Validation of commercial processes for inactivation of *Escherichia coli* O157:H7, *Salmonella* Typhimurium, and *Listeria monocytogenes* on the surface of whole-muscle turkey jerky[1]

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ABSTRACT Three strips of turkey breast meat were separately inoculated with multistrain mixtures of *Escherichia coli* O157:H7, *Salmonella* Typhimurium, or *Listeria monocytogenes* and placed on the top, middle, and bottom levels of a loading rack. The strips on the rack were then loaded into a smokehouse and cooked-dried for either 2.5 or 3.5 h at 73.8°C (165°F) or 1.5 or 2.5 h at 82.2°C (180°F) with constant hickory smoking and without addition of humidity. Cooking-drying marinated turkey jerky at 73.8°C (165°F) or 82.2°C (180°F) resulted in a ≥7.1 $\log_{10}$ cfu/strip reduction of all 3 pathogens. For nonmarinated jerky strips that were inoculated with *E. coli* O157:H7 or *L. monocytogenes* and cooked-dried at 82.2°C (180°F), a reduction of ≥7.4 $\log_{10}$ cfu/strip was observed, whereas for strips that were inoculated with *Salmonella*, a reduction of ≥6.8 $\log_{10}$ cfu/strip was observed. Cooking-drying nonmarinated turkey breast strips at 73.8°C (165°F) for 3.5 h resulted in a reduction of ca. 7.1 to 7.6 $\log_{10}$ cfu/strip for all 3 pathogens, whereas for strips that were cooked-dried for 2.5 h, a reduction of ca. 5.4 to 6.2 $\log_{10}$ cfu/strip was observed. Only marinated turkey jerky that was cooked-dried for 3.5 h at 73.8°C (165°F) satisfied the USDA-FSIS standard of identity (moisture:protein ≤0.75:1.0) or shelf-stability (water activity of ≤0.80), or both, requirements for jerky.

Key words: turkey jerky, validation, pathogen, food safety, lethality

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INTRODUCTION

Jerky-type products are an increasingly popular, shelf-stable, ready-to-eat (**RTE**) dried meat. However, human illnesses have been linked to commercially produced beef jerky and homemade venison jerky due to contamination with *Salmonella* spp. (CDC, 1995; Eidson et al., 2000; Smelser, 2004) and *Escherichia coli* O157:H7 (Keene et al., 1997), respectively. In addition, there have also been recalls due to contamination of beef jerky with *Salmonella* spp. and *Listeria monocytogenes* (http://www.fsis.usda.gov/Fsis_Recalls/index.asp). To date, poultry jerky has not been associated with foodborne illnesses or recalls, or both.

Between 1990 and 1999, the USDA-FSIS reported a cumulative prevalence of *Salmonella* and *L. monocytogenes* for meat and poultry jerky produced in federally inspected plants of 0.31 and 0.52%, respectively (Levine et al., 2001). In response to recalls and outbreaks epidemiologically linked to jerky and other RTE red meat and poultry products, the USDA-FSIS requires that commercial jerky manufacturers validate that their processes deliver a 5.0 $\log_{10}$ reduction for *E. coli* O157:H7 in beef and poultry, a 6.5 $\log_{10}$ reduction of *Salmonella* in beef, or a 7.0 $\log_{10}$ reduction in poultry, as well as meet the zero-tolerance policy or current compliance guidelines for *L. monocytogenes* (USDA-FSIS, 2001, 2004), or both. In addition, the USDA guidelines require that jerky products have a moisture:protein ratio (**M:Pr**) value of ≤0.75:1.0 to be classified as jerky and a water activity ($\mathbf{a_w}$) value of ≤0.80 to be considered as shelf-stable (USDA-FSIS, 2004, 2005). If such conditions are achieved, jerky products are shelf-stable for up to 2 yr when vacuum-packaged and stored at ambient temperature.

The consumption of turkey jerky has expanded rapidly over the last 10 yr due to its relatively mild fla-

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vor and high nutritional value (http://www.meatprocessing-digital.com) compared with beef jerky. Several studies have been published on destruction of foodborne pathogens in the processing of beef jerky, but to our knowledge, there is a paucity of published literature on process lethality against pathogens in commercial or homemade poultry jerky. Therefore, the objective of this study was to evaluate the effectiveness of commercial cooking-drying processes for efficacy toward cells of *E. coli* O157:H7, *Salmonella*, and *L. monocytogenes* surface-inoculated onto marinated and nonmarinated strips of whole-muscle turkey jerky that were subsequently cooked-dried at 73.8°C (165°F) or 82.2°C (180°F) for 1.5 to 3.5 h.

MATERIALS AND METHODS

Bacterial Strains and Preparation of Inoculum

Detailed information on the growth-maintenance of the 5 isolates of *L. monocytogenes* (MFS2, MFS102, MFS104, MFS105, and MFS110), the 6 isolates of *Salmonella* Typhimurium (H3278, G7601, H3402, H2662, H3380, and G8430), and the 5 isolates of *E. coli* O157:H7 (EC505B, C7927, SLH21788, KSU21, and 380-94) used in this study can be found in Porto-Fett et al. (2008). Briefly, a single colony of each isolate was individually transferred into 50 mL of brain heart infusion (Becton, Dickinson, and Co., Sparks, MD) broth and incubated at 37°C for 24 h with shaking (100 rpm). A 100-μL portion was transferred into 50 mL of fresh brain heart infusion broth and incubated at 37°C for 18 h with shaking. The resulting stationary-phase cells were harvested by centrifugation at 4,000 × g for 5 min at 4°C and were then washed and resuspended in 10 mL of sterile peptone water (0.1%; Becton, Dickinson, and Co.). The individual cocktails were prepared by combining approximately equal volumes of cell suspensions of each strain for a given pathogen, and the final volume was adjusted to 30 mL with sterile peptone water to yield ca. 9.5 $\log_{10}$ cfu/mL. Pathogen levels were quantified by spread-plating onto duplicate MacConkey sorbitol (Difco Laboratories Inc., Detroit, MI), xylose-lysine-tergitol-4 (Difco Laboratories Inc.), or modified Oxford (Difco Laboratories Inc.) agar plates for *E. coli* O157:H7, *Salmonella* Typhimurium, or *L. monocytogenes*, respectively. The MacConkey sorbitol and xylose-lysine-tergitol-4 agar plates were incubated at 37°C for 24 h and the modified Oxford agar plates were incubated at 37°C for 48 h before colonies were counted.

Inoculation and Processing of Whole-Muscle Turkey Jerky

Between January and February of 2007, six batches of partially frozen, raw, whole-muscle turkey breast were purchased at wholesale and sliced into strips (ca. 15 cm length × 4 cm width × 7 mm height) weighing on average ca. 34.1 ± 8.4 g and stored at −18°C for up to 5 d. Before inoculation, the strips of turkey breast were thawed at 4°C for ca. 24 h. The strips were inoculated, but not marinated, or inoculated and then marinated in bulk as described previously (Porto-Fett et al., 2008). For those strips that were marinated, whole-muscle turkey breast was immersed in a nonacidic (~pH 5.5) marinade solution applied at a ratio of 18.0% (vol/wt) relative to the weight of the meat for 15 min at 4°C. The commercial marinade solution, supplied and prepared as recommended by Wild Bill's Foods Inc. (Leola, PA), was formulated with soy sauce (water, salt, hydrolyzed soy protein, corn syrup, caramel color, and potassium sorbate) and seasoning powder (black pepper, red pepper, and garlic powder).

Individual strips of whole-muscle turkey breast were separately inoculated on both sides of each strip (0.5 mL/side) of the multistrain pathogen cocktails to a target level on average of ca. 9.1 $\log_{10}$ cfu/strip, that being equal to ca. 8.4 $\log_{10}$ cfu/g. Next, the inoculated and noninoculated strips of turkey breast, with and without marination, as well as additional filler strips of meat, were placed on stainless steel wire racks that were positioned horizontally on the top, middle, and bottom levels of a 3-level loading truck to fill the commercial smokehouse to capacity [volume = ca. 5,088 ft^3 (ca. 144.1 m^3); Vortron Smokehouse, model TR2-1700; Kusel Equipment Co., Beloit, WI]. Smoke was supplied using hickory wood chips (Gregory General Farms, Java, VA) and an external smoke generator (model 32 03 22, Koch Supplies, Kansas City, MO). The entire volume of air inside the smokehouse was exchanged ca. 40 to 50 times/min. When the smokehouse chamber achieved the target dry-bulb temperature of 73.8°C (165°F) or 82.2°C (180°F), the turkey strips were cooked-dried for 2.5 or 3.5 h or for 1.5 or 2.5 h, respectively, with constant smoke and with the dampers completely open. The temperature and RH of the air within the smokehouse and the temperature of the meat were monitored and recorded as described previously (Porto-Fett et al., 2008). After cooking-drying, the strips on the loading truck were cooled (10 to 15 min) to room temperature [ca. 22°C (72°F)] directly in the smokehouse by opening the door. The strips were then aseptically weighed and transferred into sterile bags (B00736WA, Nasco, Modesto, CA) and held on ice for up to 30 min until further processed.

Microbiological Analyses

For each of the 3 trials, 3 strips placed on each level of the loading truck for each pathogen type, for each treatment, and for each cooking-drying regimen were sampled. For enumeration of the initial populations of total plate count aerobic bacteria (**TPC**) and total lactic acid bacteria (**LAB**) on marinated and nonmari-

nated strips, a total of 3 uncooked strips for each of the 6 batches of jerky were analyzed (n = 6 batches; n = 3 strips per batch; 18 strips total). When levels of the 3 pathogens decreased to below detection ($\leq$1.12 $\log_{10}$ cfu/strip or $\leq$0.06 $\log_{10}$ cfu/g) by direct-plating, samples were enriched as described previously (Porto-Fett et al., 2008). Bacterial numbers were expressed as $\log_{10}$ cfu/strip.

Proximate Composition of Whole-Muscle Turkey Jerky

For each time-temperature treatment, the proximate composition of whole-muscle turkey jerky was determined using a 60-g composite sample of meat in 2 of the 3 trials comprised of ca. 20 g from 1 noninoculated strip obtained from each of the 3 levels of the loading truck (n = 2 trials; n = 3 strips per trial) for both marinated and nonmarinated strips. The analyses were performed according to methods approved and described by the Association of Official Analytical Chemists (McNeil, 1990) as conducted by a commercial testing laboratory.

Statistical Analyses

Data were analyzed with version 9.1.3 of the SAS statistical package (SAS Institute Inc., Cary, NC). An ANOVA was performed to evaluate the effects and interactions of cooking-drying time and temperature and proximate composition on lethality of *E. coli* O157:H7, *Salmonella* Typhimurium, or *L. monocytogenes* on whole-muscle turkey breast jerky dried for 2.5 or 3.5 h at a target temperature of 73.8°C (165°F) or for 1.5 and 2.5 h at a target temperature of 82.2°C (180°F). Mean separations were performed using the least significant difference test.

RESULTS

Initial Levels of TPC and LAB in Raw Whole-Muscle Turkey Strips

The results showed the absence of any indigenous *E. coli* O157:H7, *Salmonella* Typhimurium, or *L. monocytogenes* by direct-plating ($\leq$1.12 $\log_{10}$ cfu/strip) or by enrichment on raw marinated or nonmarinated whole-muscle turkey breast strips (data not shown), or by both methods. Likewise, the initial populations of TPC or LAB were relatively similar among batches or treatments (n = 6 batches; n = 3 raw turkey breast strips per batch). The average levels of TPC and LAB on marinated raw, whole-muscle turkey breast strips were 6.01 ± 0.61 and 5.11 ± 0.63 $\log_{10}$ cfu/strip (5.25 and 4.18 $\log_{10}$ cfu/g), respectively, whereas for nonmarinated, raw whole-muscle turkey breast, the TPC and LAB populations were 5.69 ± 0.95 and 5.01 ± 0.30 $\log_{10}$ cfu/strip (4.22 and 4.17 $\log_{10}$ cfu/g), respectively.

Proximate Composition of Raw Meat and Whole-Muscle Turkey Jerky

In general, the results of the proximate composition analyses showed that the use of a marinade (~pH 5.5) did not significantly ($P \geq 0.05$) affect the pH, moisture, protein, carbohydrate, ash, fat, phenolic content, acidity, or M:Pr ratio of the final product among treatments compared with those strips that did not receive the marinade (Table 1). However, when turkey breast strips were marinated, a significant ($P \leq 0.05$) difference was observed in the levels of salt and values of a_w for marinated jerky compared with those strips that were not marinated (Table 1).

Regardless of cooking-drying temperature or whether or not strips were marinated, or both, the longer the cooking-drying time, the lower the values of a_w and M:Pr of the final product (Table 1). The results revealed that only marinated turkey breast strips that were cooked-dried for 3.5 h to a target temperature of 73.8°C (165°F) achieved M:Pr ($\leq$0.75:1.0) and a_w ($\leq$0.80) values required by the USDA to be designated as shelf-stable and turkey jerky (USDA-FSIS, 2005).

Come-Up Time, Internal Meat and Smokehouse Temperatures, and RH During Cooking-Drying of Whole-Muscle Turkey Jerky

The average come-up time (**CUT**) to achieve the target air-smokehouse temperatures of 73.8°C (165°F) or 82.2°C (180°F) were ca. 18.9 ± 3.6 min (range = 13 to 25 min; Table 2). During cooking-drying at 73.8°C (165°F) or 82.2°C (180°F), the average temperature of the air inside the smokehouse was 73.4 ± 6.0°C (164.1 ± 10.8°F) or 82.0 ± 0.36°C (179.6 ± 1.25°F), respectively. The average internal temperature of the meat strips before cooking-drying was 15.7 ± 5.5°C (60.2 ± 10°F). The average internal temperature of turkey breast strips during CUT was 37.3 ± 15.8°C (99.1 ± 28.5°F) for strips that were cooked to a target temperature of 73.8°C (165°F), whereas for strips that were cooked-dried to a target temperature of 82.2°C (180°F), the average internal temperature of turkey breast strips during the CUT was 40.9 ± 15.7°C (105.7 ± 28.3°F). The average internal temperatures of turkey breast strips from when CUT was attained throughout cooking-drying to a target temperature of 73.8°C (165°F) and 82.2°C (180°F) were 64.8 ± 3.4°C (148.7 ± 6.1°F) and 73.5 ± 3.3°C (164.3 ± 5.9°F), respectively. The average initial RH inside the smokehouse immediately after closing the door was 49.1 ± 11.7%. However, during CUT for the 2.5- and 3.5-h cooking-drying regimens at 73.8°C (165°F), the RH decreased on average to 38.6 ± 7.5%, whereas for the 1.5- and 2.5-h cooking-drying regimens at 82.2°C (180°F), the RH decreased on average to 35.8 ± 9.0%. The average RH inside the smokehouse from when CUT was attained throughout cook-

Table 1. Proximate composition of marinated and nonmarinated whole-muscle turkey jerky strips that were cooked-dried at a target air temperature of 73.8°C (165°F) for 2.5 or 3.5 h or at 82.2°C (180°F) for 1.5 or 2.5 h with constant smoke at an average RH of 29.9% during cooking-drying[1]

		73.8°C		82.2°C	
Analyses	0	2.5	3.5	1.5	2.5
Marinated					
Salt (g/100 g)	$1.75^{c} \pm 1.33$	$3.54^{b} \pm 0.01$	$5.66^{a} \pm 0.01$	$3.22^{b} \pm 0.72$	$2.84^{bc} \pm 0.79$
pH	$6.29^{a} \pm 1.60$	$5.81^{a} \pm 0.09$	$5.87^{a} \pm 0.24$	$5.86^{a} \pm 0.16$	$5.88^{a} \pm 0.11$
a_w[2]	$0.96^{abc} \pm 0.00$	$0.89^{d} \pm 0.04$	$0.80^{e} \pm 0.03$	$0.92^{cd} \pm 0.01$	$0.84^{e} \pm 0.04$
Moisture (g/100 g)	$71.0^{a} \pm 0.81$	$45.21^{bc} \pm 3.27$	$35.27^{d} \pm 1.51$	$48.46^{b} \pm 0.87$	$37.67^{cd} \pm 1.51$
Protein (g/100 g)	$23.0^{d} \pm 0.57$	$45.97^{bc} \pm 0.75$	$52.34^{abc} \pm 0.06$	$44.15^{c} \pm 2.33$	$52.55^{ab} \pm 1.21$
M:Pr[3]	$3.08^{a} \pm 0.04$	$0.98^{bc} \pm 0.43$	$0.67^{c} \pm 0.03$	$1.10^{bc} \pm 0.08$	$0.72^{bc} \pm 0.05$
Fat (g/100 g)	$0.45^{cd} \pm 0.02$	$1.38^{ab} \pm 0.26$	$0.69^{bcd} \pm 0.72$	$1.08^{abcd} \pm 0.54$	$0.65^{bcd} \pm 0.78$
Carbohydrates (g/100 g)	$2.04^{abc} \pm 1.92$	$1.28^{abc} \pm 1.81$	$5.38^{a} \pm 3.95$	$1.17^{abc} \pm 1.65$	$4.57^{ab} \pm 3.87$
Ash (g/100 g)	$3.64^{ab} \pm 0.4$	$6.37^{a} \pm 1.66$	$6.33^{a} \pm 4.67$	$5.43^{ab} \pm 0.04$	$4.58^{ab} \pm 2.79$
Phenolics	$0.09^{a} \pm 0.00$	$0.21^{a} \pm 0.11$	$0.22^{a} \pm 0.10$	$0.17^{a} \pm 0.07$	$0.18^{a} \pm 0.09$
Acidity	$0.75^{cd} \pm 0.24$	$1.11^{bc} \pm 0.09$	$1.67^{a} \pm 0.15$	$1.19^{bc} \pm 0.01$	$1.22^{abc} \pm 0.23$
Nonmarinated					
Salt (g/100 g)	$0.05^{d} \pm 0.04$	$0.05^{d} \pm 0.01$	$0.02^{d} \pm 0.01$	$0.04^{d} \pm 0.01$	$0.11^{d} \pm 0.14$
pH	$6.99^{a} \pm 1.41$	$5.83^{a} \pm 0.16$	$6.01^{a} \pm 0.06$	$5.99^{a} \pm 0.12$	$6.14^{a} \pm 0.28$
a_w	$0.99^{a} \pm 0.01$	$0.97^{ab} \pm 0.02$	$0.94^{bcd} \pm 0.02$	$0.97^{ab} \pm 0.01$	$0.95^{abc} \pm 0.00$
Moisture (g/100 g)	$72.3^{a} \pm 2.18$	$50.61^{b} \pm 9.89$	$39.06^{cd} \pm 3.97$	$50.88^{b} \pm 0.50$	$43.18^{bcd} \pm 0.54$
Protein (g/100 g)	$24.83^{d} \pm 1.03$	$46.90^{bc} \pm 11.31$	$57.98^{a} \pm 11.53$	$47.15^{bc} \pm 0.07$	$52.30^{abc} \pm 0.86$
M:Pr	$2.91^{a} \pm 0.21$	$1.14^{b} \pm 0.49$	$0.67^{c} \pm 0.09$	$1.08^{bc} \pm 0.01$	$0.83^{bc} \pm 0.00$
Fat (g/100 g)	$0.24^{d} \pm 0.30$	$1.10^{abcd} \pm 0.06$	$1.05^{abcd} \pm 0.21$	$1.36^{abc} \pm 0.08$	$1.84^{a} \pm 0.24$
Carbohydrates (g/100 g)	$1.25^{abc} \pm 0.36$	$0.25^{bc} \pm 0.35$	$0.05^{c} \pm 0.07$	$0.01^{c} \pm 0.0$	$0.22^{bc} \pm 0.31$
Ash (g/100 g)	$1.42^{b} \pm 0.48$	$2.61^{ab} \pm 0.50$	$3.20^{ab} \pm 0.76$	$3.13^{ab} \pm 1.30$	$3.15^{ab} \pm 1.35$
Phenolics	$0.09^{a} \pm 0.05$	$0.08^{a} \pm 0.01$	$0.16^{a} \pm 0.08$	$0.12^{a} \pm 0.01$	$0.12^{a} \pm 0.02$
Acidity	$0.34^{d} \pm 0.71$	$1.08^{bc} \pm 0.04$	$1.23^{ab} \pm 0.47$	$1.17^{bc} \pm 0.18$	$0.79^{bcd} \pm 0.22$

[a–e]Means with different superscripts within rows are significantly different ($P \leq 0.05$).

[1]Mean of 2 trials ± SD. Means represent the results from analyses performed on a composite sample (ca. 60 g) consisting of 1 strip from each of 3 levels on the loading truck in each of the 2 trials (n = 2 trials; n = 3 strips per trial).

[2]a_w = water activity.

[3]M:Pr = moisture:protein ratio.

ing-drying was 29.9 ± 8.6%. After cooking-drying, but before opening the door of the smokehouse, the final RH was on average 29.1 ± 2.6% after 2.5 and 3.5 h at a target temperature of 73.8°C (165°F) and on average 23.4 ± 5.9% after 1.5 and 2.5 h at a target temperature of 82.2°C (180°F). These levels of RH are well below the 90% level recommended by USDA-FSIS compliance guidelines for jerky products and are easier to attain in commercial processes.

Thermal Inactivation of E. coli O157:H7, Salmonella Typhimurium, or L. monocytogenes on Whole-Muscle Turkey Breast Jerky

When turkey breast strips were cooked-dried at 73.8°C (165°F) for 3.5 h, the use of marinade did not significantly ($P \geq 0.05$) affect lethality toward the 3 pathogens tested; however, when marinated turkey breast strips were cooked-dried at 73.8°C (165°F) for 2.5 h, significant ($P \leq 0.05$) lower differences on lethality were observed for all 3 pathogens when compared with those strips that did not receive the marinade (Table 2). Cooking-drying marinated and nonmarinated turkey breast strips for 3.5 h at a target temperature of 73.8°C (165°F) resulted in a reduction of ≥7.1 $\log_{10}$ cfu/strip for all 3 pathogens tested. When marinated turkey breast strips were cooked-dried for 2.5 h at a target temperature of 73.8°C (165°F), there was a ≥7.7 $\log_{10}$ cfu/strip reduction of all 3 pathogens. Cooking-drying nonmarinated turkey breast strips at 165°F for 2.5 h resulted in a reduction of ca. 5.4 to 6.2 $\log_{10}$ cfu/strip for all 3 pathogen cocktails.

For turkey breast strips that were inoculated with *E. coli* O157:H7 and *Salmonella* and then cooked-dried at 82.2°C (180°F) for 1.5 or 2.5 h, the use of a marinade did not significantly ($P \geq 0.05$) affect the lethality against either of these pathogens. However, when marinated turkey breast strips were inoculated with *L. monocytogenes* and then cooked-dried at 82.2°C (180°F) for 1.5 or 2.5 h, significant ($P \leq 0.05$) differences on lethality toward this pathogen were observed on marinated jerky compared with those strips that did not receive the marinade (Table 2). More specifically, cooking-drying marinated turkey breast strips for 1.5 or 2.5 h, at a target temperature of 82.2°C (180°F), resulted in a reduction of ≥7.1 $\log_{10}$ cfu/strip for *E. coli* O157:H7, *Salmonella*, and *L. monocytogenes*. When nonmarinated turkey breast strips were cooked-dried at 82.2°C (180°F) for 1.5 or 2.5 h, a ≥7.4 $\log_{10}$ cfu/strip reduction was observed for *E. coli* O157:H7 and *L. monocytogenes*; however, a 6.8 $\log_{10}$ cfu/strip reduction was observed for strips inoculated with *Salmonella*.

Table 2. Relevant processing parameters, proximate composition values, and inactivation of *Escherichia coli* O157:H7 (EC), *Salmonella* Typhimurium (ST), and *Listeria monocytogenes* (LM; $\log_{10}$ cfu/strip) for marinated and nonmarinated whole-muscle turkey jerky strips cooked-dried for 2.5 or 3.5 h at a target air temperature of 73.8°C (165°F) for 2.5 or 3.5 h or at 82.2°C (180°F) for 1.5 or 2.5 h with constant smoke at an average RH of 29.9% during cooking-drying

Target cooking temperature (°C)	Time (h)	CUT (min)	Smokehouse air temperature (°C)	Jerky internal temperature (°C)	Initial RH (%)	Final RH (%)	EC	ST	LM	a_w	M:Pr
Marinated											
	0	NA[1]	17.88[2] (±3.31) [11.38 to 21.4]	14.43[2] (±3.24) [11.0 to 17.72]	47.1[2] (±11.52)	NA	9.09 (±0.22)	8.84 (±0.36)	9.41 (±0.17)	0.96[3] (±0.004)	3.08 (±0.04)
73.8	2.5	17.7[4] (13, 17, 23; ±5.03)	73.22[5] (±0.54) [73.16 to 73.22]	64.38[6] (±4.95) [64.16 to 65.68]	43.2[7] (±11.01)	27.9 (±1.33)	≤1.12[8,A] (±0.17) [0/27]	≤1.12[A] (±0.17) [3/27]	1.22[A] (±0.07)	0.89 (±0.038)	0.64 (±0.43)
	3.5	20.3 (18, 18, 25; ±4.04)	72.88 (±0.67) [72.16 to 73.27]	66.5 (±4.18) [65.5 to 68.11]	54.9 (±10.02)	29.98 (±3.45)	≤1.12[AB] (±0.18) [1/27]	1.22[A] (±0.23)	≤1.12[AB] (±0.16) [0/27]	0.80[9] (±0.030)	0.67[9] (±0.03)
82.2	1.5	19.0 (16, 19, 22; ±3.00)	82.16 (±0.67) [81.88 to 88.66]	70.83 (±4.33) [81.88 to 82.66]	59.7 (±16.4)	24.1 (±5.8)	≤1.12[A] (±0.11) [2/27]	1.12[A] (±0.39)	≤1.12[A] (±0.25) [1/27]	0.92 (±0.006)	1.10 (±0.08)
	2.5	18.7 (17, 19, 20; ±1.53)	81.83 (±0.67) [81.33 to 82.38]	74.94 (±5.83) [81.5 to 82.11]	41.8 (±3.9)	23.9 (6.1)	1.4[AB] (±0.17)	≤1.22[A] (±0.34)	2.3[CD] (±1.54)	0.84 (±0.042)	0.72 (±0.05)
Nonmarinated											
	0	NA	17.88[2] (±3.31) [11.38 to 21.4]	14.43[2] (±3.24) [11.0 to 17.72]	47.1[2] (±11.52)	NA	9.14 (±0.33)	8.97 (±0.57)	9.61 (±0.17)	0.99 (±0.010)	2.91 (±0.21)
73.8	2.5	17.7[4] (13, 17, 23; ±5.03)	73.22[5] (±0.54) [73.16 to 73.22]	64.38[6] (±4.95) [64.16 to 65.68]	43.2[7] (±11.01)	27.9 (±1.33)	3.15[C] (±0.23)	3.55[B] (±0.58)	3.43[D] (±0.28)	0.97 (±0.017)	1.14 (±0.49)
	3.5	20.3 (18, 18, 25; ±4.04)	72.88 (±0.67) [72.16 to 73.27]	66.5 (±4.18) [65.5 to 68.11]	54.9 (±10.02)	29.98 (±3.45)	2.02[BC] (±0.79)	1.88[A] (±0.94)	2.02[ABC] (±0.96)	0.94 (±0.019)	0.67 (±0.09)
82.2	1.5	19.0 (16, 19, 22; ±3.00)	82.16 (±0.67) [81.88 to 88.66]	70.83 (±4.33) [81.88 to 82.66]	59.7 (±16.4)	24.1 (±5.8)	1.2[AB] (±1.66)	1.6[A] (±1.52)	2.15[BC] (±0.64)	0.97 (±0.001)	1.08 (±0.01)
	2.5	18.7 (17, 19, 20; ±1.53)	81.83 (±0.67) [81.33 to 82.38]	74.94 (±5.83) [81.5 to 82.11]	41.8 (±3.9)	23.9 (±6.1)	1.7[AB] (±1.22)	2.17[AB] (±1.69)	1.12[AB] (±0.66)	0.95 (±0.002)	0.83 (±0.05)

[A–D]For a given pathogen, means with different superscript letters in common within rows and columns are significantly different ($P \leq 0.05$).

[1]NA = not applicable.

[2]Mean of 3 trials (n = 3 trials; n = 4 cooking-drying regimens; total of 12 runs) (±SD) [range of minimum and maximum temperature]. The air temperature of the oven, internal temperature of the turkey breast strips, and initial RH at time 0 were measured with 2 temperature-RH combination probes. The air temperature of the oven, initial RH (n = 3 trials; n = 2 probes per trial), and internal temperature of the turkey breast strips (n = 3 trials; n = 1 probe per trial) listed in this table are the average readings taken immediately after closing the smokehouse door for each of the 2 temperature-RH probes for each trial.

[3]Mean of 2 trials (±SD). Means represent the results from analyses performed on a composite sample (60 g) taken from 1 strip from each of 3 levels on the loading truck in each of the 2 trials (n = 2 trials; n = 3 strips per trial).

[4]Mean of 3 trials (n = 3 trials; n = 1 probe per trial). The come-up time (CUT) temperature of the air in the smokehouse was measured with 1 type K thermocouple connected to a 6-channel digital panel temperature indicator. Temperature measurements were recorded every minute manually. Actual CUT values for each of 3 trials are listed in parentheses.

[5]Mean of 3 trials (±SD) [range of minimum and maximum temperature]. The air temperature of the oven was measured with 2 temperature-RH combination probes. The oven temperatures listed in this table are the average of continuous readings taken every 30 s after the CUT was attained for each of the 2 temperature-RH probes for each trial (n = 3 trials; n = 2 probes per trial) over 2.5 h (1,800 total measurements) and 3.5 h (2,520 total measurements) at 73.8°C and over 1.5 h (1,080 total measurements) and 2.5 h (1,800 total measurements) at 82.2°C.

[6]Mean of 3 trials (±SD). The internal temperature of the turkey breast strips was measured using a 12-bit temperature probe inserted at the center of 1 strip that was placed toward the middle level of the loading truck and connected to a datalogger. The internal temperatures of the turkey breast strips listed in this table are the average of continuous readings taken every 30 s from when CUT was attained throughout each cooking-drying regimen using 1 temperature probe for each trial (n = 3 trials; n = 1 probe per trial) over 2.5 h (900 total measurements) and 3.5 h (1,260 total measurements) at 73.8°C and over 1.5 h (540 total measurements) and 2.5 h (900 total measurements) at 82.2°C.

[7]Mean of 3 trials (±SD). The RH was measured with 2 temperature-RH combination probes. The initial RH values listed in this table are the average of 1 reading of the RH values inside the smokehouse immediately after closing the door for each of the 2 temperature-RH probes for each trial (n = 3 trials; n = 2 probes per trial). The final RH values listed in this table are the average of 1 reading of the RH inside the smokehouse immediately after cooking-drying regimens were attained for each of the 2 temperature-RH probes for each trial for each time (n = 3 trials; n = 2 probes per trial).

[8]Mean of 3 trials (±SD) (n = 3 trials; n = 9 turkey breast strips per trial) for each pathogen. Detection limit = <1.2 $\log_{10}$ cfu/strip or ≤0.06 $\log_{10}$ cfu/g. Numbers in brackets are numbers of positive enrichment samples from a total of samples analyzed (n = 3 trials; n = 9 turkey breast strips per trial per pathogen).

[9]Treatments and cooking-drying regimens that meet both the standard of identity [moisture:protein (M:Pr) ≤0.75:1.0] and shelf-stability [water activity (a_w) of ≤0.80] for jerky (USDA-FSIS, 2004, 2005).

DISCUSSION

The USDA-FSIS recommends that commercial jerky manufacturers reassess and validate the lethality of their thermal processes (USDA-FSIS, 2004). Several studies have reported on the thermal inactivation of foodborne pathogens during processing of jerky made with ground or whole-muscle beef (Harrison et al., 1997; Faith et al., 1998; Calicioglu et al., 2002a,b, 2003; Buege et al., 2006; Porto-Fett et al., 2008), but to our knowledge, there have been no reports on lethality of foodborne pathogens in jerky made with poultry meat. In the present study, we validated the effectiveness of 2 commercial processes, that being cooking-drying turkey breast strips for 2.5 or 3.5 h at a target temperature of 73.8°C (165°F) or for 1.5 or 2.5 h at a target temperature of 82.2°C (180°F), for efficacy toward *E. coli* O157:H7, *Salmonella*, and *L. monocytogenes* during processing of jerky made with whole-muscle turkey breast meat. Our results revealed that cooking-drying marinated whole-muscle turkey breast strips for 3.5 h at a dry-bulb temperature of 73.8°C (165°F) or for 1.5 or 2.5 h at a dry-bulb temperature of 82.2°C (180°F) in a commercial smokehouse with constant (natural hickory) smoke and an average initial and final RH of 49.1 and 29.9%, respectively, resulted in a decrease of at least 7.1 $\log_{10}$ cfu/strip for each of the 3 pathogens tested. These results for turkey jerky are in general agreement with related studies showing a $\geq$6.4 $\log_{10}$ reduction for *E. coli* O157:H7, *Salmonella*, and *L. monocytogenes* in whole-muscle beef jerky that was processed at higher temperatures [$\geq$76.7°C ($\geq$170°F)] and shorter processing times (for up to 3 h), and with a RH of $\geq$20% (Buege et al., 2006; Porto-Fett et al., 2008). These results substantiate that regardless of the specie of meat or the maximum RH attained in the smokehouse, or both, the use of relatively short times and high temperatures for cooking-drying would satisfy the current USDA-FSIS lethality performance standards of *E. coli* O157:H7, *Salmonella*, and *L. monocytogenes* in jerky products.

In the present study, with the exception of strips that were cooked-dried at 73.8°C (165°F) for 2.5 h, marination did not significantly ($P \geq 0.05$) affect survival of *E. coli* O157:H7, *Salmonella*, or *L. monocytogenes* compared with those strips that did not receive the marinade. Previous studies also reported that survival of pathogens on jerky during cooking-drying was not significantly affected by the use of a marinade (Faith et al., 1998; Calicioglu et al., 2002a,b; Porto-Fett et al., 2008). At a lower temperature (73.8°C; 165°F) and shorter processing time (2.5 h), these data suggested a synergistic effect of salt (NaCl; ca. 3.5%) content and spices in the marinade solution on inactivation of all 3 pathogens. Moreover, our results revealed that the use of a marinade and the duration of the cooking-drying step significantly ($P \leq 0.05$) affected the final values for a_w. In a previous study, we reported that when marinated and nonmarinated whole-muscle beef jerky was cooked-dried at 82.2°C (180°F) for 2.5 or 3.5 h, the USDA-FSIS-recommended M:Pr and a_w values were achieved (Porto-Fett et al., 2008). Differences in achieving the M:Pr and a_w in beef versus turkey jerky may be explained by differences in their proximate composition and in the form, shape, and thickness of the meat tested.

The present study substantiated that cooking-drying marinated whole-muscle turkey jerky for 2.5 or 3.5 h at 73.8°C (165°F) or for 1.5 or 2.5 h at 82.2°C (180°F), with constant (natural hickory) smoke and with a decrease in RH from 49.1 to 29.9% during cooking-drying, is sufficient to meet the current performance standard of a 5.0 $\log_{10}$ lethality for *E. coli* O157:H7 and a 7.0 $\log_{10}$ lethality for *Salmonella*, as well as to meet the zero-tolerance policy or compliance guidelines, or both, established for *L. monocytogenes* in RTE poultry products (USDA-FSIS, 2001). However, to meet the USDA-FSIS shelf-stability requirements for jerky, that being a M:Pr of 0.75:1.0 and an a_w of $\leq$0.80, turkey breast strips must be marinated and cooked-dried for at least 3.5 h at 73.8°C (165°F). More importantly, following the processes validated herein will satiate existing regulatory requirements and result in high-quality products that remain safe and wholesome.

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REFERENCES

Buege, D. R., G. Searls, and S. C. Ingham. 2006. Lethality of commercial whole muscle beef jerky manufacturing processes against *Salmonella* serovars and *Escherichia coli* O157:H7. J. Food Prot. 69:2091–2099.

Calicioglu, M., J. N. Sofos, J. Samelis, P. A. Kendall, and G. C. Smith. 2002a. Destruction of acid-adapted and non-adapted *Listeria monocytogenes* during drying and storage of beef jerky. Food Microbiol. 19:545–559.

Calicioglu, M., J. N. Sofos, J. Samelis, P. A. Kendall, and G. C. Smith. 2002b. Inactivation of acid-adapted and non-adapted *Escherichia coli* O157:H7 during drying and storage of beef jerky treated with different marinades. J. Food Prot. 65:1394–1405.

Calicioglu, M., J. N. Sofos, J. Samelis, P. A. Kendall, and G. C. Smith. 2003. Effect of acid adaptation on inactivation of *Salmonella* during drying and storage of beef jerky treated with marinades. Int. J. Food Microbiol. 89:51–65.

CDC. 1995. Outbreak of salmonellosis associated with beef jerky – New Mexico, 1995. Morb. Mortal. Wkly. Rep. 44:785–788.

Eidson, M., C. M. Sewell, G. Graves, and R. Olson. 2000. Beef jerky gastroenteritis outbreaks. J. Environ. Health 62:9–13.

Faith, N. G., N. S. Le Coutour, M. B. Alvarenga, M. Calicioglu, D. R. Buege, and J. B. Luchansky. 1998. Viability of *Escherichia coli* O157:H7 in ground and formed beef jerky prepared at levels of 5 and 20% fat and dried at 52°, 57°, 63°, or 68°C in a home-style dehydrator. Int. J. Food Microbiol. 41:213–221.

Harrison, J. A., M. A. Harrison, and R. A. Rose. 1997. Fate of *Listeria monocytogenes* and *Salmonella* species in ground beef jerky. J. Food Prot. 60:1139–1141.

Keene, W. E., E. Sazie, J. Kok, D. H. Rice, D. D. Hancock, V. K. Balan, T. Zhao, and M. P. Doyle. 1997. An outbreak of *Escherichia coli* O157:H7 infections traced to jerky made from deer meat. JAMA 277:1229–1231.

Levine, P. B., B. Rose, S. Green, G. Ransom, and W. Hill. 2001. Pathogen testing of ready-to-eat meat and poultry products collected at federally-inspected establishments in the United States, 1990 to 1999. J. Food Prot. 64:1188–1193.

McNeil, J. E. 1990. Meat and meat products. Pages 931–938 in Official Methods of Analysis. 15th ed. K. Erlich, ed. AOAC Int., Arlington, VA.

Porto-Fett, A. C. S., J. E. Call, and J. B. Luchansky. 2008. Validation of a commercial process for inactivation of *Escherichia coli* O157:H7, *Salmonella* Typhimurium, and *Listeria monocytogenes* on the surface of whole muscle beef jerky. J. Food Prot. 71:918–926.

Smelser, C. 2004. Outbreak of salmonellosis associated with beef jerky in New Mexico. N. M. Epidemiol. Rep. 3:1–3.

USDA-FSIS. 2001. Performance Standards for the Production of Processed Meat and Poultry Products. 9CFR parts 301, 303. Fed. Regist., Washington, DC.

USDA-FSIS. 2004. Compliance guidelines for meat and poultry jerky. http://www.fsis.usda.gov/PDF/Compliance_Guideline_Jerky.pdf Accessed Dec. 2007.

USDA-FSIS. 2005. Food Standards and Labeling Policy Book. http://www.fsis.usda.gov/OPPDE/larc/Policies/Labeling_Policy_Book_082005.pdf Accessed Dec. 2007.