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Antimicrobials for Reduction of *Salmonella* Contamination in 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 was conducted to evaluate 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 by 5 by 5 cm) were inoculated (4 to 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, and the mixtures were ground (5% total moisture enhancement level) and formed into portions (9 by 5 by 3 cm). The products were breaded and surface browned by baking in an oven (208°C for 15 min) or deep frying in vegetable oil (190°C for 15 s), packaged in polyethylene bags, and stored at −20°C for 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, regardless of the antimicrobial concentration and browning method. Treatment with 1.0% CAA (oven browned) or 0.5% CAR (oven or fryer browned) reduced *Salmonella* to nondetectable levels (<0.3 log CFU/g) in stored frozen products. These data may be useful for 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 and chicken Kiev) *(22)*. Such not-ready-to-eat chicken products have been linked to salmonellosis outbreaks in the United States *(21),* Canada *(8, 17),* and Australia *(15)*. 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 or browning (fried or baked) step to maintain the shape of the product and induce a desirable golden-brown color before freezing and packaging. However, this browning step is not a complete lethality step and is not intended to fully cook the product *(3, 19)*.

Because the chicken meat used during manufacture of breaded chicken products is raw, the bacteriological quality of these products should be considered the same as that of 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,* and no other lethality interventions are used for these products before consumer cooking. Bucher et al. *(3)* found that 27% ($n = 92$) of retail and wholesale raw, frozen chicken nugget and chicken strip samples were 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 caution than they typically would use with a visibly raw product. Consumers may thus undercook these products, making them a significant risk factor for contracting foodborne salmonellosis. Therefore, 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, very little work has been done on interventions that can be applied to these types of products to reduce the risk of *Salmonella*. The objective of this study was to evaluate

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the antimicrobial effects against *Salmonella* of caprylic acid, carvacrol, and ε-polylysine applied individually to 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 comprised seven *Salmonella* isolates of chicken or turkey origin (kindly provided by Dr. Vijay Juneja, Microbial Food Safety Research Unit, U.S. Department of Agriculture, Agricultural Research Service, Eastern Regional Research Center, Wyndmoor, PA): *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 of tryptic soy broth (Difco, BD, Sparks, MD) for 18 to 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 of 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 of PBS and further diluted in PBS to 6 to 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. Before use, the frozen breasts were thawed at 4°C for approximately 48 h. The chicken breast meat was cut into pieces (approximately 5 by 5 by 5 cm), and batches of 2 kg were inoculated with 20 ml of the *Salmonella* inoculum to a target level of 4 to 5 log CFU/g. The chicken meat and inoculum were thoroughly mixed for 2 min with a Professional 600 mixer (KitchenAid, 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 mixed with 20 ml of one of the following treatments: (i) sterile distilled water (control), (ii) caprylic acid (CAA; 0.5 and 1.0%, vol/wt; Fisher Scientific, Hampton, NH), (iii) carvacrol (CAR; 0.3 and 0.5%, vol/wt; Acros Organics, Geel, Belgium), or (iv) ε-polylysine (POL; 0.125 and 0.25%, vol/wt; Chisso Corporation, Minamata, Japan). These antimicrobials were selected for evaluation based on results of a screening study (unpublished data) in which four concentrations of each of 10 antimicrobials (allyl isothiocyanate, CAA, CAR, citric acid, grapefruit distilled terpene, malic acid, oregano oil, POL, sodium citrate, and sodium lactate) were evaluated for antimicrobial effects against *Salmonella* inoculated on raw chicken portions. CAA and CAR were the most effective acid and essential oil, respectively (unpublished data). POL, a cationic surfactant, was not as effective as CAA or CAR against the pathogen, but it was included in the present study based on previous published reports *(6, 11, 14)* of its antimicrobial activity against *Salmonella* and other foodborne pathogens.

In the present study, the inoculated chicken portions were mixed with the distilled water or antimicrobial solution for 5 min in the KitchenAid mixer, and then sodium chloride (Fisher Scientific) and sodium tripolyphosphate (kindly provided by BK Giulini Corporation, Simi Valley, CA) were added and mixed (5 min) to yield concentrations of 1.2 and 0.3% (wt/wt), respectively, in the final product. This final 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 150-g portions (9 cm long by 5 cm wide by 3 cm high). These product dimensions were representative of commercially available frozen, not-ready-to-eat breaded chicken products found in local supermarkets. The portions were then brushed with beaten pasteurized egg whites (All Whites, Crystal Farm, Lake Mills, WI), rolled in plain (i.e., unseasoned) breadcrumbs (Kroger, Cincinnati, OH), and browned for 15 min (900 s) in a standard kitchen oven (Magic Chef, Maytag Corp., Newton, IA) at 208°C. The temperature of the oven chamber and the geometric center of products was monitored and recorded with type-K thermocouples and PicoLog data acquisition software (Pico Technology Ltd., Cambridge, UK) at 1-s intervals during browning. Samples were turned over halfway through the browning period (at 7.5 min). In an additional study, the same methodology and antimicrobial treatments were used, except that 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) with a digital Pro Fry deep fryer (Presto, 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 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 sampling points during the process: after inoculation (sampling point 1), after grinding (i.e., approximately 15 min after antimicrobial addition; sampling point 2), after browning (i.e., within 2 to 3 min after removal of the products from the oven or fryer; sampling point 3), and after 7 days of frozen (−20°C) storage (sampling point 4). At sampling points 1 and 2, 25-g samples were analyzed, and at sampling points 3 and 4 the samples analyzed comprised the entire 150-g breaded chicken product. Frozen samples (sampling point 4) were thawed for 15 to 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, BD]) was added at a 1:1 ratio (wt/vol) of sample (grams) to diluent (milliliters). The samples were homogenized (Masticator, IUL Instruments, Barcelona, Spain) for 2 min, serially diluted in 0.1% buffered peptone water (Difco, BD), and surface plated for *Salmonella* counts on XLD agar and for 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 microbial contamination level of the chicken meat used to prepare the surface-browned, uncooked breaded chicken products.

After microbial analysis, the pH of the sample homogenates was measured with a pH meter (Denver Instruments, Arvada, CO) fitted with a glass electrode. Water activity (AquaLab model series 3, Decagon Devices, Pullman, WA) of the surface-browned breaded chicken products was determined before frozen storage.

Statistical analysis. At each sampling point, three samples per treatment were analyzed in each of two repetitions for each

TABLE 1. *Effect of various concentrations of caprylic acid, carvacrol, and ε-polylysine on the pH values and water activity values of samples at various stages during the manufacture of a frozen, not-ready-to-eat breaded chicken product surface browned in an oven*[a]

Treatment	pH[b]				Water activity after baking
	After inoculation	After grinding	After baking	After frozen storage	
Distilled water (control)	5.87 ± 0.04 a C	5.98 ± 0.03 c B	6.04 ± 0.04 b A	6.04 ± 0.02 b A	0.978 ± 0.000 b
Caprylic acid, 0.5%	5.85 ± 0.08 a B	5.81 ± 0.02 d B	5.95 ± 0.02 c A	5.95 ± 0.02 c A	0.977 ± 0.001 bc
Caprylic acid, 1.0%	5.83 ± 0.06 a A	5.66 ± 0.01 e B	5.78 ± 0.04 d A	5.77 ± 0.04 d A	0.976 ± 0.000 cd
Carvacrol, 0.3%	5.87 ± 0.11 a B	6.01 ± 0.05 c A	6.09 ± 0.06 b A	6.10 ± 0.05 b A	0.978 ± 0.001 b
Carvacrol, 0.5%	5.82 ± 0.05 a C	6.01 ± 0.03 c B	6.09 ± 0.02 b A	6.09 ± 0.02 b A	0.980 ± 0.001 a
ε-Polylysine, 0.125%	5.88 ± 0.04 a C	6.13 ± 0.03 b B	6.18 ± 0.02 a A	6.18 ± 0.02 a A	0.977 ± 0.001 b
ε-Polylysine, 0.25%	5.92 ± 0.07 a B	6.22 ± 0.01 a A	6.20 ± 0.06 a A	6.20 ± 0.05 a A	0.975 ± 0.001 d

[a] Samples were surface browned at 208°C for 15 min. Values are means ± standard deviations. Within a column, means without a common lowercase letter are significantly different ($P < 0.05$).
[b] Within a row, means without a common uppercase letter are significantly different ($P < 0.05$).

product type (i.e., oven or fryer browned). The pH, water activity, and microbiological (converted to log CFU per gram) data were analyzed with the PROC MIXED procedures of SAS (version 9.3, SAS Institute Inc., Cary, NC) with independent variables of antimicrobial treatment, sampling point, and their interaction. Means were separated with the Tukey-adjusted procedure and were considered significant when P values were less than 0.05.

RESULTS AND DISCUSSION

Physicochemical properties of products. The pH values of untreated control surface-browned chicken samples after frozen storage were 6.04 (oven browned) and 6.19 (fryer browned) (Tables 1 and 2). Treatment of the chicken breast meat with CAA (0.5 and 1.0%), CAR (0.5%), or POL (0.125 and 0.25%) had significant effects ($P < 0.05$) on the pH of the final products (i.e., sampling point 4) in some cases. However, in all these cases, the actual difference between the pH of the treated products and that 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 samples 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, and hydrogen sulfide–producing populations were not detected (<0.3 log CFU/g) on XLD agar for any of the uninoculated samples (data not shown).

Initial counts of inoculated *Salmonella* 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, regardless of antimicrobial concentration (Tables 3 and 4). However, only CAA- and CAR-treated samples had significantly lower counts ($P < 0.05$) compared with 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-

TABLE 2. *Effect of various concentrations of caprylic acid, carvacrol, and ε-polylysine on the pH values and water activity values of samples at various stages during the manufacture of a frozen, not-ready-to-eat breaded chicken product surface browned in a deep fryer*[a]

Treatment	pH[b]				Water activity after frying
	After inoculation	After grinding	After frying	After frozen storage	
Distilled water (control)	5.88 ± 0.11 ab B	6.11 ± 0.08 b A	6.10 ± 0.09 a A	6.19 ± 0.10 ab A	0.977 ± 0.001 b
Caprylic acid, 0.5%	5.94 ± 0.09 ab A	5.90 ± 0.06 d A	5.94 ± 0.06 bc A	6.02 ± 0.10 cd A	0.977 ± 0.001 bc
Caprylic acid, 1.0%	5.90 ± 0.07 ab A	5.68 ± 0.02 e B	5.86 ± 0.04 c A	5.89 ± 0.06 d A	0.976 ± 0.001 c
Carvacrol, 0.3%	5.95 ± 0.07 ab B	6.01 ± 0.02 c B	6.00 ± 0.03 b B	6.11 ± 0.02 bc A	0.977 ± 0.000 bc
Carvacrol, 0.5%	5.81 ± 0.05 b C	5.95 ± 0.02 cd B	5.97 ± 0.01 b B	6.04 ± 0.01 c A	0.979 ± 0.001 a
ε-Polylysine, 0.125%	5.96 ± 0.09 a B	6.16 ± 0.01 b A	6.11 ± 0.05 a A	6.20 ± 0.06 ab A	0.977 ± 0.000 bc
ε-Polylysine, 0.25%	5.97 ± 0.07 a B	6.27 ± 0.06 a A	6.19 ± 0.06 a A	6.30 ± 0.10 a A	0.977 ± 0.001 bc

[a] Samples were surface browned at 190°C for 15 s. Values are means ± standard deviations. Within a column, means without a common lowercase letter are significantly different ($P < 0.05$).
[b] Within a row, means without a common uppercase letter are significantly different ($P < 0.05$).

TABLE 3. *Effect of various concentrations of caprylic acid, carvacrol, and ε-polylysine on* Salmonella *and total bacterial counts at various stages during the manufacture of a frozen, not-ready-to-eat breaded chicken product surface browned in an oven*[a]

Treatment	*Salmonella* count (log CFU/g)				Total bacterial count (log CFU/g)			
	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 a A	4.6 ± 0.1 a AB	4.4 ± 0.2 a B	3.6 ± 0.2 a C	5.4 ± 0.4 a A	5.2 ± 0.4 a AB	4.9 ± 0.2 a AB	4.7 ± 0.4 a B
Caprylic acid, 0.5%	4.9 ± 0.2 a A	2.9 ± 0.2 b B	<1.4 ± 0.4 bc C	0.8 ± 0.4 bc D	5.5 ± 0.5 a A	3.3 ± 0.4 b B	2.6 ± 0.2 b C	2.4 ± 0.3 b C
Caprylic acid, 1.0%	4.8 ± 0.2 a A	<0.8 ± 0.5 c B	<0.8 ± 0.5 c B	<0.3 c B	5.0 ± 0.2 a A	<1.4 ± 1.2 c B	<1.3 ± 1.1 c B	<0.8 ± 0.6 c B
Carvacrol, 0.3%	4.9 ± 0.1 a A	<1.4 ± 1.0 c BC	1.8 ± 0.3 b B	<0.9 ± 0.4 b C	5.1 ± 0.2 a A	2.8 ± 0.3 b B	2.7 ± 0.1 b B	2.3 ± 0.1 b C
Carvacrol, 0.5%	4.9 ± 0.2 a A	<0.9 ± 0.5 c B	<0.8 ± 0.5 c B	<0.3 c B	5.4 ± 0.4 a A	2.5 ± 0.7 b B	2.7 ± 0.4 b B	3.0 ± 1.1 b B
ε-Polylysine, 0.125%	4.9 ± 0.1 a A	4.4 ± 0.2 a B	4.0 ± 0.1 a C	3.4 ± 0.2 a D	5.4 ± 0.3 a A	5.0 ± 0.1 a B	4.7 ± 0.3 a C	4.1 ± 0.0 a D
ε-Polylysine, 0.25%	4.8 ± 0.2 a A	4.3 ± 0.1 a B	3.9 ± 0.1 a C	3.2 ± 0.4 a D	5.3 ± 0.3 a A	4.9 ± 0.3 a AB	4.6 ± 0.2 a BC	4.5 ± 0.3 a C

[a] Samples were surface browned at 208°C for 15 min. Values are means ± standard deviations. Detection limit was 0.3 log CFU/g. Within a column, means without a common lowercase letter are significantly different ($P < 0.05$). Within a row and within each type of microbial count (*Salmonella* or total bacterial counts), means without a common uppercase letter are significantly different ($P < 0.05$).

TABLE 4. *Effect of various concentrations of caprylic acid, carvacrol, and ε-polylysine on* Salmonella *and total bacterial counts at various stages during the manufacture of a frozen, not-ready-to-eat breaded chicken product surface browned in a deep fryer*[a]

Treatment	*Salmonella* count (log CFU/g)				Total bacterial count (log CFU/g)			
	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 a A	4.7 ± 0.1 a AB	4.6 ± 0.1 a B	4.1 ± 0.3 a C	5.3 ± 0.3 a A	5.1 ± 0.1 a AB	4.9 ± 0.2 a AB	4.8 ± 0.3 a B
Caprylic acid, 0.5%	4.9 ± 0.1 a A	3.1 ± 0.1 b B	2.7 ± 0.2 b B	1.6 ± 0.5 b C	5.3 ± 0.3 a A	3.7 ± 0.0 c B	3.5 ± 0.2 b B	3.5 ± 0.5 b B
Caprylic acid, 1.0%	4.8 ± 0.1 a A	<0.4 ± 0.1 e B	<0.8 ± 0.4 c B	<0.5 ± 0.4 cd B	5.3 ± 0.2 a A	2.1 ± 0.2 e B	2.0 ± 0.5 d B	2.4 ± 0.6 c B
Carvacrol, 0.3%	5.0 ± 0.1 a A	1.9 ± 0.5 c B	2.3 ± 0.4 b B	0.9 ± 0.4 c C	5.2 ± 0.1 a A	2.8 ± 0.1 d B	2.6 ± 0.2 c B	2.6 ± 0.8 c B
Carvacrol, 0.5%	5.0 ± 0.1 a A	<1.1 ± 0.6 d B	1.3 ± 0.4 c B	<0.3 d C	5.0 ± 0.1 a A	2.0 ± 0.2 e B	2.1 ± 0.1 d B	1.5 ± 0.1 d C
ε-Polylysine, 0.125%	4.9 ± 0.1 a A	4.6 ± 0.1 a AB	4.2 ± 0.5 a BC	3.8 ± 0.2 a C	5.2 ± 0.2 a A	4.9 ± 0.1 ab B	4.9 ± 0.1 a B	4.8 ± 0.3 a B
ε-Polylysine, 0.25%	4.9 ± 0.2 a A	4.4 ± 0.2 a B	4.4 ± 0.1 a B	3.8 ± 0.1 a C	5.3 ± 0.3 a A	4.8 ± 0.1 b B	4.8 ± 0.1 a B	4.7 ± 0.2 a B

[a] Samples were surface browned at 190°C for 15 s. Values are means ± standard deviations. Detection limit was 0.3 log CFU/g. Within a column, means without a common lowercase letter are significantly different ($P < 0.05$). Within a row and within each type of microbial count (*Salmonella* or total bacterial counts), means without a common uppercase letter are significantly different ($P < 0.05$).

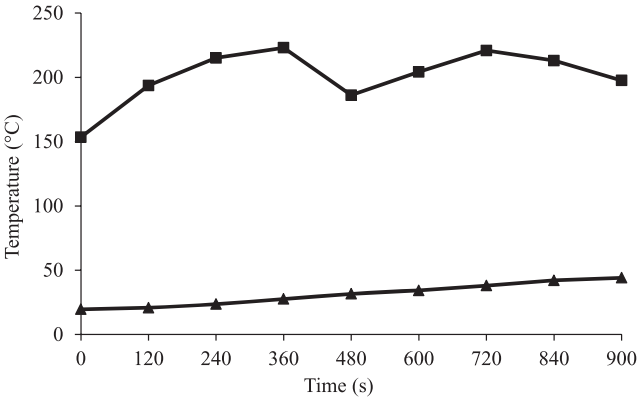

FIGURE 1. *Changes in the temperature of the oven chamber (■) and of the geometric center of samples (▲) during oven browning of breaded chicken products.*

grade chemical 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 also reduced *Salmonella* colonization of day-old chicks *(13)*. CAR is one of the main components of oregano essential oil, and its antimicrobial activity against *Salmonella* and other foodborne pathogens in laboratory media and various food products is 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 treated ground meat samples were organoleptically acceptable to 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. Regardless of antimicrobial treatment, *Salmonella* counts of samples analyzed after fryer browning (sampling point 3) were not different ($P \geq 0.05$) from 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 0.125 or 0.25% POL (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.

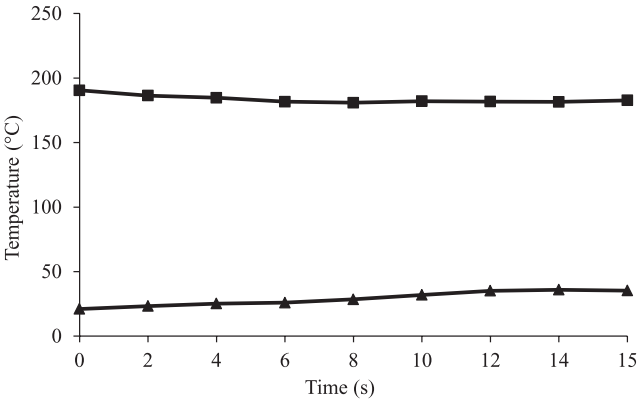

FIGURE 2. *Changes in the temperature of the vegetable oil in the deep fryer (■) and of the geometric center of samples (▲) during fryer browning of breaded chicken products.*

TABLE 5. *End-point temperatures of the geometric center of breaded chicken products surface browned in an oven or deep fryer*[a]

Treatment	Temp (°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

[a] Samples were surface browned in an oven at 208°C for 15 min or in a deep fryer at 190°C for 15 s. Values are means ± standard deviations.

Pathogen counts of samples analyzed after frozen storage (−20°C for 7 days; sampling point 4) were numerically and in most cases significantly lower ($P < 0.05$) than those of samples analyzed after oven or fryer browning (sampling point 3), regardless of antimicrobial treatment (Tables 3 and 4). Overall, compared with 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, whereas 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)*. *Salmonella* populations recovered on xylose lysine Tergitol 4 agar from fully cooked breaded chicken nuggets or uncooked breaded chicken strips inoculated (4 to 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 with the untreated control in each study, all antimicrobials and concentrations tested except POL (0.125 or 0.25%) significantly reduced ($P < 0.05$) *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 ($P \geq 0.05$) than

those of the untreated control after frozen storage. Based on previous reports *(6, 11, 14)* on the antimicrobial activity of POL either alone or in combination with other antimicrobials, further studies are warranted to determine the effectiveness against *Salmonella* of POL alone, 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 CAA and CAR 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 concentrations of these antimicrobials, used individually or in combinations, against *Salmonella* in raw chicken portions. In such future studies, POL should be included because it also could 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 current means of lowering the risk of salmonellosis associated with these types of products.

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