Running title: *Salmonella* reduction in frozen NRTE breaded chicken products

Antimicrobials for Reduction of *Salmonella* Contamination in Uncooked, Surface-Browned Breaded Chicken Products

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Key words: *Salmonella*, antimicrobials, uncooked surface-browned breaded chicken products

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ABSTRACT

Surface-browned but uncooked, frozen breaded chicken products have been associated with salmonellosis outbreaks due to inadequate or no cooking of the products before consumption. This study evaluated the effect of three antimicrobials against *Salmonella* during manufacture of a surface-browned, uncooked, frozen breaded chicken meat product. Fresh chicken breast meat portions (5 × 5 × 5 cm) were inoculated (4-5 log CFU/g) with *Salmonella* and mixed with caprylic acid (CAA; 0.5 and 1.0%), carvacrol (CAR; 0.3 and 0.5%), ε-polylysine (POL; 0.125 and 0.25%) or distilled water (control). Sodium chloride (1.2%) and sodium tripolyphosphate (0.3%) were added to all treatments followed by grinding of the mixtures (5% total moisture enhancement level) and forming into 9 × 5 × 3 cm portions. The products were breaded and surface-browned by oven baking (208°C, 15 min) or deep frying in vegetable oil (190°C, 15 s), packaged in polyethylene bags, and stored at -20°C (7 days). Total reductions of inoculated *Salmonella* in untreated control oven- or fryer-browned products after frozen storage were 1.2 and 0.8 log CFU/g, respectively. In comparison, treatment with CAA, CAR or POL reduced initial pathogen counts by 3.3 to >4.5, 4.1 to >4.7, and 1.1 to 1.6 log CFU/g, respectively, irrespective of antimicrobial concentration and browning method. Treatment with 1.0% CAA (oven-browned) or 0.5% CAR (oven/fryer-browned) reduced *Salmonella* to non-detectable levels (<0.3 log CFU/g) in stored frozen products. These data may be useful in the development of suitable antimicrobial treatments to reduce the risk of *Salmonella* contamination in surface-browned, uncooked, frozen breaded chicken products.

Frozen, breaded chicken products containing raw poultry that appear ready-to-eat but in fact are only surface-browned, include raw, frozen chicken nuggets, strips, and stuffed entrees (e.g., chicken cordon bleu, chicken Kiev) *(22)*. Such not-ready-to-eat (NRTE) chicken products have been linked to salmonellosis outbreaks in the United States *(21)*, Canada *(8, 17)*, and Australia *(14)*. Manufacture of such products involves use of raw chicken meat that undergoes particle size reduction to improve protein extraction and binding of meat pieces with the addition of binding ingredients, such as salt and phosphates. Once the product is formed, it undergoes a partial cooking/browning (fried or baked) step to maintain the shape of the product and induce a desirable golden-brown color prior to freezing and packaging; however, the browning step is not a complete lethality step and is not intended to fully cook the product *(3, 19)*.

Since the chicken meat used during manufacture of breaded chicken products is raw, the bacteriological quality of these products should be considered the same as raw poultry *(2, 10)*. Typical control strategies for *Salmonella* in raw chicken products involve chemical antimicrobial interventions applied as rinses, primarily at the slaughter facility *(1, 16)*. However, this process does not eliminate *Salmonella* because raw chicken meat can become cross-contaminated or recontaminated during further processing steps *(3)*. Thus, the raw chicken meat used to manufacture these processed chicken products has a reasonable likelihood of being contaminated with *Salmonella* after which there is no other lethality intervention prior to consumer cooking. A study by Bucher et al. *(3)* found 27% (n=92) of retail and wholesale raw, frozen chicken nugget and chicken strip samples positive for *Salmonella*.

The fact that these products do not appear raw, and sometimes are placed in close proximity to ready-to-eat (i.e., fully cooked) processed chicken products in retail display cases *(20)*, may lead consumers to treat them with less precaution than they typically would a visibly raw

product. Therefore, there is still concern that consumers may undercook these products, making them a significant risk factor in contracting foodborne salmonellosis. Hence, there is a need for the industry to take additional measures to reduce the risk of *Salmonella* contamination in these types of products. Despite the risk of foodborne illness arising from consumption of undercooked, raw, frozen processed chicken products, there has been very little work investigating interventions that can be applied to these types of products to reduce the risk of *Salmonella*. Therefore, the objective of this study was to evaluate the antimicrobial effects against *Salmonella* of caprylic acid, carvacrol, and ε-polylysine, applied individually, on raw chicken meat intended for manufacture of a frozen, surface-browned, uncooked, breaded chicken product.

MATERIALS AND METHODS

Bacterial strains and inoculum preparation. The inoculum was comprised of seven *Salmonella* isolates of chicken or turkey origin (kindly provided by Dr. Vijay Juneja, Microbial Food Safety Research Unit, ERRC-ARS-USDA, Wyndmoor, PA), and included *Salmonella* Hadar FSIS 064/VJS6 (chicken), *Salmonella* Hadar FSIS MF61777/VJS19 (turkey), *Salmonella* Kentucky FSIS 044/VJS2 (chicken), *Salmonella* Kentucky FSIS 062/VJS1 (chicken), *Salmonella* Muenster FSIS MF61976/VJS15 (turkey), *Salmonella* Reading FSIS MF58210/VJS17 (turkey), and *Salmonella* Thompson FSIS 132/VJS7 (chicken). These *Salmonella* serotype strains formed colonies with black centers on xylose lysine deoxycholate (XLD) agar (Acumedia, Lansing, MI) indicating hydrogen sulfide production. The strains were individually cultured and subcultured in 10 ml tryptic soy broth (Difco, Becton Dickinson, Sparks, MD) for 18-24 h at 35°C. The cell

cultures were then combined, harvested by centrifugation (4,629×g, 15 min, 4°C; Eppendorf model 5810 R, Brinkmann Instruments Inc., Westbury, NY) and washed twice in 10 ml phosphate-buffered saline (PBS, pH 7.4; 0.2 g/liter KH_2PO_4, 1.5 g/liter $Na_2HPO_4 \cdot 7H_2O$, 8.0 g/liter NaCl, and 0.2 g/liter KCl). The washed cell pellet was resuspended in 70 ml PBS and further diluted, in PBS, to a concentration of 6-7 log CFU/ml.

Inoculation, treatment, product preparation, and storage. Fresh, boneless, skinless chicken breasts were purchased directly from a poultry processing facility in Colorado. If not used within 24 h, the chicken breasts were vacuum-packaged and stored at -20°C. When needed, they were thawed at 4°C for approximately 48 h before use. The chicken breast meat was cut into pieces (approximately 5 × 5 × 5 cm), and batches of 2 kg were inoculated with 20 ml of the *Salmonella* inoculum to a target level of 4-5 log CFU/g. The chicken meat and inoculum were thoroughly mixed for 2 min using a KitchenAid Professional 600^{TM} mixer (St. Joseph, MI) at a speed setting of "stir", and then left to stand at 4°C for 30 min for bacterial cell attachment. The inoculated batches (2 kg) of chicken meat were then treated with 20 ml of one of the following treatments; as indicated, two concentrations of each antimicrobial were tested: (i) sterile distilled water (control), (ii) caprylic acid (CAA, 0.5 and 1.0% v/w; Fisher Scientific, Hampton, NH), (iii) carvacrol (CAR, 0.3 and 0.5% v/w; Acros Organics, Geel, Belgium), and (iv) ε-polylysine (POL, 0.125 and 0.25% v/w; Chisso Corporation, Minamata, Japan). These antimicrobials were selected for evaluation based on results of a screening study (unpublished data) in which four concentration levels each of 10 antimicrobials (allyl isothiocyanate, caprylic acid, carvacrol, citric acid, grapefruit distilled terpene, malic acid, oregano oil, ε-polylysine, sodium citrate, and sodium lactate) were evaluated for antimicrobial effects against *Salmonella* inoculated on raw

chicken portions. Based on the results of the screening study, caprylic acid and carvacrol were found to be the most effective acid and essential oil, respectively (unpublished data). ε-Polylysine, a cationic surfactant, was not as effective against the pathogen as caprylic acid or carvacrol, but it was included in the present study based on previous published reports *(6, 11, 13)* of its antimicrobial activity against *Salmonella* and other foodborne pathogens.

The inoculated chicken portions, in the present study, were mixed with the distilled water or antimicrobial solution for 5 min using the KitchenAid mixer, followed by addition and mixing (5 min) of sodium chloride (Fisher Scientific) and sodium tripolyphosphate (kindly provided by BK Giulini Corporation, Simi Valley, CA) to yield concentrations of 1.2 and 0.3% (w/w), respectively, in the final product. The mixture, with a total moisture enhancement level of 5%, was then ground (0.6 cm grinder plate) with an electric meat grinder (TSM#8, The Sausage Maker Inc., Buffalo, NY), and formed into rectangular (9 cm length × 5 cm width × 3 cm height) 150 g portions. These product dimensions were representative of commercially-available frozen, NRTE breaded chicken products found in local supermarkets. The portions were then brushed with beaten pasteurized egg whites (All Whites, Crystal Farm, Lake Mills, WI) and rolled in plain (i.e., unseasoned) breadcrumbs (Kroger, Cincinnati, OH), followed by browning for 15 min (900 s) in a standard kitchen oven (Magic Chef, Maytag Corp., Newton, IA) set at 208°C. The temperature of the oven chamber and the geometric center of products was monitored and recorded at 1 s intervals during browning, using type-K thermocouples and PicoLog data acquisition software (Pico Technology Ltd., Cambridge, UK). Samples were flipped over halfway (7.5 min) during the browning period. In a separate study, the same methodology and antimicrobial treatments described above was repeated, but this time, the treated, breaded samples were browned by deep frying (190°C, 15 s) in 3 liters of vegetable oil (Pure Wesson

Vegetable Oil, ConAgra Foods, Omaha, NE), using a Presto Digital Pro Fry deep fryer (Eau Claire, WI). The temperature of the vegetable oil in the deep fryer and the geometric center of products was continuously monitored and recorded at 1 s intervals during browning, as described above. After oven or fryer browning, products were allowed to cool and were then individually packaged in double zipper polyethylene bags (Ziploc, S.C. Johnson, Racine, WI) and stored at -20°C for 7 days.

Microbiological and physicochemical analyses. Samples were analyzed for microbial counts at four points of the process, specifically, (1) after inoculation, (2) after grinding (i.e., approximately 15 min after antimicrobial addition), (3) after browning (i.e., within 2 to 3 min after removal of the products from the oven or fryer), and (4) after 7 days of frozen (-20°C) storage. For sampling points 1 and 2, 25 g samples were analyzed, whereas for analysis points 3 and 4, samples were comprised of the entire 150 g breaded chicken product. Frozen samples (sampling point 4) were thawed for 15-18 h at 4°C before microbial analysis. Samples (25 or 150 g) were placed in a Whirl-Pak filter bag (Nasco, Modesto, CA), to which diluent (0.85% NaCl and 0.1% peptone [Difco, Becton Dickinson]) was added at a 1:1 ratio of sample weight (g) to volume (ml) of diluent. The samples were homogenized (Masticator, IUL Instruments, Barcelona, Spain) for 2 min, serially diluted in 0.1% buffered peptone water (Difco, Becton Dickinson), and surface-plated for *Salmonella* counts on XLD agar, and total bacterial counts on tryptic soy agar (Acumedia) supplemented with 0.1% sodium pyruvate (Fisher Scientific, Pittsburgh, PA) (TSAP). Colonies were enumerated after incubation of plates at 35°C for 24 h (XLD agar) or 25°C for 72 h (TSAP). The detection limit of the analysis was 0.3 log CFU/g. Uninoculated, raw chicken breast meat samples were also analyzed to determine the natural

156 microbial contamination level of the chicken meat used to prepare the surface-browned,
157 uncooked, breaded chicken products.
158 After microbial analysis, pH measurements were taken of the sample homogenates with a
159 Denver Instruments (Arvada, CO) pH meter fitted with a glass electrode. Also, water activity
160 measurements (AquaLab model series 3, Decagon Devices, Pullman, WA) were taken of the
161 surface-browned, breaded chicken products before frozen storage.
162
163 **Statistical analysis.** At each sampling point, three samples per treatment were analyzed in
164 each of two repetitions of each product type (i.e., oven- or fryer-browned). The pH, water
165 activity, and microbiological (converted to log CFU/g) data were analyzed with the PROC
166 MIXED procedures of SAS (version 9.3, SAS Institute Inc., Cary, NC) with independent
167 variables including antimicrobial treatment, sampling point, and their interaction. Means were
168 separated with the Tukey-adjusted procedure and were considered significant when P-values
169 were less than 0.05.
170
171 **RESULTS AND DISCUSSION**
172
173 **Physicochemical properties of products.** The pH values of untreated control surface-
174 browned chicken samples after frozen storage were 6.04 (oven-browned) and 6.19 (fryer-
175 browned) (Tables 1 and 2). Treatment of the chicken breast meat with CAA (0.5 and 1.0%),
176 CAR (0.5%), or POL (0.125 and 0.25%) had, in some cases, statistically significant ($P<0.05$)
177 effects on the pH of the final products (i.e., sampling point 4). However, in all these cases, the
178 actual difference in pH values of these treatments and the pH of the corresponding untreated

control in each study was small (0.09 to 0.30 pH units; Tables 1 and 2). Water activities of untreated surface-browned chicken samples were 0.978 (oven-browned) and 0.977 (fryer-browned), and for samples treated with antimicrobials water activities ranged from 0.975 (0.25% POL) to 0.980 (0.5% CAR) in oven-browned products, and 0.976 (1.0% CAA) to 0.979 (0.5% CAR) in fryer-browned samples (Tables 1 and 2).

Microbial counts during manufacture and after frozen storage of products. Total bacterial counts of the uninoculated, raw chicken breast meat used to prepare the products were 4.7±0.8 to 4.9±0.5 log CFU/g, while hydrogen sulfide-producing populations, on XLD agar, were not detected (<0.3 log CFU/g) in any of the uninoculated samples (data not shown in tables).

Initial inoculated *Salmonella* counts for all treatments ranged from 4.8 to 5.0 log CFU/g, and initial total bacterial counts ranged from 5.0 to 5.5 log CFU/g (Tables 3 and 4). As previously described, between sampling point 1 (i.e., after inoculation) and sampling point 2, inoculated chicken meat portions were treated with an antimicrobial solution or distilled water, salt and phosphate were added and the resulting mixture was ground. During the approximately 15 min period between sampling points 1 and 2, initial pathogen counts of CAA-, CAR-, and POL-treated samples were reduced by 1.8 to >4.4, 3.1 to >4.0, and 0.3 to 0.5 log CFU/g, respectively, irrespective of antimicrobial concentration (Tables 3 and 4). However, only CAA- and CAR-treated samples had significantly ($P<0.05$) lower counts compared to the untreated control at sampling point 2; thus, these antimicrobials and tested concentrations effectively reduced *Salmonella* contamination in the raw, ground chicken breast mixture. CAA is a generally recognized as safe (CFR 184.1025) food-grade chemical and has been found to be effective

against *Salmonella* in sterile chicken cecal contents *(23)* and on alfalfa seeds *(7)*. Use of 0.7 or 1.0% CAA as a feed supplement was also reported to reduce *Salmonella* colonization of day-old chicks *(15)*. CAR is one of the main components of oregano essential oil and its antimicrobial properties against *Salmonella* and other foodborne pathogens, in laboratory media and various food products, are well-documented *(4, 5, 24)*. Addition of 0.6 or 0.9% oregano essential oil to ground sheep meat resulted in significant reductions of *Salmonella* Enteritidis populations during a 12-day storage period at 4 or 10°C, and furthermore, treated ground meat samples were found organoleptically acceptable by a trained sensory panel *(12)*. Further studies are needed to determine the organoleptic acceptability of CAA and CAR in breaded chicken products.

The average maximum temperature of the geometric center of samples from all treatments was 44.1±3.0°C during the 15 min oven browning period (Fig. 1), and 35.3±1.0°C during the 15 s deep fryer browning period (Fig. 2). End-point geometric center temperatures for the individual product treatments and two surface browning methods are shown in Table 5. Irrespective of antimicrobial treatment, *Salmonella* counts of samples analyzed after fryer browning (sampling point 3) were not ($P \geq 0.05$) different than those of samples analyzed after grinding (sampling point 2) (Table 4). Similar findings were obtained for oven-browned products except for samples treated with 0.5% CAA or POL (0.125 and 0.25%) (Table 3). For these treatments, pathogen counts after oven browning were 0.4 (0.125 and 0.25% POL) and at least 1.5 (0.5% CAA) log CFU/g lower ($P<0.05$) than those obtained at sampling point 2.

Pathogen counts of samples analyzed after frozen storage (-20°C, 7 days; sampling point 4) were numerically, and in most cases, significantly ($P<0.05$) lower than those of samples analyzed after oven or fryer browning (sampling point 3), regardless of antimicrobial treatment (Tables 3 and 4). Overall, compared to initial populations (sampling point 1), total reductions of inoculated

Salmonella in untreated control oven- or fryer-browned products after frozen storage were 1.2 and 0.8 log CFU/g, respectively, while total bacterial populations were reduced by 0.7 and 0.5 log CFU/g, respectively (Tables 3 and 4). Survival of *Salmonella* during frozen storage of breaded chicken products has been previously reported by Dominguez and Schaffner *(9)*. Specifically, *Salmonella* populations, as recovered on XLT-4 agar, in fully-cooked breaded chicken nuggets or uncooked breaded chicken strips inoculated (4-5 log CFU/g) after manufacture, decreased by approximately 1 log CFU/g after 16 weeks of storage at -20°C *(9)*. In the present study, total pathogen reductions for samples treated with CAA (0.5 or 1.0%), CAR (0.3 or 0.5%) or POL (0.125 or 0.25%) were 4.1 to >4.5, >4.0, and 1.5 to 1.6 log CFU/g, respectively, after frozen storage of oven-browned samples (Table 3), and 3.3 to >4.3, 4.1 to >4.7, and 1.1 log CFU/g, respectively, after frozen storage of fryer-browned samples (Table 4). In particular, treatment of samples with 1.0% CAA (oven-browned) or 0.5% CAR (oven- or fryer-browned) reduced initial *Salmonella* counts to below the detection limit (<0.3 log CFU/g) in stored frozen products. Compared to the untreated control in each study, all antimicrobials and concentrations tested, except POL (0.125 or 0.25%), significantly ($P<0.05$) reduced *Salmonella* and total bacterial counts in the final, oven- or fryer-browned, frozen product. *Salmonella* counts of products treated with 0.125 or 0.25% POL were 0.2 to 0.4 log CFU/g lower ($P\geq0.05$) than those of the untreated control after frozen storage. Based on previous reports *(6, 11, 13)* on the antimicrobial activity of POL, alone or in combination with other antimicrobials, further studies are warranted to determine the effectiveness against *Salmonella* of POL added individually, possibly at higher concentrations than those tested in this study and/or in combination with other antimicrobials, in breaded chicken products.

In summary, this study demonstrated the potential of caprylic acid and carvacrol to reduce *Salmonella* contamination in raw chicken meat portions intended for the manufacture of surface-browned, frozen, breaded chicken products. Further work is needed to determine minimum effective concentration levels of these antimicrobials, used individually or in combinations, against *Salmonella* contamination in raw chicken portions. In such future studies, ε-polylysine should not be neglected as it could also be effective when used at higher concentrations or in combination with other antimicrobials. Until antimicrobial interventions are used or other preventive control measures are taken by the industry, appropriate labeling *(18, 22)* on the package of surface-browned, uncooked, frozen breaded chicken products and consumer education about the hazards associated with consumption of raw or undercooked chicken products, are the only means to lower the risk of salmonellosis from these types of products.

ACKNOWLEDGEMENTS

This work was funded in part by the American Meat Institute Foundation, and the Colorado State University Agricultural Experiment Station.

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FIGURE LEGENDS

FIGURE 1. Changes in the temperature of the oven chamber (■) and the geometric center of samples (▲) during oven browning of breaded chicken products.

FIGURE 2. Changes in the temperature of the vegetable oil in the deep fryer (■) and the geometric center of samples (▲) during fryer browning of breaded chicken products.

TABLE 1. The effect of various concentrations of caprylic acid, carvacrol, and ε-polylysine on the pH values (mean±standard deviation) of samples at different stages during the manufacture of a frozen, not-ready-to-eat breaded chicken product surface-browned in an oven (208°C, 15 min), and on the water activity values (mean±standard deviation) of the browned breaded chicken products.

Treatment	pH				Water activity
	After inoculation	After grinding	After baking	After frozen storage	After baking
Distilled water (control)	5.87±0.04 aC	5.98±0.03 cB	6.04±0.04 bA	6.04±0.02 bA	0.978±0.000 b
Caprylic acid (0.5%)	5.85±0.08 aB	5.81±0.02 dB	5.95±0.02 cA	5.95±0.02 cA	0.977±0.001 bc
Caprylic acid (1.0%)	5.83±0.06 aA	5.66±0.01 eB	5.78±0.04 dA	5.77±0.04 dA	0.976±0.000 cd
Carvacrol (0.3%)	5.87±0.11 aB	6.01±0.05 cA	6.09±0.06 bA	6.10±0.05 bA	0.978±0.001 b
Carvacrol (0.5%)	5.82±0.05 aC	6.01±0.03 cB	6.09±0.02 bA	6.09±0.02 bA	0.980±0.001 a
ε-Polylysine (0.125%)	5.88±0.04 aC	6.13±0.03 bB	6.18±0.02 aA	6.18±0.02 aA	0.977±0.001 b
ε-Polylysine (0.25%)	5.92±0.07 aB	6.22±0.01 aA	6.20±0.06 aA	6.20±0.05 aA	0.975±0.001 d

Within a column, means lacking a common lowercase letter are different ($P<0.05$).

Within a row and pH values, means lacking a common uppercase letter are different ($P<0.05$).

354 TABLE 2. The effect of various concentrations of caprylic acid, carvacrol, and ε-polylysine on the pH values (mean±standard
355 deviation) of samples at different stages during the manufacture of a frozen, not-ready-to-eat breaded chicken product surface-
356 browned in a deep fryer (190°C, 15 s), and on the water activity values (mean±standard deviation) of the browned breaded chicken
357 products.

Treatment	pH				Water activity
	After inoculation	After grinding	After frying	After frozen storage	After frying
Distilled water (control)	5.88±0.11 abB	6.11±0.08 bA	6.10±0.09 aA	6.19±0.10 abA	0.977±0.001 b
Caprylic acid (0.5%)	5.94±0.09 abA	5.90±0.06 dA	5.94±0.06 bcA	6.02±0.10 cdA	0.977±0.001 bc
Caprylic acid (1.0%)	5.90±0.07 abA	5.68±0.02 eB	5.86±0.04 cA	5.89±0.06 dA	0.976±0.001 c
Carvacrol (0.3%)	5.95±0.07 abB	6.01±0.02 cB	6.00±0.03 bB	6.11±0.02 bcA	0.977±0.000 bc
Carvacrol (0.5%)	5.81±0.05 bC	5.95±0.02 cdB	5.97±0.01 bB	6.04±0.01 cA	0.979±0.001 a
ε-Polylysine (0.125%)	5.96±0.09 aB	6.16±0.01 bA	6.11±0.05 aA	6.20±0.06 abA	0.977±0.000 bc
ε-Polylysine (0.25%)	5.97±0.07 aB	6.27±0.06 aA	6.19±0.06 aA	6.30±0.10 aA	0.977±0.001 bc

358 Within a column, means lacking a common lowercase letter are different ($P<0.05$).

359 Within a row and pH values, means lacking a common uppercase letter are different ($P<0.05$).

360

TABLE 3. The effect of various concentrations of caprylic acid, carvacrol, and ε-polylysine on *Salmonella* and total bacterial counts (mean±standard deviation; log CFU/g) at different stages during the manufacture of a frozen, not-ready-to-eat breaded chicken product surface-browned in an oven (208°C, 15 min).

Treatment	*Salmonella* counts				Total bacterial counts			
	After inoculation	After grinding	After baking	After frozen storage	After inoculation	After grinding	After baking	After frozen storage
Distilled water (control)	4.8±0.1 aA	4.6±0.1 aAB	4.4±0.2 aB	3.6±0.2 aC	5.4±0.4 aA	5.2±0.4 aAB	4.9±0.2 aAB	4.7±0.4 aB
Caprylic acid (0.5%)	4.9±0.2 aA	2.9±0.2 bB	<1.4±0.4 bcC	0.8±0.4 bcD	5.5±0.5 aA	3.3±0.4 bB	2.6±0.2 bC	2.4±0.3 bC
Caprylic acid (1.0%)	4.8±0.2 aA	<0.8±0.5 cB	<0.8±0.5 cB	<0.3[1] cB	5.0±0.2 aA	<1.4±1.2 cB	<1.3±1.1 cB	<0.8±0.6 cB
Carvacrol (0.3%)	4.9±0.1 aA	<1.4±1.0 cBC	1.8±0.3 bB	<0.9±0.4 bC	5.1±0.2 aA	2.8±0.3 bB	2.7±0.1 bB	2.3±0.1 bC
Carvacrol (0.5%)	4.9±0.2 aA	<0.9±0.5 cB	<0.8±0.5 cB	<0.3 cB	5.4±0.4 aA	2.5±0.7 bB	2.7±0.4 bB	3.0±1.1 bB
ε-Polylysine (0.125%)	4.9±0.1 aA	4.4±0.2 aB	4.0±0.1 aC	3.4±0.2 aD	5.4±0.3 aA	5.0±0.1 aB	4.7±0.3 aC	4.1±0.0 aD
ε-Polylysine (0.25%)	4.8±0.2 aA	4.3±0.1 aB	3.9±0.1 aC	3.2±0.4 aD	5.3±0.3 aA	4.9±0.3 aAB	4.6±0.2 aBC	4.5±0.3 aC

[1]Detection limit: 0.3 log CFU/g.

Within a column, means lacking a common lowercase letter are different (P<0.05).

Within a row and within each microbial count (*Salmonella* or total bacterial counts), means lacking a common uppercase letter are different (P<0.05).

TABLE 4. The effect of various concentrations of caprylic acid, carvacrol, and ε-polylysine on *Salmonella* and total bacterial counts (mean±standard deviation; log CFU/g) at different stages during the manufacture of a frozen, not-ready-to-eat breaded chicken product surface-browned in a deep fryer (190°C, 15 s).

Treatment	*Salmonella* counts				Total bacterial counts			
	After inoculation	After grinding	After frying	After frozen storage	After inoculation	After grinding	After frying	After frozen storage
Distilled water (control)	4.9±0.2 aA	4.7±0.1 aAB	4.6±0.1 aB	4.1±0.3 aC	5.3±0.3 aA	5.1±0.1 aAB	4.9±0.2 aAB	4.8±0.3 aB
Caprylic acid (0.5%)	4.9±0.1 aA	3.1±0.1 bB	2.7±0.2 bB	1.6±0.5 bC	5.3±0.3 aA	3.7±0.0 cB	3.5±0.2 bB	3.5±0.5 bB
Caprylic acid (1.0%)	4.8±0.1 aA	<0.4±0.1 eB	<0.8±0.4 cB	<0.5±0.4 cdB	5.3±0.2 aA	2.1±0.2 eB	2.0±0.5 dB	2.4±0.6 cB
Carvacrol (0.3%)	5.0±0.1 aA	1.9±0.5 cB	2.3±0.4 bB	0.9±0.4 cC	5.2±0.1 aA	2.8±0.1 dB	2.6±0.2 cB	2.6±0.8 cB
Carvacrol (0.5%)	5.0±0.1 aA	<1.1±0.6 dB	1.3±0.4 cB	<0.3[1] dC	5.0±0.1 aA	2.0±0.2 eB	2.1±0.1 dB	1.5±0.1 dC
ε-Polylysine (0.125%)	4.9±0.1 aA	4.6±0.1 aAB	4.2±0.5 aBC	3.8±0.2 aC	5.2±0.2 aA	4.9±0.1 abB	4.9±0.1 aB	4.8±0.3 aB
ε-Polylysine (0.25%)	4.9±0.2 aA	4.4±0.2 aB	4.4±0.1 aB	3.8±0.1 aC	5.3±0.3 aA	4.8±0.1 bB	4.8±0.1 aB	4.7±0.2 aB

[1]Detection limit: 0.3 log CFU/g.

Within a column, means lacking a common lowercase letter are different (P<0.05).

Within a row and within each microbial count (*Salmonella* or total bacterial counts), means lacking a common uppercase letter are different (P<0.05).

376 TABLE 5. End-point temperatures (mean±standard deviation) of the geometric center of breaded

377 chicken products surface-browned in an oven (208°C, 15 min) or deep fryer (190°C, 15 s).

Treatment	Temperature (°C)	
	Oven-browned	Fryer-browned
Distilled water (control)	42.4±1.5	35.9±0.2
Caprylic acid (0.5%)	43.1±1.1	36.4±0.8
Caprylic acid (1.0%)	49.1±6.3	35.5±0.8
Carvacrol (0.3%)	43.5±1.9	34.9±0.1
Carvacrol (0.5%)	46.2±3.3	34.9±2.1
ε-Polylysine (0.125%)	42.9±2.0	34.6±0.7
ε-Polylysine (0.25%)	43.1±0.2	35.2±1.5

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379

FIGURE 1

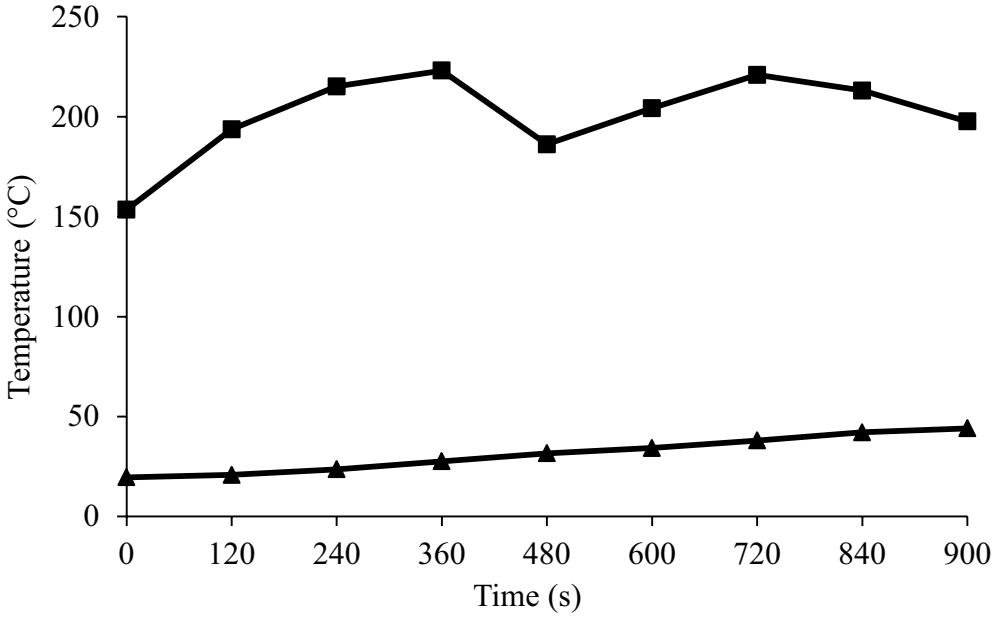
250
200
150
100
50
0
Temperature (°C)
0
120
240
360
480
600
720
840
900
Time (s)

FIGURE 2