation was detected as an increase in off-flavors and rancidity (Overholt et al., 2016a). While sodium chloride directly affects the initiation of lipid oxidation, metal cations in salt can also act as pro-oxidants, further contributing

to increased rancidity and off flavors through increased rate of lipid oxidation (Overholt et al., 2016a; Love and Pearson, 1971). Therefore, reducing salt in processed meats may be beneficial in slowing the development of rancidity and associated off-flavors and off-odors.

Despite the known functionality of salt and the interest in reducing its level in processed meats, little direct research on reducing salt inclusion in bacon is available. This includes limited research on the effects of reducing salt on cook yield and commercial bacon slicing yields. Muscle and meat products tend to release excess fluids during processing and storage resulting in an increase in weight loss and dehydration, and ultimately decreasing overall yield (Kauffman et al., 1986). Salt is often added to meat products to improve water holding capacity (Puolanne et al., 2001) with the expectation that an increase in water holding capacity will improve overall yield. Because salt increases the water-binding of meat (Puolanne et al., 2001), it is expected that a reduction of salt in bacon would result in reduced cook yield as well as a reduction in commercial bacon slicing yield. A reduction in salt also negatively affected flavor and consumer preference of bacon and other further processed products (Aaslyng et al., 2014; Ruusunen et al., 1999). A reduction in salt inclusion could also negatively affect perceived saltiness. The effect of reducing salt inclusion in bacon on slicing yield, development of lipid oxidation, and sensory saltiness has yet to be determined.

While reducing salt inclusion in bacon may result in a lower sodium product and slow the rate of lipid oxidation, due to the relationship between water holding capacity and cook yield, it is expected that reducing salt inclusion in bacon would also reduce pump uptake and cook yield. A reduction in pump uptake inhibits the ability of the curing solution to deliver the nitrite to myoglobin necessary for the cure reaction to take place. Therefore, the objective was to determine the effects of salt inclusion level on processing yields specifically to include pump yield, cooked yields, and commercial bacon slicing yields. It was also intended to determine effects on saltiness and oxidized flavor, and lipid oxidation of bacon.

Materials and Methods

Fresh bellies were obtained from a USDA Food Safety Inspection Service bacon processing facility, manufactured into sliced bacon, and transported to the University of Illinois Meat Science Laboratory. Therefore, a review of procedures by the University of Illinois Institutional Animal Care and Use Committee was not needed.

Experimental design

A total of 144 bellies were selected at random from within a specified weight class (5.8 to 6.6 kg) from 2 different suppliers (bellies per supplier = 72). Selected bellies met the specifications of a #409 belly; skinned and free from bone, cartilage, and leaf fat, as described by the North American Meat Processors Association (2007). Diets and management of pigs within supplier were not made known to the investigators beyond the fact that pigs within supplier were all managed and fed similarly. Therefore, supplier served as a block in this experiment. Within each block, 24 bellies were randomly assigned to 1 of 3 targeted salt levels in the final product: 1.2%, 1.5% (industry average), or 1.8%.

Fresh belly characteristics

Fresh bellies were weighed to determine an initial weight (green weight). An adipose tissue sample for fatty acid profile analyses was collected from the dorsal edge of the anterior end of each belly. The sample was free of lean and contained all 3 layers of adipose tissue. Flop distance was determined by placing bellies lateral side down, over a stationary bar, and measuring the distance between the inside edges. Dimensional characteristics (width, length, and depth) were determined using a MeatMaster food analyzer (FOSS North America, Eden Prairie, MN).

Fatty acid profile

Fresh adipose tissue samples were prepared using the procedure described by Overholt et al. (2016b). Fat samples were submerged in liquid N₂ until completely frozen and then pulverized and homogenized in a blender (Waring Products, Torrington, CT) until completely powdered. The resulting powder was collected and used to obtain fatty acid methyl esters according to the procedure described by the American Oil Chemists' Society (AOCS, 1998) official method Ce 2 to 66. The resulting fatty acid methyl esters extract were analyzed using a gas chromatograph (Hewlett-Packard 5890 Series II; Agilent Technologies, Santa Clara, CA) equipped with an auto-sampler and a DB-Wax capillary column (30 m × 0.25 mm × 0.25 μm film coating; Agilent Technologies, Santa Clara, CA). The equipment was operated under a constant pressure of 1.30 kg/cm² using He gas as the carrier and a 100:1 split ratio. Temperature of the injector was held at 250°C and the temperature of the flame-ionization detector was held at 260°C. The oven was operated at 170°C for 2 min and programmed to increase 4°C/min

up to 240°C and then held constant for 12.5 min. The resulting chromatograph peaks were integrated using Agilent Chemstation software for gas chromatograph systems (version B.01.02; Agilent Technologies, Inc.). Peaks were identified using a gas chromatograph reference standard (GLC 461 A, Nu-check-prep, Elysian, MN). Fatty acids were normalized such that the area under each peak was calculated as a percentage of the total area. Individual fatty acids were expressed as a percentage of total fatty acids analyzed and then used to calculate iodine value. Iodine value was calculated using both the AOCS (1998) equation:

$$\text{Iodine Value} = \text{C16:1} (0.95) + \text{C18:1} (0.86) + \text{C18:2} (1.732) + \text{C18:3} (2.616) + \text{C20:1} (0.785) + \text{C22:1} (0.723)$$

and an equation by Meadus et al. (2010) that accounted for long chain polyunsaturated fatty acids (PUFA):

$$\text{Iodine Value} = \text{C16:1} (0.95) + \text{C18:1} (0.86) + \text{C18:2} (1.732) + \text{C18:3} (2.616) + \text{C20:1} (0.795) + \text{C20:2} (1.57) + \text{C20:3} (2.38) + \text{C20:4} (3.19) + \text{C20:5} (4.01) + \text{C22:4} (2.93) + \text{C22:5} (3.68) + \text{C22:6} (4.64)$$

Bacon manufacturing and slicing

Bellies were injected by treatment group with a commercial cure solution that differed only in salt content. The cure solution was formulated to deliver 1.2, 1.5, or 1.8% sodium chloride (salt) in the final product with a targeted pump uptake of 13%. The cure solution was formulated to deliver 1.19% sugar, 0.50% sodium phosphate, 120 mg/kg nitrite, and 550 mg/kg erythorbate. Bellies were weighed immediately after injection to calculate pump uptake using the following equation:

$$\text{Pump Uptake} = [(\text{Injected weight} - \text{Initial weight}) / \text{Initial weight}] \times 100$$

Bellies were hung on smoke house trees within treatment groups. Bellies were cooked to an internal temperature of 53.3°C and did not receive any wood or liquid smoke during thermal processing. Cooked bellies were chilled for approximately 24 h, before slicing, to an internal temperature between -5.6 and -4.4°C. Chilled bacon slabs were weighed to calculate cook yield using the following equation:

$$\text{Cook yield} = [(\text{Cooked weight} - \text{Initial weight}) / \text{Initial weight}] \times 100$$

Bacon slabs were pressed and then sliced with an automated slicer, anterior end first, to attain a target of 27 to 31 slices per kg (12 to 14 slices per pound). Slices were sorted by trained personnel, based on grading procedures of the manufacturer, to remove incomplete slices, end pieces, and slices of unacceptable quality. The total number of slices were counted and recorded for each bacon slab. Starting at the anterior portion, bacon slabs were divided into 5 equal zones (A, B, C, D, and E) with approximately equal slices in each zone similar to Tavárez et al. (2014). The number of slices within a zone differed for each sliced bacon slab based on total number of slices in each sliced bacon slab such that each quintile was equally represented.

Bacon slice proximate composition

Moisture and extractible lipid of bacon slices was quantified in the manner described by Novakofski et al. (1989). Five-g samples were weighed in duplicate and placed in a drying oven at 110°C for at least 24 h. After drying, samples were weighed to quantify moisture loss and lipid was extracted using an azeotropic mixture of chloroform and methanol (87:13). Samples were placed back in the drying oven for at least an additional 24 h before collecting a lipid extracted weight. Percent moisture and extractible lipid were determined by the difference between initial weight, dried weight, and extracted weight.

Salt content

Two slices from each zone (A, B, C, D, and E) were collected, combined, and homogenized in a blender (Waring Products). Percent salt content was analyzed, on each sample, according to the procedure described by the Association of Official Analytical Chemists (AOAC, 1990) official method 971.27, using potentiometer titration.

Lipid oxidation

Two slices from the middle of each bacon slab (Zone C) were assigned to storage times of 0 d, 30 d, 60 d, and 90 d, for a total of 8 slices per sliced bacon slab. Slices were laid flat on white parchment paper, identified by belly ID, stacked in cardboard boxes (ULINE S-16463) based on treatment, and stored at -29°C. These slices were stored exposed to oxygen. Slices for 0 d analysis were vacuum packaged on plastic lined cardstock to limit oxidation before analysis. Storage conditions and durations were

based on previous work evaluating the shelf-life of food service style bacon (Lowe et al., 2014).

For each storage time, 144 samples, representing each sliced bacon slab, were analyzed over the course of 4 d. Only 36 samples could be analyzed on a given day. Therefore, bacon slices were randomized to sampling groups such that equal numbers of each treatment by supplier combination were present in each sampling group. One sampling group was then analyzed each day in 30-d intervals starting at d 33 of storage through d 36 of storage, d 63 of storage through d 66 of storage, and d 93 of storage through d 96 of storage. These data are reported as 0 d, 30 d, 60 d, and 90 d for simplicity.

Lipid oxidation was measured using the thiobarbituric acid reactive substances procedure described by Herrick et al. (2016). Lipid oxidation was expressed as mg MDA/kg of meat and also corrected for lipid content using data from proximate analysis and expressed as $\mu\text{g/g}$ lipid.

Sensory analysis

Exempt status from the University of Illinois Institutional Review Board was not sought. However, sensory work for this experiment followed the 2013 WMA Declaration of Helsinki. Participation in the panels was voluntary. Panelists consented to participate in the research. The study involved minimal or no risk to the panelists as they consumed bacon samples that were inspected and deemed wholesome by a Food Safety and Inspection Service inspector. Each panelist was informed that they were not obligated to consume any sample they chose not to. All panelist personal information was kept confidential. Three slices from zone C were collected for sensory analysis. Slices were packaged in the same manner as those analyzed for lipid oxidation. Slices for initial analyses were vacuum packaged to limit lipid oxidation and evaluated approximately 14 d after slicing (11 d after evaluation for lipid oxidation). Final sensory analysis was conducted 90d after initial sensory analysis. To accomplish sensory analysis in a timely manner and given the limited numbers of samples trained panelist could evaluate each day, a subset of samples were used for sensory analysis. Thirty six sliced bacon slabs from each salt inclusion group, a total of 108 samples, were used for sensory analysis. Samples were randomly selected from all 3 treatment groups and balanced by supplier such that each treatment and supplier combination was equally represented.

A total of 18 sensory sessions for initial sensory were conducted over the course of 9 d with each session having 6 samples (1 each from every supplier by salt treatment combination). No more than 2 sessions

occurred per day, and concurrent sessions were held a minimum of 1 h apart. A total of 18 sensory sessions, for final sensory, were conducted over the course of 6 d with each session having 6 samples. Bacon slices were randomized to sensory sessions, therefore, between initial and final sensory analysis there was a minimum of 90 d and a maximum of 98 d of frozen storage.

Twelve panelists were trained according to the American Meat Science Association Guidelines (AMSA, 1995). Panelists used a 15-cm anchored, unstructured line scale where 0 = no oxidized flavor, oxidized odor, or saltiness and 15 = extreme oxidized flavor, oxidized odor, or saltiness. Panelists were trained using a 1.0, 1.5, and 2.0% salt solution, such that 1.0% salt was ~ 3.5 , 1.5% salt was ~ 7.5 , and 2.0% salt was ~ 10.5 cm on the 15-cm line scale. Six panelists were selected from the possible 12 for each panel. Panelists were separated in individual booths and provided apple juice and unsalted crackers as palate cleansers. Panelists were also given ground coffee to smell and serve as an olfactory palate cleanser. Panelist scores for each sample were averaged for analysis.

Prior to evaluation, samples were thawed overnight at 6°C . Slices were placed on racks on baking sheets and cooked at 204°C for 14 min in a convection oven (Southbend Model V-15, Fuquay-varina, NC). Halfway through cooking, baking sheets were rotated to ensure all samples were uniformly cooked. Cooked slices were cut into 2.54-cm pieces and served hot immediately after being removed from the oven and cut into sections. Each panelist received 3 pieces per sample on a small paper plate. Samples were identified with randomized single digit codes and were presented to panelists in numerical order.

Statistical analyses

Data were analyzed using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC). For fresh belly characteristics, fatty acids, belly processing characteristics, and proximate composition, the model included the fixed effect of salt inclusion level and the random effect of supplier. Normality of residuals was tested using the UNIVARIATE procedure of SAS. Effect of salt treatment was considered significant at $P \leq 0.05$, and least square means were separated using a probability of difference statement.

Data for lipid oxidation and sensory analysis were analyzed using the mixed procedure of SAS with repeated measures (Littell et al., 1998). The model included fixed effects of salt inclusion, storage time, and the interaction between salt inclusion and storage time. Supplier was included in the model as a random variable. An unstructured covariance structure was selected for all

dependent variables based on the Akaike's information criteria (Littell et al., 2002). Main effects and interactions were considered significant at $P \leq 0.05$. Means were separated using a probability of difference statement using a Tukey's adjustment for multiple comparisons.

Results

Fresh belly characteristics and fatty acid profile

Belly weight among salt treatments were similar ($P = 0.56$, Table 1). Despite similarities in weights, bellies did differ in length, depth, density, and flop among salt treatments. The 1.2% bellies had approximately 2 cm greater ($P \leq 0.05$) flop distance compared with the 1.5 and 1.8% bellies, but flop distance did not differ between the 1.5 and 1.8% bellies. The 1.8% bellies were shorter ($P \leq 0.05$) than the 1.2 and 1.5% bellies, but length did not differ between the 1.2 and 1.5% bellies. Belly depth was greater ($P \leq 0.05$) in the 1.8% bellies compared with the 1.2 and 1.5% bellies but did not differ between the 1.2 and 1.5% bellies. The 1.8% bellies were more ($P \leq 0.05$) dense than the 1.2 and 1.5% bellies, and 1.2% bellies were more ($P \leq 0.05$) dense than the 1.5% bellies.

Despite similar weights, iodine value differed among salt treatments. Iodine value was reduced by approximately 2 units ($P \leq 0.05$) in 1.2% bellies compared with 1.5 and 1.8% bellies, but did not differ between 1.5 and 1.8% bellies (Table 2). The total number of saturated fatty acids (SFA) was approximately 1 unit greater ($P \leq 0.05$) in 1.2% bellies compared with 1.5 and 1.8% bellies, but did not differ between 1.5 and 1.8% bellies. The unsaturated fatty acids (UFA) to SFA was reduced

($P \leq 0.05$) in 1.2% bellies compared with 1.5 and 1.8% bellies, but did not differ between 1.5 and 1.8% bellies.

Bacon processing characteristics

Neither initial ($P = 0.56$) nor injected weights ($P = 0.90$) were statistically different among treatments, but subtle numerical differences in initial weights resulted in pump uptake differences (Tables 1 and 3). Pump uptake was approximately 1 unit greater ($P \leq 0.05$) in 1.2% bacon slabs compared with 1.5 and 1.8% bacon slabs, which were similar to each other. Cook yield was increased 1 unit ($P \leq 0.05$) in 1.2% bacon slabs compared with 1.8% bacon slabs while cook yield was 0.6 units greater ($P \leq 0.05$) in 1.8% bacon slabs compared with 1.5% bacon slabs. Slice yield on an initial weight basis was not different ($P = 0.11$) among treatments. Slice yield on a cooked weight basis was approximately 3% units greater ($P \leq 0.05$) in the 1.8% bacon compared with the 1.2% bacon, but 1.5% bacon did not differ from either extreme. Total slice count was 16 slices greater ($P \leq 0.05$) in the 1.8% bacon compared with the 1.2% and 12 slices greater than 1.5% bacon, but did not differ between 1.2 and 1.5% bacon. Percent lipid was approximately 3 units greater ($P \leq 0.05$) in 1.2% bacon compared with 1.5 and 1.8% bacon, which were similar to each other.

Lipid oxidation

As frozen storage time increased, lipid oxidation increased ($P \leq 0.05$) approximately 0.46 mg MDA/kg meat from d 0 to d 90 (Fig. 1A). Lipid oxidation (MDA/kg meat) was greater ($P \leq 0.05$) on d 90 compared with d 0 and d 30, but was similar to d 60 within treatments. When thiobarbituric acid reactive substances were corrected for differences in lipid content, lipid oxidation (MDA/kg fat) increased as storage time increased ($P \leq 0.05$, Fig. 1B). As storage time increased, lipid oxidation increased ($P \leq 0.05$) approximately 1.15 μg MDA/kg fat from d 0 to d 90, with each sampling time being greater than the last.

Despite the increase in lipid oxidation with increasing storage time, lipid oxidation did not differ ($P \geq 0.05$) among salt inclusion levels for either the absolute measure or that corrected for lipid content. A lack of interaction ($P = 0.61$) between day of storage and salt inclusion level indicated all treatments oxidized at a similar rate.

Sensory analyses

Saltiness was greater ($P \leq 0.05$) in 1.8% bacon compared with 1.2% bacon, but saltiness of 1.5% ba-

Table 1. Characteristics of fresh bellies assigned to various salt treatments

Item	Salt inclusion level			SEM	P-value
	1.2%	1.5%	1.8%		
Bellies, n	48	48	48		
Initial weight, kg	6.13	6.18	6.16	0.03	0.56
Flop, cm	13.36 ^a	11.55 ^b	11.38 ^b	1.80	< 0.01
Length, cm ¹	60.98 ^a	61.31 ^a	57.96 ^b	0.83	< 0.01
Width, cm ¹	35.04	35.50	35.39	0.48	0.48
Depth, cm ¹	3.05 ^b	3.00 ^b	3.16 ^a	0.03	< 0.01
Density, g lean/cm ³¹	33.26 ^b	30.29 ^c	35.68 ^a	0.97	< 0.01

^{a-c}Means within rows without a common superscript differ ($P \leq 0.05$).

¹Measures were obtained from a MeatMaster food analyzer (FOSS, Eden Prairie, MN).

con was similar to that of 1.2 and 1.8% bacon (Fig. 2A). Saltiness increased ($P \leq 0.05$) with increasing storage time. There was a lack of interaction ($P = 0.49$) between salt inclusion treatment and day of evaluation indicating that saltiness increased with storage at similar rates between salt inclusion levels.

Oxidized flavor and oxidized odor did not differ between treatments during initial or final sensory analysis (Fig. 2B and 2C). However, oxidized flavor and oxidized odor both increased ($P \leq 0.05$) with increasing storage time. There was no interaction ($P \geq 0.88$) between salt level and day of storage, indicating that oxidized flavor and oxidized odor increased at similar rates between salt inclusion levels during storage.

Discussion

As meat processors are challenged to reduce salt as a response to human health concerns, changes in product quality and processing yields may be expected due to the functionality of salt in processed meats. Processing yield is a multi-faceted trait encompassing pump uptake, cook yield, slicing yield and slice count in bacon. In terms of pump uptake and cook yield, bacon with 1.2% salt inclusion was greater than 1.8% in contrast to previously published reports. Typically, additional salt inclusion would result in increased pump uptake due to increased water holding capacity (Puolanne et al., 2001; Gault, 1985). Aaslyng et al. (2014) indicated that, spe-

Table 2. Fatty acid profile (g/100g fatty acid methyl esters) of bellies assigned to various salt treatments¹

Item	Salt inclusion level			SEM	P-value
	1.2% Salt	1.5% Salt	1.8% Salt		
Bellies, n	48	48	48		
C14:0	1.30 ^{ab}	1.25 ^b	1.33 ^a	0.02	0.03
C16:0	22.67 ^a	21.85 ^b	22.31 ^{ab}	0.24	< 0.01
C16:1	2.41	2.46	2.58	0.08	0.09
C18:0	10.94	10.55	10.44	0.17	0.05
C18:1 _{n-9}	41.35	41.49	41.03	1.75	0.64
C18:2 _{n-6}	17.65	18.58	18.56	1.66	0.26
C18:3 _{n-3}	0.63 ^b	0.75 ^a	0.76 ^a	0.08	0.04
C20:1 _{n-9}	0.76	0.75	0.73	0.06	0.35
C20:2 _{n-6}	0.80	0.85	0.83	0.03	0.18
C20:3 _{n-6}	0.10	0.10	0.10	0.00	0.60
C20:4 _{n-6}	0.26	0.26	0.26	0.01	0.56
C20:3 _{n-3}	0.09	0.11	0.10	0.01	0.09
C22:4 _{n-6}	0.03	0.05	0.04	0.01	0.07
C22:5 _{n-3}	0.00	0.00	0.00	0.00	0.00
C22:6 _{n-3}	0.00	0.01	0.01	0.01	0.35
Total saturated fatty acids (SFA) ²	35.45 ^a	34.15 ^b	34.57 ^b	0.29	< 0.01
Total monounsaturated fatty acids (MUFA) ³	44.51	44.70	44.34	1.88	0.75
Total polyunsaturated fatty acids (PUFA) ⁴	19.45	20.55	20.51	1.78	0.21
UFA:SFA ⁵	1.81 ^b	1.92 ^a	1.89 ^a	0.03	< 0.01
PUFA:SFA ⁶	0.55	0.61	0.60	0.05	0.07
IV AOCS ⁷	70.69 ^b	72.76 ^a	72.44 ^a	1.50	0.04
IV Meadus ⁸	73.30 ^b	75.61 ^a	75.20 ^a	1.60	0.04

^{a,b}Means within a row for experimental treatments without a common superscript differ ($P < 0.05$).

¹Fatty acids representing less than 0.5% of the total FA and not included in the iodine value equations are not displayed.

²Total SFA = ([C14:0] + [C16:0] + [17:0] + [C18:0] + [C20:0] + [C24:0]); brackets indicate concentration.

³Total MUFA = ([C14:1] + [C16:1] + [18:1_{n-7}] + [18:1_{n-9}] + [20:1]); brackets indicate concentration.

⁴Total PUFA = ([C18:2_{n-6}] + [C18:3_{n-3}] + [C18:3_{n-6}] + [C20:2] + [C20:3] + [C20:4_{n-6}]); brackets indicate concentration.

⁵Unsaturated fatty acids (UFA):SFA = (total MUFA + total PUFA)/total SFA.

⁶PUFA:SFA = total PUFA/total SFA.

⁷Iodine Value = [C16:1 (0.95) + C18:1 (0.86) + C18:2 (1.732) + C18:3 (2.616) + C20:1 (0.785) + C22:1 (0.723)] (AOCS, 1998).

⁸Iodine Value = [C16:1 (0.95) + C18:1 (0.86) + C18:2 (1.732) + C18:3 (2.616) + C20:1 (0.785) + C20:2 (1.57) + C20:3 (2.38) + C20:4 (3.19) + 20:5 (4.01) + C22:4 (2.93) + C22:5 (3.68) + C22:6 (4.64)] (Meadus et al., 2010).

cifically in bacon, reducing salt from 2.8 to 1.4% did not alter cook yield (calculated from weights before injection and before slicing). However, in this study, that was not the case as reducing salt from 1.8 to 1.2% resulted in an increased pump uptake and cook yield. However, this result is complicated by the compositional differences between 1.2 and 1.8%. Ultimately though, slicing yields of bacon slabs provide the greatest information for processors in terms of total premium saleable product (bacon) that is produced from raw materials (bellies). For slicing yield and slice count, bacon with 1.8% salt inclusion was greater than 1.2% salt inclusion with 1.8% salt bacon having a 3 unit greater slicing yield on a cooked weight basis, a numerically increased slicing yield on a green weight basis, and 16 more slices of bacon per belly. Compared with 1.2% bellies, the 1.8% bellies had greater iodine value and narrower flop distances, usually suggestive of poorer quality bellies (Semán et al., 2013; Boler et al., 2012; Shackelford et al., 1990) and thought to result in poorer slicing yield (Semán et al., 2013). Kyle et al. (2014) reported a ~3 unit increase in iodine value and a ~19 cm decrease in flop distance between barrows and boars, which translated to a ~4% decrease in cooked slice yield. However, Tavárez et al. (2014) and Overholt et al. (2016b) reported no differences in cooked slice yield in pigs fed 0 and 30% dried distillers grains with solubles regardless of a 7 to 8 unit difference in iodine value. One possible explanation for an increase in cooked slice yield in 1.8 compared with 1.2% bacon slabs is the amount of slices that were removed from the 1.2 vs the 1.8% bacon

slabs. As salt inclusion is increased, the number of salt soluble proteins (specifically myosin) extracted increases (Knight and Parsons, 1988). It is possible that with the increase in salt inclusion to 1.8%, binding strength of the lean was increased and resulted in more stable slices and therefore, fewer sorted slices compared with the 1.2% bacon slabs. Despite these differences between 1.2 and 1.8% in terms of slicing yield, slice yields of 1.2 and 1.5% salt inclusion did not differ. Given that 1.5% salt is a typical industry formulation for bacon, no reductions in slicing yield would be expected by reducing salt to 1.2 from 1.5% based on the results of this study.

Perception of saltiness increased ($P \leq 0.05$) with increasing storage time. It is possible that, over time, open air storage would allow for evaporation of water. The evaporation of water from the product would decrease the water to salt ratio. Therefore, there would be less

Table 3. Effects of salt inclusion level on bacon processing characteristics and proximate composition

Item	Salt inclusion level			SEM	P-value
	1.2%	1.5%	1.8%		
Bellies, n	48	48	48		
Initial weight, kg	6.13	6.18	6.16	0.03	0.56
Pumped weight, kg	6.96	6.93	6.94	0.06	0.90
Pump uptake, %	13.42 ^a	12.26 ^b	12.73 ^b	1.13	< 0.01
Cooked weight, kg	6.31	6.25	6.27	0.07	0.46
Analyzed salt content, %	1.00 ^c	1.28 ^b	1.46 ^a	0.04	< 0.01
Cook yield, %	102.8 ^a	101.2 ^c	101.8 ^b	1.30	< 0.01
Sliced weight, kg	5.48	5.50	5.63	0.17	0.17
Slice yield (initial), % ¹	89.38	88.95	91.43	3.00	0.11
Slice yield (cooked), % ¹	86.89 ^b	87.85 ^{ab}	89.77 ^a	1.88	0.05
Slice count, #	164.1 ^b	167.5 ^b	180.0 ^a	2.21	< 0.01
Moisture, %	45.31	46.84	47.04	0.73	0.18
Lipid, %	41.37 ^a	38.39 ^b	38.12 ^b	0.95	0.03

^{a-c}Means within a row lacking a common superscript differ ($P < 0.05$).

¹Slicing yields were calculated by dividing the sliced weight by initial and cooked weight.

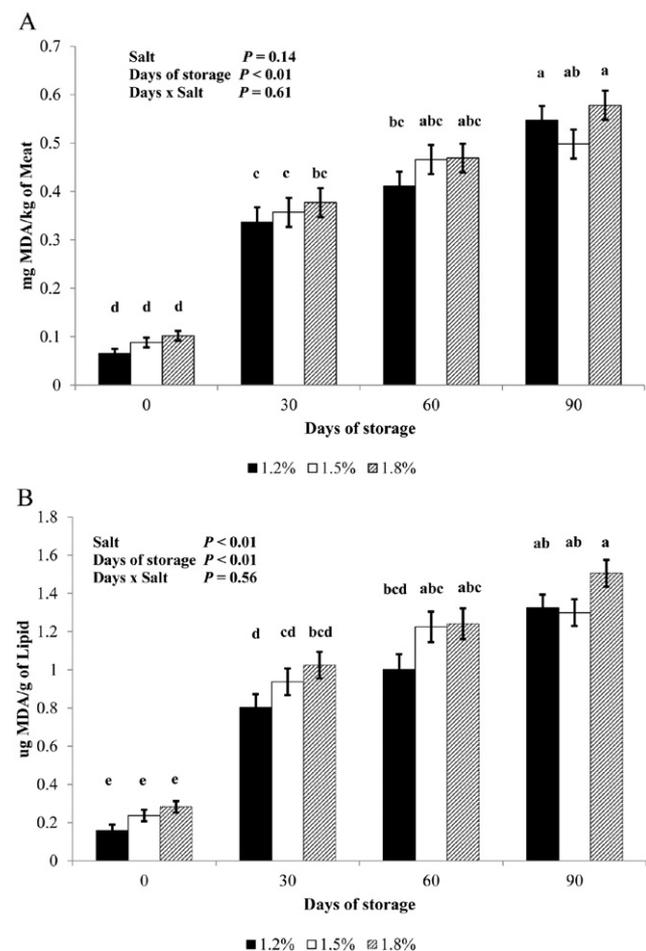


Figure 1. Effect of 3 targeted salt levels (1.2, 1.5, or 1.8%) and 4 storage times (0 d, 30 d, 60 d, or 90 d) on lipid oxidation of bacon. Traits evaluated include (A) thiobarbituric acid reactive substances (mg MDA/kg of meat), and (B) thiobarbituric acid reactive substances (μg MDA/g of fat), corrected for differences in lipid content. Data are depicted as least square means \pm SEM, and means lacking common superscripts differ ($P \leq 0.05$).

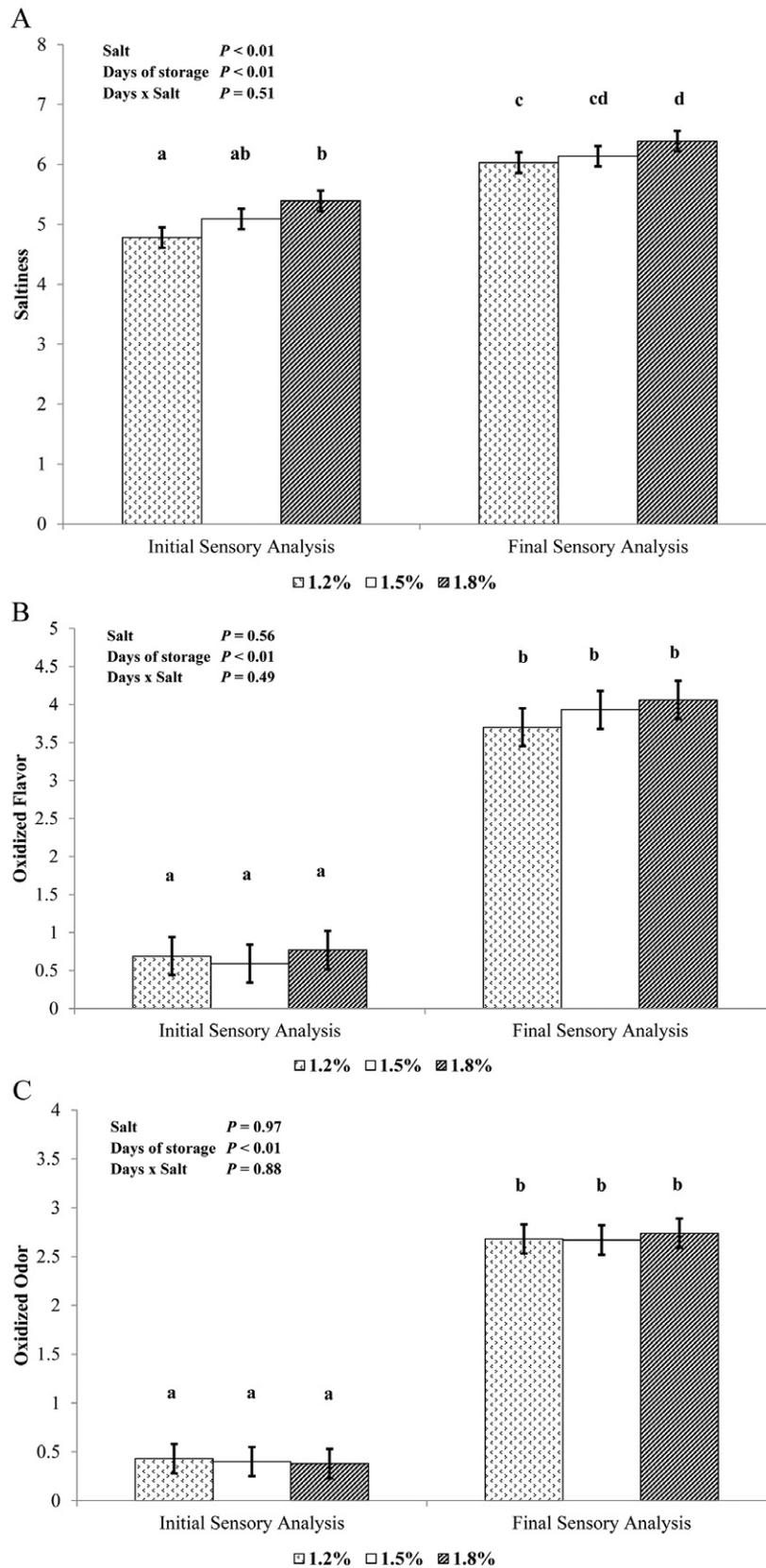


Figure 2. Effect of salt level, time of sensory analysis, and their interaction on saltiness (A), oxidized flavor (B), and oxidized odor (C) of bacon. Data are depicted as least square means \pm SEM, and means lacking common superscripts differ ($P \leq 0.05$). Units were assigned by trained panelist using a 15-cm anchored, unstructured line scale where 0 = no saltiness, oxidized flavor, or oxidized odor and 15 = extreme saltiness, oxidized flavor, or oxidized odor. Initial sensory analysis was conducted 14 to 24 d after slicing. Final sensory was conducted 90 to 97d after initial sensory analysis.

water available to dilute the salt, resulting in an increase in overall perceived saltiness. Extended storage time of up to 90 d of vacuum packaged beef steaks resulted in decreased water holding capacity (Vieira et al., 2009). This in turn resulted in increased freezing loss (dehydration of the steaks, Vieira et al., 2009). Additionally, Overholt et al. (2016a) reported a 13% increase ($P < 0.05$) in saltiness of fresh pork patties, manufactured with 1.5% salt, over an 11 d storage period. Further, Brewer et al. (1991) also reported an increase ($P < 0.05$) in saltiness scores of 80% lean fresh pork sausage blended with 2% salt and stored in vacuum packages for up to 21 d. Potential dehydration of the bacon samples increased the salt content of bacon samples during frozen storages and offers an explanation for the greater saltiness rates of bacon samples after the 90 d storage period compared with the initial sensory rates.

Typically, reducing salt can adversely affect flavor and consumer preference of further processed meat products. In a study by Ruusunen et al. (1999) panelists scored bacon samples, with different levels of salt (1.2, 1.5, and 1.8%) for “pleasantness” or acceptability of taste. Panelists determined that 1.8% salt was more pleasant than 1.2% salt but that there were no differences in pleasantness between 1.8 and 1.5% or 1.5 and 1.2% salt, suggesting there was not enough of a difference between the 1.2% and 1.5% samples to create a panelist distinction (Ruusunen et al., 1999). Although the unstructured line scale used in this current study differs from the hedonic scale used by Ruusunen et al. (1999), and samples were scored based on degree of saltiness rather than preference, the results support one another as there were no differences in saltiness between 1.2 and 1.5% salt. There were no differences in oxidized odors and flavors among treatments. So, it can be speculated that consumers would find bacon manufactured with 1.2 and 1.5% salt similar.

Previous studies have not evaluated differences in lipid oxidation with various levels of salt inclusion, however in other products, such as fresh pork sausage patties, greater levels of salt increased lipid oxidation over time (Overholt et al., 2016a). Therefore, it was hypothesized that reduced salt inclusion would result in a slower rate of lipid oxidation. This was not the case as all levels of salt inclusion oxidized at the same rate and there were no differences between treatments in oxidized odors or flavors. Lipid oxidation of bacon in this study was similar to previous studies (Herrick et al., 2016; Lowe et al., 2014). The threshold range of TBA numbers for detection is approximately 0.05 to 1.0 mg MDA/kg of meat. Based on this accepted threshold of thiobarbituric acid reactive substances levels, all bacon at all storage times would be acceptable to consumers (Greene and Cumuze, 1982).

Conclusions

The results suggest that salt content can be reduced from a typical industry level of 1.5% to 1.2% without having adverse effects on overall bacon yield or perceived saltiness. While increasing salt content in bacon did affect slicing yield and slice count, reducing salt content to 1.2 from 1.5% did not reduce slice count or commercial slice yield. While trained panelists could detect differences in perceived saltiness, oxidized odor and flavor among the treatments were not affected by level of salt content. Also, reducing salt content to 1.2 from 1.5% does not reduce oxidized odor or flavor, or TBARS. Overall, reduction of salt content to 1.2 from 1.5% does not affect percent slice yield nor reduce the rate of lipid oxidation of bacon.

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