Effect of Salts of Organic Acids on *Listeria monocytogenes*, Shelf Life, Meat Quality, and Consumer Acceptability of Beef Frankfurters

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Abstract: The objective of this study was to evaluate anti-listerial efficacy of salts of organic acids, and their impact on the quality of frankfurters. Beef frankfurters were manufactured by incorporating organic acids in 5 different combinations: (1) control (no marinade addition; C); (2) sodium lactate (2% wt/wt; SL); (3) potassium lactate (2% wt/wt; PL); (4) sodium citrate (0.75% wt/wt; SC); and (5) sodium lactate (2% wt/wt)/sodium diacetate (0.25% wt/wt; SL/SD). Cooked frankfurters were inoculated with streptomycin-resistant (1500 μg/mL) *L. monocytogenes* (7 $\log_{10}$ CFU/frank). Inoculated and noninoculated frankfurters were vacuum packaged and stored at 4 °C. Samples were taken weekly up to 10 wk for estimation of *L. monocytogenes* as well as aerobic plate count (APC) and psychrotrophs (PSY), respectively. Total of 2 independent trials of the entire experiment were conducted. Noninoculated beef frankfurters were evaluated weekly by untrained sensory panelists for 7 wk. SL, PL, and SC treatments did not ($P > 0.05$) adversely affect consumer acceptability through 8 wk although, SL/SD treatment was significantly ($P \leq 0.05$) less preferred across all sensory attributes. SL/SD treatment negatively affected product quality, but was able to control APC, PSY, and *L. monocytogenes* levels. SC performed similar to the control throughout the 8, 9, and 10 wk storage periods, providing no benefit for inhibiting *L. monocytogenes* (increasing from 7 logs CFU/frank to 10 logs CFU/frank throughout storage) or extending shelf life of the beef frankfurters. In conclusion, 2% SL and PL, and 2% SL/0.25% SD may be effective *L. monocytogenes* inhibitors (maintaining inoculation levels of 7 logs CFU/frank during storage), but changes in SL/SD treatment formulation should be studied to improve product quality.

Keywords: consumer acceptability, frankfurters, *Listeria monocytogenes*, quality, salts of organic acids, shelf life

Practical Application: This research is important to the further processing meat and poultry industries because the results will validate the current use, functionality, and usefulness of salts of organic acids as inhibitors of *Listeria* and spoilage microorganisms in frankfurters. Moreover, results of this study will also demonstrate the impact of frankfurters formulated with salts of organic acids on organoleptic properties and shelf life.

Introduction

Listeria monocytogenes is a postprocess contaminant, frequently isolated from ready-to-eat (RTE) foods, causing 19% of the total foodborne pathogen-related fatalities in the United States (Scallan and others 2011). RTE meat products contaminated with *Listeria* are a high-risk food-pathogen combination especially because these foods do not undergo additional kill/cook steps (Schwartz and others 1988; Barnes and others 1989; Gottlieb and others 2006; Mataragas and others 2008; CDC 2009). Consumption of RTE foods contaminated with *L. monocytogenes* by immunocompromised, elderly, newborn, and pregnant women can lead to fatalities. Therefore, there is a "zero tolerance policy" by the United States Dept. of Agriculture (USDA; 64 FR 27351).

The USDA-Food Safety and Inspection Service (FSIS) and the Food and Drug Administration (FDA) regulatory policy requires a scientifically validated *L. monocytogenes* control programs from processors producing RTE products (Gottlieb and others 2006). The FSIS *Listeria* Interim Final Rule (*Listeria* Rule) applies to any plant producing RTE meat or poultry products exposed to the environment after primary lethality treatments/cooking. The rule establishes three strategies for controlling *L. monocytogenes* in RTE foods (3 alternatives). A RTE processor can employ a post-lethality treatment and a growth inhibitor which is the best control or a less stringent second alternative where either post-lethality or a growth inhibitor is used. Alternative 3, employs only a sanitation program for controlling *L. monocytogenes* in the environment.

Growth inhibitors such as salts of organic acids are commonly used in raw products and/or postprocessing steps by RTE meat or poultry product processors. Food grade salts, including sodium lactate, potassium lactate, sodium citrate, and sodium diacetate not only exhibit anti-listerial activity but also function as pH controllers, humectants, and flavor enhancers when incorporated into raw product (Brewer and others 1991; Gottlieb and others 2006). Sodium lactate (SL; salt of lactic acid) is a generally recognized as safe (GRAS) ingredient and is permitted at 3% or less in RTE meat products as a *Listeria* inhibitor, shelf life extender, and a partial replacement for sodium chloride (NaCl) (Angersbach 1971; Houtsma and others 1996; USDA-FSIS 2003). Studies indicate

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that the application of sodium lactate (3%) in pork liver sausages exhibited listeriostatic effects, up to 50 d at 5 °C and at reduced levels (2.5%) with sodium acetate (0.25%) in vacuum packaged sliced servelat sausage (Blom and others 1997; Weaver and Shelef 1993). These observations suggest that sodium lactate can be equally listeriostatic and act synergistically with other salts of organic acids such as sodium acetate.

Similarly, sodium diacetate (SD; sodim salt of acetic acid) is also a GRAS additive (JII 2009; USDA 2009). It is characterized by a vinegar odor, while higher concentrations can affect organoleptic qualities of the food (JII 2009). Although SD should not affect product pH significantly, Islam and others (2002) demonstrated that turkey frankfurters dipped in 20% wt/vol SD solution (0.25% product concentration), significantly lowered frank surface pH from 5.75 in controls to 4.58 to 4.69. They also found that a 25% wt/vol SD solution reduced *L. monocytogenes* levels on aerobically packaged franks stored at 4 °C for 10 d (Islam and others 2002). In addition, the effectiveness of SD has been reported to have increased with a decrease in temperature and when used in combination with SL (Ahmad and Marth 1989; Islam and others 2002; Schlyter and others 1993). Although potassium lactate (PL) has similar uses as SL in RTE foods, it is less preferential as it imparts a bitter flavor to the product (Weaver and Shelef 1993). Anti-listerial activity of PL (2% and 3%) was effectively demonstrated by Porto and others (2001) in mixed-species frankfurters at 4 °C for 90 d. Similarly, Weaver and Shelef (1993) reported that PL was listeriostatic at 3% wt/wt in pork liver sausages at 5 °C for 50 d. In addition to its anti-listerial properties, PL decreases lipid oxidation in refrigerated meats, increases meat tenderness, color, and flavor stability by increasing water-holding capacity (Purac 2012).

Sodium citrate (SC; salt of citric acid) is another buffered GRAS ingredient used to control pH, bind water (lower water activity), enhance flavor, and inhibit growth of foodborne pathogens in foods such as ice-cream, candy, gelatin desserts, jams, and RTE meats (Purac 2012). Sodium citrate has been shown to be an equally effective bacteriostatic at 3 to 6 times SL concentration against *Listeria*, *Salmonella*, and *Escherichia coli* O157:H7 (Purac 2012). Similar to SL and PL, combination of acetic and citric acid (both at 2.5%) applied on franks inhibits *L. monocytogenes* for up to 90 d at 5 °C (Palumbo and Williams 1994**).**

Although the previously mentioned salts of organic acids have been documented to be effective in controlling the growth of *L. monocytogenes* and other foodborne pathogens, they have the potential to negatively affect product quality and consumer acceptability. There has been minimal research on the effect of these salts on meat quality, shelf life, and consumer acceptability of RTE meat products. Therefore, the objective of this study was to validate the efficacy of commonly used salts of organic acids against *L. monocytogenes* on beef frankfurters stored at 4 °C and to determine their impact on product quality.

Materials and Methods

Preparation and treatment of beef frankfurters

The basic frankfurter formulation (no salts included) consisted of beef trimmings (87.9% wt/wt; approximately 28% fat), ice (10%), 2.1% seasoning and sodium nitrite (A.C. Legg Inc., Calera, Ala., U.S.A.). Total of 10 formulation batches were prepared (2 replications/treatment) separately to contain (1) no organic acid salts (control); (2) sodium lactate (SL) at 3.30% of a 60% (wt/wt), which is equivalent to 2% pure SL (Trumark, Linden, N.J., U.S.A.); (3) potassium lactate (PL) at 3.30% of a 60% (wt/wt), which is equivalent to 2% pure PL (Trumark); (4) 0.75% sodium citrate (SC) (Tate & Lyle, Decatur, Ill., U.S.A.); and (5) 2% SL (Trumark) combined with 0.25% sodium diacetate (SD) (Jungbunzlauer Inc., Ladenburg, Germany). These inclusion levels of organic acid salts in the beef frankfurter formulation were chosen based on manufacturers' recommendations and results of other published literature.

Although replications were included at the batch level, 2 independent trials were also conducted. In each trial, meat ingredients were mixed and ground once through a 3/8 in. die plate and a second time through a 3/16 in. die plate (Hollymatic 3000, Thompson Meat Machinery, Queensland, Australia). The resulting ground meat was partitioned into 13.6 kg (30 lb) batches (10 replicates total); 2 replications/treatment. Each 13.6 kg batch was emulsified with non-meat ingredients in a bowl chopper (Model C-35 ST, Smith Equipment Co., Clifton, N.J., U.S.A.) for 5 min and/or until a temperature probe placed in the batter read 10 °C (50°F). All the emulsified batches were kept separate throughout the post-emulsification steps. Emulsified, individual batches were extruded into 22-mm cellulose casings (Viscofan USA Inc., Montgomery, Ala., U.S.A.) using a vacuum stuffer (VEMAG Robot 500, Reiser, Canton, Mass., U.S.A.). The bowl chopper and vacuum stuffer were cleaned after each individual batch to prevent mixing of different treatments. Batches were equally and randomly allocated to smoke racks and smoked in a single truck Koch smokehouse (Model 35003, Koch Equipment LLC, Kansas City, Mo., U.S.A.). After reaching an internal temperature of 68.9 °C (156 °F), the franks were showered for 10 min with cool water and stored overnight at 4 °C. Frankfurters were stripped manually to get an approximate 56 g frankfurter and vacuum packaged according to treatment.

Inoculation and packaging of frankfurters

Streptomycin resistant (1500 μg/mL) *Listeria monocytogenes* Brie 1 (Source: R. W. Hutkins, The Univ. of Nebraska Lincoln, Nebr., U.S.A.) was cultured in brain–heart infusion broth (BHI; Acumedia Manufacturers Inc., Lansing, Mich., U.S.A.) for 24 h (9 $\log_{10}$ CFU/mL) at 37 °C. Frankfurters (36/replication/treatment) were aseptically placed on a sterile aluminum foil sheet. Each frankfurter was then inoculated by evenly spreading 10 μL of inoculum (9 $\log_{10}$ CFU/mL) along the length of each frankfurter with a sterile inoculating loop. Inoculated frankfurters were placed in a sterile laminar flow biosafety hood for 5 min for bacterial attachment after which these frankfurters (1 per bag) were aseptically placed into a vacuum bag (20.3 by 25.4 cm, 3 mil standard barrier, nylon/PE vacuum pouch, Prime Source Vacuum Pouches, Koch Supplies Inc., Kansas City, Mo., U.S.A.), vacuum packaged (Ultravac 225 Vacuum Chamber Packaging Machine, Koch Equipment LLC), and stored at 4 °C.

For shelf life determination, noninoculated frankfurters (4 per bag, 144 per replication, 288 per treatment, and 1440 total frankfurters) were vacuum packaged (Ultravac UV2100-C, Koch Supplies Inc.; Koch Equipment LLC) and stored at 4 °C to determine aerobic plate count (APC) and psychrotroph (PSY) populations.

For sensory evaluation, noninoculated frankfurters (6 per bag × 4 bags per sampling d × 2 replications × 5 treatments × 12 wk = 2880 total frankfurters) from each replication were vacuum packaged (Ultravac UV2100-C, Koch Supplies, Inc.; Koch Equipment LLC) and randomly distributed throughout a walk-in cooler (Thermo-Kool, Mid-South Industries Inc., Laurel, Miss., U.S.A.) at 4 °C for the duration of the study (1 to 78 d).

Microbiological analyses

Sampling was conducted weekly from week 1 through 10 for total aerobic populations (APC) on standard methods agar (PCA; Acumedia Manufacturers Inc.); for psychrotrophs (PSY) on PCA agar (Acumedia Manufacturers Inc.); for *L. monocytogenes* Brie 1 on BHI agar (Acumedia Manufacturers Inc.) supplemented with 1500 μg/mL streptomycin sulfate (Fisher Scientific, Fair Lawn, N.J., U.S.A.). Vacuum packaged noninoculated frankfurters (3 bags/replication/treatment) were used for APC and PSY determination. Total of 1 frankfurter from each bag was aseptically removed into a separate sterile Whirl-Pak Filter bag (15 × 23 cm, 710 mL Whirl-Pak Filter bag, Nasco, Fort Atkinson, Wis., U.S.A.); 1% phosphate buffered saline (50 mL; PBS 1× powder concentrate; Fisher Scientific) was added and rinsed manually for 1 min. Serial dilutions (1 : 10) were made and 1 mL of each sample was pour plated (4 plates) with PCA (20 mL). After setting, the agar APC plates were incubated for 24 to 48 h at 37 °C and PSY plates were incubated for 10 d at 4 °C (Limit of Detection; LOD = 5 CFU/g).

Frankfurters kept under refrigeration for sensory analysis were monitored for APC and PSY to monitor spoilage of the product. APC and PSY estimation was carried out as previously described but instead, serial dilutions (50 μL) of each sample were spiral plated (WASP II automated spiral plater, Microbiology Intl., Frederick, Md., U.S.A.) onto PCA (LOD = 5 CFU/g). After spiral plating, APC plates were incubated for 24 to 48 h at 37 °C and PSY plates were incubated for 10 d at 4 °C. Frankfurters were considered unsuited for sensory analysis after they had reached APC of 6 $\log_{10}$ CFU/frank.

L. *monocytogenes* estimation. Sampling and microbiological analysis was similar to procedures for APC and PSY. Total of 50 μL of each sample were spiral plated onto BHI agar supplemented with 1500 μg/mL streptomycin sulfate and incubated for 24 to 48 h at 35 °C (LOD = 5 CFU/g). Bacterial colonies from all incubated samples were enumerated using QCount® equipment and software (Spiral Biotech Inc., Norwood, Mass., U.S.A.), and results were reported as $\log_{10}$ CFU/frank.

Physical and chemical properties

The pH and temperature (°C) of raw frankfurter batter was recorded before (3 samples/replicate/treatment) and after (3 samples/replicate/treatment per replicate, 6 samples per treatment) acid marinade addition using an Accumet Excel XL20 pH/conductivity meter (Fisher Scientific).

Sensory evaluation

Sensory analysis was performed to evaluate consumer acceptability of noninoculated frankfurters formulated with and without acids (Morey and others 2011). An untrained test panel (n = 60; 30/replicate) was recruited to evaluate frankfurters for appearance, flavor, texture, juiciness, and overall acceptability on an 8-point hedonic scale as suggested by the IFT (1981). Frankfurters were boiled to re-heat, cut into approximately 2 cm pieces and placed in capped (PL2 clear plastic soufflé lids, Solo Cup Comp., Highland Park, Ill., U.S.A.) plastic sample cups (59.2 mL B200 plastic soufflé's, Solo Cup Comp.), labeled with a random 3-digit code and kept warm (approximately 82 °C; FlavorView C175-C(1)N Heated Cabinet, Intermetro Industries Corp., Wilkes-Barre, Pa., U.S.A.) until served. Each panelist evaluated individual frankfurter samples for 5 sensory attributes based on the 8-point hedonic scale that ranged from, (1) Like Extremely; (2) Like Very Much; (3) Like Moderately; (4) Like Slightly; (5) Dislike Slightly; (6) Dislike Moderately; (7) Dislike Very Much; and (8) Dislike Extremely. Room temperature water and unsalted crackers were provided to cleanse panelists' palates between samples. Sensory analysis was suspended once the products had aerobic plate counts of 6 $\log_{10}$ CFU/frank.

Statistical analysis

Data was analyzed using Proc Mixed procedures in the SAS 9.1 software (SAS Insti. 1993). Comparisons were made using LS means and significant differences ($P \leq 0.05$) were identified. The experimental unit for expressing microbiological data was frankfurter.

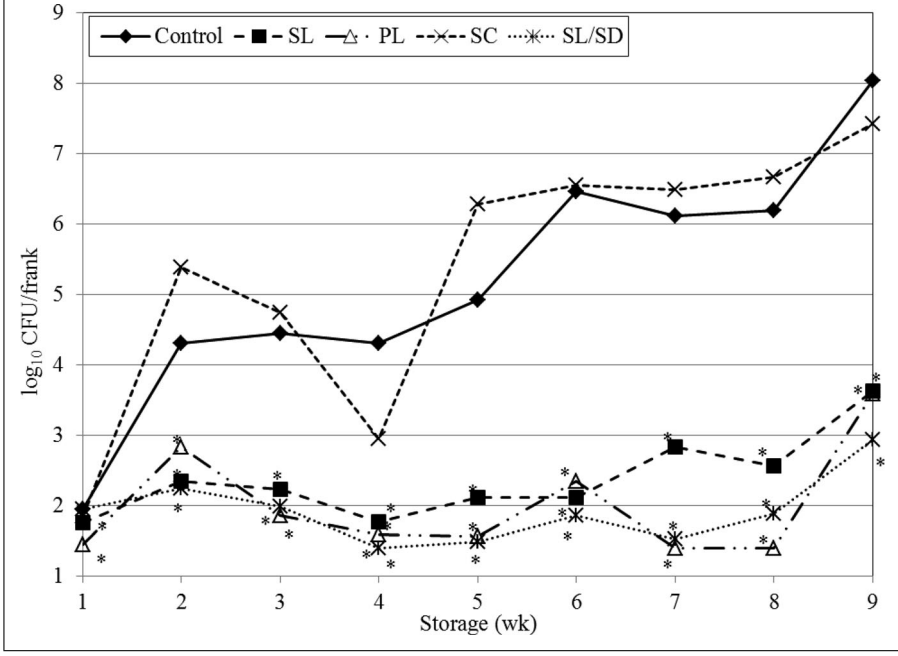

Figure 1–Aerobic plate count (log CFU/frank) of beef frankfurters either formulated without acid marinades (Control) or formulated with sodium lactate (SL; 2%), potassium lactate (PL; 2%), sodium citrate (SC; 0.75%), and sodium lactate/sodium diacetate combination (SL/SD; 2%/0.25%) during 10 wk of storage at 4 °C. Standard deviations varied from 0 to 2.58.

Results and Discussion

Microbiological analysis

Although, sensory evaluations were suspended on week 7, the effect of salts of organic acids on microbiological shelf life (APC and PSY) and LM was monitored for 12 wk (Figure 1 and 2). The products were considered unacceptable when APC and PSY levels reached 5×10^6 CFU/frank.

Aerobic plate count

APC levels, for all treatments, increased from < 2 logs at week 1 during storage at 4 °C (Figure 1). Treatments, SL, PL, and SL/SD, were more effective at controlling APCs than the control and SC treatment (Figure 1). Frankfurters made with SL, PL, and SL/SD did not reach spoilage during the entire 10 wk; however, SC and control were unacceptable within 7 wk (Figure 1). At the beginning of shelf life, week 1 to 2, SC treated frankfurters' APC counts increased from 1.84 to 5.34 $\log_{10}$ CFU/frank; just over 1 log more than the control during the same time period (Figure 1). During week 3 to 10, increase in the APC counts of SC showed no differences ($P \leq 0.05$) from the control (Figure 1). These results can be attributed to the randomness of the data.

During week 2, the APC for SC treated franks were significantly ($P \leq 0.05$) higher than that of SL, PL, and SL/SD treated franks though, not different from the control (Figure 1). APC of organic acid treatments (SL, PL, and SL/SD) were significantly suppressed during week 3 to 10 compared to the control and SC (Figure 1). Similar to this study, Carroll and others (2007) found that SL (3%)/SD (0.25%) combination treatment kept APC levels below spoilage for 70 d on turkey deli loaf slices. In addition, Brewer and others (1991) reported that incorporation of 2% SL to fresh pork sausages delayed the microbial spoilage; wherein, the TPC reached 8 logs after 24 d as compared to 10 d in control samples.

Although the control and SC frankfurters had reached 7 logs on week 10, the SL, PL, and SL/SD treatment levels did not exceed 4 logs (Figure 1). Similarly, Drosinos and others (2006) and Ouattara and others (1997) reported the suppression of spoilage microbiota and subsequent shelf life extension of cooked meats due to addition of organic acids and their salts.

Results also indicated that SL and PL were effective ($P \leq 0.05$) at controlling APC levels (< 4 logs CFU/frank) in frankfurters throughout the 10-wk storage period (Figure 1). Addition of SD along with SL exhibited further suppression of spoilage microbiota compared to SL alone. The increase in antimicrobial effect is probably due to the increased inhibitory effect of SD at refrigerated temperatures (Ahmad and Marth 1989; Islam and others 2002).

Psychrotrophs

Because psychrotrophs (PSY) exhibit growth between 0 and 20 °C; they are good indicators of refrigerated product spoilage (Morita 1975). PSY counts were collected for a period of 8 wk and during this storage period, PSY levels increased ($P \leq 0.05$) for control and all treatments (Figure 2). Through the entire 8-wk storage period, SC treated frankfurter PSY levels were not different ($P > 0.05$) than the controls (Figure 2). PSY counts of SL, PL, SC, and SL/SD treatments at week 1 were not different ($P > 0.05$) than the controls (Figure 2). As the storage progressed, PSY counts of control and SC were higher (6 logs CFU/frank; $P \leq 0.05$) at week 5 as compared to SL, PL, and SL/SD (3 logs CFU/frank; Figure 2).

The trends in psychrotrophic counts were similar to the APC, indicating that SL, PL, and SL/SD treatments were effective at controlling the growth of spoilage microorganisms on the frankfurters compared to the control and SC treatment (Figure 2).

***Listeria monocytogenes*.** Organic acids formulated into beef frankfurters stored at 4 °C showed that SL, PL, and SL/SD treatments were effective ($P \leq 0.05$) at inhibiting the growth of *L. monocytogenes* through 9 wk of storage compared to the control (maintaining approximately 6 to 7 logs CFU/frank; Figure 3). Similarly, Porto and others (2001) found that potassium lactate (2% and 3%) added as an ingredient in frankfurters was effective at inhibiting the growth of *L. monocytogenes* (approximately 1.6 $\log_{10}$ CFU and approximately 1.4 $\log_{10}$ CFU, respectively) at 4 °C for up to 90 d. Additionally, Wederquist and others (1995,

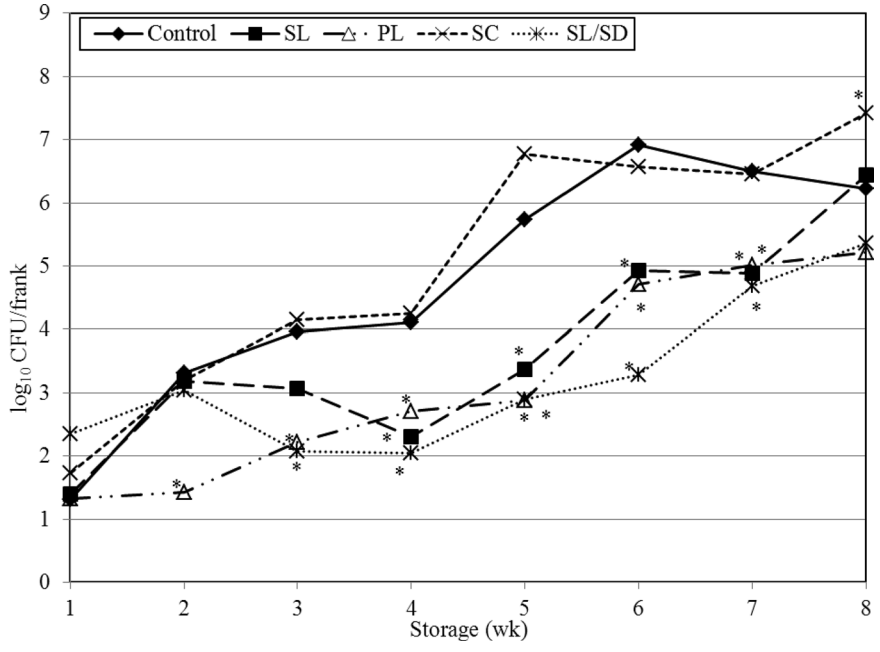

Figure 2–Psychrotroph results ($\log_{10}$ CFU/frank) of beef frankfurters either formulated without acid marinades (Control) or formulated with sodium lactate (SL; 2%), potassium lactate (PL; 2%), sodium citrate (SC; 0.75%), and sodium lactate/sodium diacetate combination (SL/SD; 2%/0.25%) during 8 wk of storage at 4 °C. Standard deviations varied from 0.03 to 1.96.

1994) found that when 2% sodium lactate alone was added to bologna (< 100 CFU/g *L. monocytogenes*), it was effective against *L. monocytogenes* at 5 °C. Although, Weaver and Shelef (1993) used 3% sodium lactate on pork liver sausages, they found that SL exhibited listeriostatic activity rather than listericidal. Another study by Blom and others (1997) reported that 2.5% sodium lactate with 0.25% sodium acetate inhibited *L. monocytogenes* (3 log CFU/g) after heating on sliced, vacuum packaged servelat sausage stored at 4 °C.

L. monocytogenes growth was higher ($P \leq 0.05$) in control and SC treatments and continued to increase throughout the storage period, 7 to 10 logs CFU/frank, indicating the inefficacy of SC in inhibiting growth of the pathogen on frankfurters (Figure 3). Contradictory to these findings, Palumbo and Williams (1994) demonstrated that a combination of acetic and citric acid (both at 2.5%) applied to frankfurters as a secondary lethality step (postcooking) significantly inhibited *L. monocytogenes* for 90 d at when stored at 5 °C. These results from Palumbo and Williams (1994) may be due to high concentration of acetic acid in the formulation (2.5%) counteracting the growth promotion effect of citric acid (Ryser and Marth 2007). Also, the researchers used the combination on the surface, while in the current study, SC was incorporated in the formulation. Surface contaminates may be more susceptible to a postcook application due to the nature of the surface of the frankfurter (coagulated protein surface) than applications where the organic acid salts are incorporated into the product. In the current study, sodium diacetate suppressed growth of *L. monocytogenes* at 3 times less the concentration (0.25%) than SC (0.75%) (Figure 3) while SL, PL, and SL/SD treatments significantly inhibited the growth of *L. monocytogenes* throughout the storage period.

Sensory attributes

Salts of organic acids impart off-flavors to food products and their effect on sensory attributes of beef frankfurters has not been widely published. Therefore, untrained sensory panel evaluations were administered to reflect consumer acceptability of various organic acid treated frankfurters. Sensory analysis of frankfurters was conducted until week 7 since the APCs had reached 6 $\log_{10}$ CFU/frank. Sensory panelists evaluated frankfurters based on the degree of liking with high scores representing less favorable and vice versa (Table 1). SL/SD frankfurters obtained higher ($P \leq 0.05$) scores (range: 5.27 to 6.71, dislike slightly to dislike moderately) on week 1 for all attributes compared to other treatments and were found to be dry, rubbery, and had an acetic acid odor. Therefore, SL/SD frankfurters were served to panelists only during week 1. These observations are in agreement with Carroll and others (2007) who reported that a trained sensory panel found combination of 3% SL and 0.25% SD to intensify the turkey flavor of turkey deli meat. It can be concluded that small changes in lightly flavored deli meats can be easily detected, so the intensity of SL/SD flavor development cannot be masked in heavily seasoned frankfurters. SD is derived from acetic acid and therefore has the potential to impart a vinegar-like odor (JII 2009). As a result, during week 2 through 6, panelists were asked to evaluate the control, SL, PL, and SC treatments only. Interestingly, flavor scores of SL, PL, and SC frankfurters did not differ significantly, ranking between like very much to like moderately, from week 1 to 7. These results indicate either low flavor development by SL, PL, and SC addition and/or masking of those flavors by heavy seasoning and smoke. Similar results were reported by Mikel and others (1996) who found that 2% lactic and acetic acid treated beef strip loin sensory results were not affected through 112 d of storage. Brewer and others (1991) determined that SL addition (2% and 3%) to fresh pork sausages delayed the development of off-flavors for 7 d at 4 °C and did not affect product appearance. However, Aktas and Kaya (2001) suggested incorporating lower levels (up to 1%) of lactic and citric acid in marinade for bovine *longissimus dorsi* muscles to give acceptable taste and aroma. These differences can be due to the type of muscle, proximate composition, product and marinade formulations, and manufacturing methods.

In the current study, texture and overall acceptability were unaffected by SL, PL, and SC treatment addition through the entire

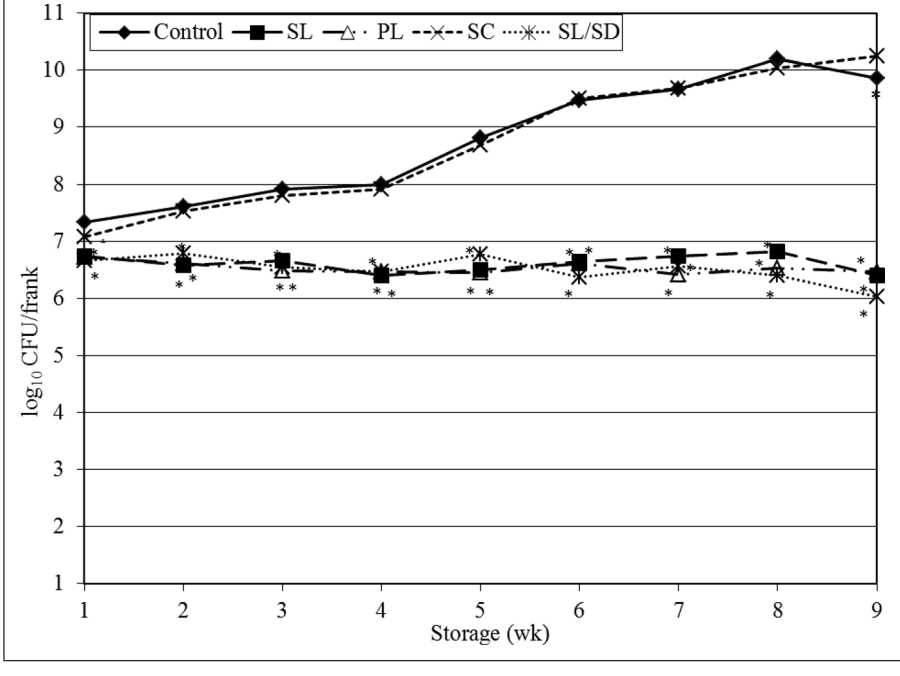

Figure 3–*Listeria monocytogenes* Brie 1 plate count (log CFU/frank) of beef frankfurters either formulated without acid marinades (Control) or formulated with sodium lactate (SL; 2%), potassium lactate (PL; 2%), sodium citrate (SC; 0.75%), and sodium lactate/sodium diacetate combination (SL/SD; 2%/0.25%) during 9 wk of storage at 4 °C. Standard deviations varied from 0 to 0.47.

Table 1–Sensory panelist results for appearance, flavor, texture, juiciness, and overall acceptability of beef frankfurters either formulated without acid marinades (Control) or formulated with sodium lactate (SL; 2%), potassium lactate (PL; 2%), sodium citrate (SC; 0.75%), and sodium lactate/sodium diacetate combination (SL/SD; 2%/0.25%) by storage period (mean ± SD).

Storage period (wk)	Treatment	Appearance[A]	Flavor[A]	Texture[A]	Juiciness[B]	Overall[A]
1	Control	2.57 ± 1.05[b]	2.59 ± 1.40[bc]	3.01 ± 0.98[b]	2.69 ± 1.13[b]	2.83 ± 1.21[b]
	SL	2.61 ± 1.24[b]	2.62 ± 1.40[bc]	2.80 ± 1.56[b]	2.58 ± 1.38[b]	2.89 ± 1.38[b]
	PL	2.68 ± 1.46[b]	2.47 ± 1.35[c]	2.89 ± 1.08[b]	2.80 ± 1.36[b]	2.72 ± 1.37[b]
	SC	2.49 ± 1.16[b]	2.89 ± 1.12[b]	2.74 ± 1.02[b]	2.73 ± 1.07[b]	2.76 ± 1.03[b]
	SL/SD	5.54 ± 1.65[a]	6.71 ± 1.56[a]	6.06 ± 1.22[a]	5.27 ± 1.77[a]	6.10 ± 1.68[a]
	Pooled SEM	0.17	0.14	0.18	0.18	0.17
2	Control	2.73 ± 1.22[a]	2.89 ± 1.24[a]	2.76 ± 1.14[a]	2.96 ± 1.04[a]	2.83 ± 1.10[a]
	SL	2.82 ± 1.24[a]	2.75 ± 1.41[a]	2.90 ± 1.32[a]	2.49 ± 0.92[b]	2.89 ± 1.37[a]
	PL	2.80 ± 1.28[a]	2.69 ± 1.28[a]	2.87 ± 1.07[a]	2.71 ± 0.97[ab]	2.80 ± 1.14[a]
	SC	2.93 ± 1.28[a]	2.70 ± 1.21[a]	2.84 ± 0.94[a]	2.71 ± 0.88[ab]	2.69 ± 1.00[a]
	SL/SD	–	–	–	–	–
	Pooled SEM	0.17	0.15	0.18	0.13	0.16
3	Control	2.55 ± 0.95[b]	2.72 ± 1.09[a]	2.98 ± 1.10[a]	2.69 ± 1.07[ab]	2.81 ± 1.03[ab]
	SL	2.91 ± 1.39[ab]	2.86 ± 1.51[a]	3.19 ± 1.25[a]	2.58 ± 0.91[ab]	3.07 ± 1.37[a]
	PL	2.56 ± 1.04[b]	2.49 ± 1.13[a]	2.74 ± 1.15[a]	2.37 ± 0.88[b]	2.58 ± 1.15[b]
	SC	3.00 ± 1.12[a]	2.74 ± 1.46[a]	2.97 ± 1.03[a]	2.79 ± 1.01[a]	2.95 ± 1.17[ab]
	SL/SD	–	–	–	–	–
	Pooled SEM	0.15	0.15	0.18	0.13	0.16
4	Control	2.30 ± 0.89[b]	2.54 ± 1.09[a]	2.71 ± 1.04[a]	2.54 ± 0.89[b]	2.59 ± 0.91[a]
	SL	2.32 ± 0.97[b]	2.32 ± 1.07[a]	2.59 ± 0.87[a]	2.43 ± 0.85[b]	2.36 ± 0.92[a]
	PL	2.29 ± 0.91[b]	2.43 ± 1.12[a]	2.63 ± 1.20[a]	2.11 ± 0.78[a]	2.41 ± 0.97[a]
	SC	2.80 ± 1.15[a]	2.54 ± 1.06[a]	2.54 ± 0.93[a]	2.52 ± 0.87[b]	2.50 ± 0.89[a]
	SL/SD	–	–	–	–	–
	Pooled SEM	0.13	0.14	0.15	0.11	0.12
5	Control	2.56 ± 0.95[a]	2.61 ± 1.43[a]	2.89 ± 1.10[a]	2.63 ± 0.98[ab]	2.75 ± 1.25[ab]
	SL	2.51 ± 0.94[a]	2.48 ± 1.17[a]	2.66 ± 1.09[a]	2.36 ± 0.85[bc]	2.58 ± 1.09[ab]
	PL	2.54 ± 1.12[a]	2.38 ± 1.21[a]	2.53 ± 1.14[a]	2.15 ± 0.96[c]	2.44 ± 1.18[b]
	SC	2.73 ± 0.91[a]	2.78 ± 1.15[a]	2.76 ± 1.13[a]	2.86 ± 0.96[a]	2.91 ± 1.02[a]
	SL/SD	–	–	–	–	–
	Pooled SEM	0.13	0.15	0.16	0.12	0.15
6	Control	2.46 ± 0.82[a]	2.69 ± 1.55[ab]	3.13 ± 0.99[a]	2.58 ± 0.96[a]	2.86 ± 1.30[a]
	SL	2.50 ± 1.27[a]	2.38 ± 1.47[b]	2.83 ± 1.12[a]	2.57 ± 0.94[a]	2.59 ± 1.18[a]
	PL	2.87 ± 1.41[a]	2.90 ± 1.44[a]	3.03 ± 1.26[a]	2.71 ± 1.29[a]	3.01 ± 1.35[a]
	SC	2.78 ± 1.12[a]	2.61 ± 1.39[ab]	2.83 ± 0.98[a]	2.80 ± 1.01[a]	2.82 ± 1.23[a]
	SL/SD	–	–	–	–	–
	Pooled SEM	0.17	0.16	0.21	0.15	0.18
7	Control	2.78 ± 1.05[ab]	2.73 ± 1.31[a]	2.81 ± 1.31[a]	2.66 ± 0.99[ab]	2.80 ± 1.31[a]
	SL	2.66 ± 0.95[b]	2.66 ± 1.24[a]	3.02 ± 1.02[a]	2.86 ± 1.05[a]	2.72 ± 0.93[a]
	PL	3.14 ± 1.33[a]	2.80 ± 1.35[a]	3.19 ± 1.37[a]	2.49 ± 0.94[b]	2.91 ± 1.37[a]
	SC	2.85 ± 1.13[ab]	2.57 ± 1.23[a]	2.83 ± 0.97[a]	2.88 ± 1.08[a]	2.78 ± 1.16[a]
	SL/SD	–	–	–	–	–
	Pooled SEM	0.15	0.16	0.17	0.13	0.16

[a,b,c]Mean values bearing different superscript letters within each storage period and treatment are significantly different.($P \leq 0.05$). Higher values indicate less acceptable panelist results. SL/SD data not collected week 2 through 7.
[A]Where 1 = like extremely; 8 = dislike extremely.
[B]Where 1 = extremely juicy; 8 = extremely dry.

storage period (Table 1). In our study, PL and SL were evaluated to be significantly ($P < 0.05$) more juicy than the other treatments (Table 1). Similar results were also reported by Vieson and others (2007) in a study that found that beef steak treated with 2.5% SL was more flavorful, tender, and juicy than untreated steaks over an extended period of time.

Conclusions

SL, PL, and SL/SD, were effective ($P \leq 0.05$) in controlling microbial spoilage and increasing shelf life of frankfurters. These treatments suppressed ($P \leq 0.05$) the growth of *L. monocytogenes* and can be used as listeristatic agents in frankfurter formulations. Although SL/SD proved to be an effective growth inhibitor, sensory analysis of these frankfurters indicated lower ($P \leq 0.05$) acceptability as compared to SL, PL, and SC treatments. On the other hand, addition of SC at 0.75% does not inhibit *L. monocytogenes* or extend shelf life of beef frankfurters stored at 4 °C. Based on this study it can be concluded that antimicrobials, which are effective in extending microbial shelf life and inhibiting *L. monocytogenes*, might impact product acceptability. Therefore, frankfurter manufacturers and product-development scientists should not only validate the antimicrobial efficacy of an additive but should also evaluate the effects on consumer acceptability.

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