Sodium diacetate and sodium lactate affect microbiology and sensory and objective characteristics of a restructured turkey breast product formulated with a fibrin cold-set binding system

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ABSTRACT Research was conducted to manufacture and evaluate a restructured turkey breast product using the Fibrimex cold-set binding system, sodium diacetate (NaD), and sodium lactate (NaL) and to ascertain effects of the treatments on proximate composition, pH, psychrotrophic organisms, water activity, onset of rancidity (TBA), thaw loss, cooking yields, and objective color, and sensory characteristics. Whole turkey breasts were cut into 5-cm-thick strips; treated with either water only (control), 1.5% NaL, 2.0% NaL, 0.1% NaD, 1.5% NaL + 0.1% NaD, or 2.0% NaL + 0.1% NaD; blended with Fibrimex ingredients; stuffed into casings; and stored at −30°C for 0, 1, 2, and 3 mo. After each storage period, frozen chubs were tempered at 4°C, sliced into 1-cm-thick steaks, packaged in retail trays, stored at 0°C to simulate retail storage, and analyzed after 0, 2, 4, 6, 8, and 10 d. Sodium diacetate used alone or in combination with NaL reduced ($P < 0.05$) growth of psychrotrophic organisms and had no adverse effects on water activity, pH, cooking yield, fat, moisture, protein, objective color, onset of rancidity, and sensory characteristics (juiciness, turkey flavor intensity, and tenderness). Panelists reported slight off-flavor in all steaks treated with NaL. Treating steaks with NaL alone or in combination with NaD resulted in increased ($P < 0.05$) ash content. Sodium lactate also functioned to minimize thaw loss in the frozen restructured turkey product.

Key words: fibrin binding system, turkey product, microbiology, sodium lactate, sodium diacetate

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INTRODUCTION

Sodium lactate (**NaL**) and sodium diacetate (**NaD**) have been used as antimicrobials in meat and poultry products (Purac, 1997a,b). Researchers have reported antimicrobial properties of NaD in various food systems such as cheese spread, malt syrups, butter, wrapping material and bread and cake products (Branen and Davidson, 1983), poultry (Schlyter et al., 1993), beef (Shelef and Addala, 1994), and seafood (Moye and Chambers, 1991; Degnan et al., 1994). Sodium lactate has been used as a humectant or flavor enhancer and antimicrobial agent in meat (Papadopoulos et al., 1991; O'Connor et al., 1993; Brewer et al., 1995), poultry (Williams and Phillips, 1998), and seafood (Williams et al., 1995) products.

Government regulations permit maximum usage levels of 0.25% NaD and 4.8% NaL and potassium lactate to inhibit microbial growth in various meat and poultry products, except infant formulas and infant food. The usage levels for NaD and NaL are based on the total product formulation (Office of the Federal Register National Archives and Records Administration, 2009).

Fibrimex is a cold-set binder that could be used in restructured meat products. Fibrimex is a 100% natural product composed of fibrinogen and thrombin and is approved by Agriculture Canada, Health Protection Canada, USDA, and US Food and Drug Administration (FNA Foods Inc., 1996). The product is patented and developed by TNO Nutrition in Zeist, the Netherlands. The major advantage of Fibrimex is that it requires no phosphate or salt sources, tumbling, nor heat or freezing to accomplish binding of muscle food proteins. Excellent binding characteristics were achieved with 2 whole tenderloins that were treated with Fibrimex, aligned in opposite directions to create maximum uniformity in the tenderloin, stuffed into a tubular casing, and stored for 6 to 8 h in a cooler. The chilled value-added tenderloin yielded 99% center cut steaks (FNA Foods Inc., 1996). Fibrimex has the advantage of binding whole muscles or pieces of fresh meat, poultry, fish, seafood, or any combination of the four into

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single uniform high-yield cuts. The binding is due to the formation of a fibrin network. The fibrin monomers are derived from a precursor, fibrinogen, by proteolytic cleavages that release small fibrinopeptides; thus, fibrin molecules are able to stick together (Mathews and van Holde, 1990). The removal of these small polar peptides during the formation of a fibrin clot (fibrinopeptides A and B) from the amino termini of the α and β chains of fibrinogen by thrombin results in polymerization of the resultant fibrin monomers to form a noncovalently bound gel and covalent cross-linking in the presence of activated factor XIII (fibrin-stabilizing factor) and calcium ion (Laudano and Doolittle, 1981). The proteolysis of fibrinogen to fibrin is catalyzed by the serine protease thrombin, which is produced from prothrombin. Thrombin has sequence and structural similarities to trypsin but with a very specific function whereby it cleaves only a few types of bonds, mainly arginine-glycine (Mathews and van Holde, 1990).

The binding system is very stable and is not adversely affected by the addition of processing intervention treatments. Shafit et al. (2007) determined that the binding ability of Fibrimex was not affected by the utilization of NaL and NaD in a restructured turkey product. However, Fibrimex, a protein source, when combined with meat protein provides an excellent medium for bacterial multiplication and spoilage. Therefore, processing interventions such as NaL and NaD for preventing, eliminating, or retarding the growth of spoilage bacteria are crucial to the shelf life of the product. No documentation was available in the literature concerning shelf-life extension of restructured turkey steaks processed with Fibrimex and treated with NaL and NaD. The objectives of this research were to manufacture a restructured turkey steak product using Fibrimex fibrin cold-set binding system and to ascertain the effects of NaD or NaL treatments, or both, on proximate composition, pH, psychrotrophic organisms, water activity, onset of rancidity (TBA), thaw loss, cooking yields, objective color, and sensory characteristics of the restructured steaks. To achieve maximum shelf life, the practice of maintaining chubs frozen and removing them as needed (1-mo intervals through 3 mo) for retail storage was also evaluated in this study.

MATERIALS AND METHODS

Preparation of Fibrimex

Fibrimex (FX Technology, Fremont, NE) was received frozen with the fibrinogen and thrombin individually packaged and was maintained in frozen storage until needed. The antimicrobials NaL (PurasalS, 60% solution of L-NaL, Purac America Inc., Lincolnshire, IL) and NaD (71% solution of NaD, Chr. Hansen Inc., Gainesville, FL) were used in this study at 1.5 and 2.0% and 0.1%, respectively, based on the final product weight. Although the maximum usage level of NaD is 0.2%, 0.1% was used to avoid the intense acidic flavor detected in chicken breast meat in preliminary research. The fibrinogen and thrombin were thawed for 1 h by immersion in warm water (26°C, Precision Scientific water bath, Chicago, IL). The thawed fibrinogen was mixed thoroughly to ensure even distribution of the protein.

Processing of Restructured Turkey Breast

Eighteen-kilogram blocks of frozen whole boneless and skinless turkey breasts were purchased from a local supplier and stored frozen (−30°C) until needed. The frozen blocks were thawed in a cooler (0 to 3°C) for 3 d (minimum time required to thaw the turkey breasts) before being further processed. Thawed whole turkey breasts were split in half longitudinally and cut into 5-cm-thick strips. The cut was made parallel to the muscle fiber. For each treatment, 18 kg of 5-cm-thick turkey breast strips was weighed and placed in individual containers.

The turkey breasts were treated with either water only (control), 1.5% NaL, 2.0% NaL, 0.1% NaD, 1.5% NaL + 0.1% NaD, or 2.0% NaL + 0.1% NaD. All solutions were formulated to contain 5% water. Initially, half of the treatment solution was added to the meat and mixed (Model 60 Keebler vacuum mixer, Chicago, IL) for 1.5 min. The remaining solution was added to the meat and mixed for an additional 1.5 min for a total mixing time of 3 min. The treated meat was divided into 2.3-kg batches. Each batch of meat was coated with 6% (wt/wt) Fibrimex (ratio of 20 parts fibrinogen to 1 part thrombin). Due to rapid formation of the fibrin clot (i.e., 10 min), thrombin was added to the fibrinogen solution at the point of coating the meat. The coated meat was stuffed (aligned grain stuffer, StanFos Inc., Edmonton, Alberta, Canada) into 12 cm × 94 cm (diameter × length) tubular casings (Package Concepts and Materials Inc., Greenville, SC) and the ends of the casings were closed using a Tipper Tie clipper (Rheem Manufacturing Company, Apex, NC). The chubs were packaged in freezer-stable corrugated boxes and stored at −30°C for up to 3 mo. At 0 mo and at the end of each 1-mo storage interval (i.e., 0, 1, 2, and 3 mo), frozen chubs were sliced into 1-cm-thick (12-cm diameter) steaks, packaged in extruded polystyrene foam trays, and overwrapped with polyvinyl chloride film (64-gauge film, oxygen transmission rate: 1,400 mL/m^2 for 24 h at 22.8°C, water vapor transmission rate: 32 g for 24 h at 37.8°C; RMF 61HY, Borden Inc., Manhattan, KS) and stored at 0°C.

Psychrotrophic Organisms

The steaks were evaluated after 0, 2, 4, 6, 8, and 10 d for total psychrotrophic counts. Two packages of turkey steaks per treatment were analyzed and plated in duplicate. A 10-g sample was diluted with 90 mL of 0.1% sterile peptone diluent (BD Diagnostics, Sparks, MD) to obtain a 10^{-1} dilution from which serial dilu-

tions were prepared. One-milliliter aliquots of each serial dilution were placed on Aerobic Plate Count 3M Petrifilm (3M, St. Paul, MN) and incubated at 20°C for 5 d for total psychrotrophic count. The isolated colonies were counted and reported as colony-forming units per gram.

pH Analyses

The steaks were evaluated after 0, 2, 4, 6, 8, and 10 d for pH. The pH of each sample was obtained from the 1:10 dilution prepared for the microbiological assay (Kempton and Bobier, 1970). Duplicate samples of 10 g from each replicate in a treatment were mixed with 90 mL of sterile deionized water and blended for 1 min in a stomacher (STO-400, Tekmar Co., Cincinnati, OH). The pH readings were recorded (Oyster pH meter, Extech Instruments Corporation, Waltham, MA) for each sample.

Proximate Composition

At each month interval (or d 0), the steaks were evaluated for proximate composition. Two packages of steaks per treatment were ground. Each ground sample was analyzed in duplicate as outlined in the Official Methods of Analysis of the Association of Official Analytical Chemists (AOAC, 2000) for moisture (oven-drying method 950.46), ash (muffle oven method 920.153), fat (method 985.15), and protein (Kjeldahl method 928.08).

Water Activity Analysis

The steaks were evaluated after 0, 2, 4, 6, and 8 d of storage at 0°C for water activity. Duplicate samples per treatment were prepared for water activity ($\mathbf{a_w}$) measurements. Before measuring a_w, the instrument (Aqualab model CX2, Decagon Devices Inc., Pullman, WA) was calibrated using saturated sodium chloride solutions as instructed by the manufacturer. After the appropriate preheating time, samples were placed in plastic sample dishes that were specifically designed for the instrument and positioned in the sample drawer of the a_w meter. To prevent dehydration of preweighed samples, the accompanying plastic lids were used to cover the dishes before a_w measurements. Due to the onset of spoilage in samples stored at 0°C, the a_w analyses were discontinued after 8 d.

TBA Analysis

At each month interval (or d 0), the steaks were evaluated for onset of rancidity (TBA). Two packages of restructured steaks were evaluated for oxidative rancidity using the TBA test as described by Rhee (1978) immediately before retail storage. Duplicate 10-g samples per package were analyzed for each treatment. The data were reported as milligrams of malonaldehyde per kilogram of meat.

Objective Color Measurement

The steaks were evaluated after 0, 2, 4, 6, and 8 d storage at 0°C for objective color. A portable Minolta Chroma Meter (CR310, Minolta, Ramsey, NJ) was used to obtain objective data for color of the restructured turkey steaks, which employed the L*a*b* color spectra. This spectra include L* (lightness), which is a measure of total light reflected on a scale ranging from 0 = black to 100 = white (MacDougall, 2002). The a* (red-green) value is a measure of the degree of redness in the sample (MacDougall, 2002). In poultry and meat, as the value of a* increases, the sample has an increase in redness and the value decreases with decreased redness. The a* value has been used as an indicator of color stability in meat and meat products (García-Esteban et al., 2003). The b* (blue-yellow) value is a measure of the yellowness (positive values) and blue (negative values) colors of a sample (MacDougall, 2002). In meat and poultry, as the value of b* increases, the sample takes on a more yellow coloration. Decreasing b*values usually denote that a brown (usually metmyoglobin) color is formed.

The colorimeter was calibrated as described in the user's manual on each sampling day. To account for the packaging material, a single sheet of the film was placed over the calibration plate before the color measurements were conducted. After calibration, 2 measurements per package were recorded and averaged. Due to the onset of spoilage in samples stored at 0°C, the objective color analyses were discontinued after 8 d.

Thaw Loss

At the end of each monthly frozen storage period, frozen chubs were weighed, thawed (4°C) overnight, and reweighed. The weights were used to determine percentage of thaw loss.

Sensory Evaluation and Cooking Yield

At each month interval (or d 0), the steaks were evaluated for cooking yield and sensory characteristics. Trained panelists were used in this study. The panelists consisted of students, faculty, and staff from the Department of Animal Sciences. Approval to conduct the sensory panel was granted by the University of Florida Review Board. All panelists had participated in previous poultry taste panels. The panelists were trained for juiciness, turkey flavor intensity, tenderness, and off-flavor using restructured turkey breast steaks. The steaks were cooked to 73.9, 76.7, and 79.4°C to train panelists on juiciness. Panelists were trained for off-flavor by tasting steaks prepared with no NaL or NaD, 2% NaL, and 5% vinegar. As for flavor intensity, the panelists were presented with different strengths of turkey broth.

The broth was prepared by boiling turkey bones, back, and thigh meat. One training session was conducted for 4 h 1 wk before the sensory evaluation.

On the day of the sensory evaluation, steaks were weighed, cooked to an internal temperature of 73.9°C in an electric skillet (72630, The West Bend Company, West Bend, WI) for a total of 5 min (2.5 min on each side), and reweighed to determine cooking yield. Each cooked steak was quartered and each panelist received one-quarter from each treatment. At each session, panelists were served 6 samples, unsalted crackers, and plain bottled water. The panelists were instructed to drink water and eat crackers between each sample to cleanse their palate. They were also instructed to allow a 20-s time lapse between evaluating samples. Lighting in the taste panel room consisted of red and white fluorescent lighting.

Panelists rated the steaks for juiciness, turkey flavor intensity, tenderness, and off-flavor. Eight-point scales were employed for juiciness (8 = extremely juicy; 7 = very juicy; 6 = moderately juicy; 5 = slightly juicy; 4 = slightly dry; 3 = moderately dry; 2 = very dry; and 1 = extremely dry), turkey flavor intensity (8 = extremely intense; 7 = very intense; 6 = moderately intense; 5 = slightly intense; 4 = slightly bland; 3 = moderately bland; 2 = very bland; and 1 = extremely bland), and tenderness (8 = extremely tender; 7 = very tender; 6 = moderately tender; 5 = slightly tender; 4 = slightly tough; 3 = moderately tough; 2 = very tough; and 1 = extremely tough). A 6-point scale was employed for off-flavor (6 = none detected; 5 = threshold, barely detected; 4 = slightly off-flavor; 3 = moderate off-flavor; 2 = strong off-flavor; and 1 = extreme off-flavor).

Statistical Analyses

A total of ninety-six 12 cm × 94 cm (diameter × length) chubs were manufactured for evaluation in this study (i.e., 2 chubs per treatment for 6 treatments for 4 frozen storage periods with 2 replications). A total of 240 packages of sliced turkey steaks (3 steaks per package) were prepared from the chubs and evaluated in this study (i.e., 144 packages for psychrotrophs, pH, proximate composition, and water activity and 96 packages for sensory and objective color). Data were analyzed using the GLM program (PROC GLM) of SAS for Windows (SAS Institute, 2001). For comparisons among treatments, CONTRAST statements were used and PROC MIXED or PROC GLM (SAS Institute, 2001) was used for the analyses of repeated measures. Significance was determined at $\alpha = 0.05$.

RESULTS AND DISCUSSION

pH Analyses

The pH values were lower ($P < 0.05$) for steaks treated with NaD alone or in combination with NaL through 10 d of storage (Table 1). The pH was similar ($P > 0.05$) for steaks treated with NaD in combination with NaL through 10 d of storage. Except for d 0 and 2, steaks treated with NaL only had pH values similar ($P > 0.05$) to the control steaks. The data demonstrated that the NaD functioned to depress the pH of the steaks. The pH-lowering effect observed in this study was attributed to NaD with a pH of 4.3 compared with a pH of 7.6 for NaL (Shelef and Addala, 1994). Schlyter et al. (1993) observed that meat slurries containing 0.3 or 0.5% NaD had pH of 5.5 and 5.2, respectively. The pH of steaks treated with 0.1% NaD were lower ($P < 0.05$) than steaks treated with a combination of NaL and NaD on d 0, 4, and 6, indicating that the NaD functioned to lower the pH of steaks treated with NaL and NaD.

Psychrotrophic Counts

Psychrotrophic counts for control steaks and steaks treated with 1.5 and 2.0% NaL alone were similar ($P > 0.05$) through 10 d of storage (Table 2). Steaks treated with NaD alone or in combination with NaL had lower ($P < 0.05$) psychrotrophic counts when compared with the control steaks and steaks treated with 1.5 and 2.0% NaL alone for 6, 8, and 10 d. On d 4, steaks treated with 2.0% NaL only and steaks treated with 0.1% NaD

Table 1. pH values for restructured turkey breast steaks manufactured with Fibrimex (FX Technology, Fremont, NE) and treated with sodium lactate and sodium diacetate and stored at 0°C for up to 10 d

	Storage time (d)					
Treatment[1]	0	2	4	6	8	10
Control	5.85[b]	5.94[a]	6.04[a]	5.94[a]	6.02[a]	6.18[a]
1.5% NaL	5.97[a]	5.89[b]	6.05[a]	5.92[a]	6.11[a]	6.18[a]
2.0% NaL	5.97[a]	5.83[b]	6.07[a]	5.96[a]	6.05[a]	6.09[a]
0.1% NaD	5.64[d]	5.66[c]	5.79[c]	5.67[c]	5.69[b]	5.72[b]
1.5% NaL + 0.1% NaD	5.76[c]	5.76[c]	5.87[b]	5.83[b]	5.79[b]	5.79[b]
2.0% NaL + 0.1% NaD	5.78[c]	5.76[c]	5.86[b]	5.81[b]	5.76[b]	5.76[b]
SEM	0.78	0.65	0.64	0.77	0.54	0.67

[a–d]Means within a column with no common superscript differ significantly ($P < 0.05$).

[1]NaL = sodium lactate; NaD = sodium diacetate. n = 16 measurements for each mean value.

Table 2. Psychrotrophic counts (log cfu/g) for restructured turkey breast steaks manufactured with Fibrimex (FX Technology, Fremont, NE) and treated with sodium lactate and sodium diacetate and stored at 0°C for up to 10 d

	Storage time (d)					
Treatment[1]	0	2	4	6	8	10
Control	4.02^{a,z}	4.51^{a,z}	5.45^{a,z}	7.14^{a,y}	8.34^{a,x}	9.11^{a,x}
1.5% NaL	4.19^{a,z}	4.45^{a,z}	5.11^{a,z}	6.62^{a,y}	7.98^{a,x}	8.76^{a,x}
2.0% NaL	3.98^{a,z}	4.04^{a,z}	4.63^{ac,z}	6.07^{a,y}	7.48^{a,x}	8.53^{a,x}
0.1% NaD	4.03^{a,x}	4.04^{a,x}	3.94^{bc,x}	4.15^{b,x}	4.92^{b,x}	5.85^{b,x}
1.5% NaL + 0.1% NaD	3.83^{a,x}	3.83^{a,x}	3.87^{bc,x}	4.23^{b,x}	4.62^{b,x}	5.43^{b,x}
2.0% NaL + 0.1% NaD	4.15^{a,x}	4.11^{a,x}	4.03^{bc,x}	4.16^{b,x}	4.50^{b,x}	4.92^{b,x}
SEM	0.52	0.61	0.49	0.39	0.55	0.47^{b,x}

$^{a–c}$Means within a column with no common superscript differ significantly ($P < 0.05$).

$^{x–z}$Means within a row with no common superscript differ significantly ($P < 0.05$).

[1]NaL = sodium lactate; NaD = sodium diacetate. n = 16 measurements for each mean value.

alone and in combination with NaL had similar ($P > 0.05$) psychrotrophic counts. Psychrotrophic counts for all steaks treated with NaD remained less than 6 log cfu/g through 10 d of storage, in contrast to control steaks and steaks treated with 1.5 and 2.0% NaL only. The data demonstrated that 0.1% NaD extended ($P < 0.05$) the lag growth phase of the bacteria when compared with control steaks and steaks treated with 1.5 and 2.0% NaL alone. Steaks treated with NaD alone or in combination with NaL resulted in 1.0 to 1.5, 2, 3, and 3 log reductions in psychrotrophic counts when compared with the positive control on d 4, 6, 8, and 10, respectively. Jensen et al. (2003) reported that pork chops enhanced with a lactate-diacetate combination had lower ($P < 0.01$) aerobic plate counts than control (unpumped) chops or those pumped with other solutions of NaL, phosphate, and salt; potassium lactate, phosphate, and salt; sodium acetate, phosphate, and salt; or phosphate and salt.

This study revealed that NaD significantly enhanced the antibacterial activity of NaL when used in combination treatments. It has been reported that psychrotrophic counts of 7 to 8 log cfu/g produced unacceptable off-odor in poultry (Barnes, 1976; Cunningham, 1979) and red meat (Jay, 1992; Brewer et al., 1995). Data in this study revealed that treatment with 0.1% NaD alone or in combination with NaL has potential for extending shelf life of refrigerated restructured turkey steaks manufactured with the Fibrimex cold-set binding system.

Proximate Composition

Ash was higher ($P < 0.05$) for all steaks treated with NaL ($P < 0.05$) when compared with control steaks and steaks treated with NaD only (Table 3). In addition, steaks treated with a combination of NaL and NaD had higher ($P < 0.05$) ash than steaks treated with NaL alone. Williams et al. (1995) determined that fresh catfish fillets treated with 1.0 and 2.0% NaL resulted in increased ash content. Bloukas et al. (1997) also observed that increasing the NaL level significantly increased the ash content of frankfurters. Zorba et al. (2005) reported an ash value of 1.19% for boneless and skinless turkey breast meat, which was similar to values of 1.07 and 1.08% ash reported for steaks treated with NaD alone and the control steaks in this study. This observation supports the finding that NaL alone and in combination with NaD contributed to the increased ash values recorded in this study. Moisture, protein, and fat contents were similar ($P > 0.05$) for all steaks in all treatments. The moisture, protein, and fat values reported by Zorba et al. (2005) for skinless turkey breast meat were 73.94, 22.82, and 3.20%, respectively. Except for fat, these values are similar to data determined in this study.

a_w

The significant differences revealed for a_w were due to overall mean effects. The a_w for steaks treated with

Table 3. Proximate composition (%) for restructured steaks manufactured with Fibrimex (FX Technology, Fremont, NE) and treated with sodium lactate and sodium diacetate and stored at −30°C for up to 3 mo

Treatment[1]	Ash	Moisture	Protein	Fat
Control	1.08^{c}	74.46	23.37	1.13
1.5% NaL	1.44^{b}	74.70	22.10	0.75
2.0% NaL	1.58^{b}	74.13	22.91	0.82
0.1% NaD	1.07^{c}	74.89	22.70	0.93
1.5% NaL + 0.1% NaD	1.65^{a}	74.35	22.22	1.14
2.0% NaL + 0.1% NaD	1.76^{a}	74.01	23.26	0.94

$^{a–c}$Means within a column with no common superscript differ significantly ($P < 0.05$).

[1]NaL = sodium lactate; NaD = sodium diacetate. n = 4 measurements for each mean value.

Table 4. Least squares means water activity and TBA values for restructured turkey breast steaks manufactured with Fibrimex (FX Technology, Fremont, NE) and treated with sodium lactate and sodium diacetate and stored at 0°C for up to 8 d

		Sodium lactate (%)		
Parameter[1]	Sodium diacetate (%)	0	1.5	2
Water activity	0	0.9883[a]	0.9826[c]	0.9809[e]
	0.1	0.9885[a]	0.9831[b]	0.9814[d]
TBA		mg of malonaldehyde/kg		
	0	0.34[c]	0.52[b]	0.53[b]
	0.1	0.55[b]	0.66[a]	0.64[a]

[a–e]Means within the same parameter with no common superscript differ significantly ($P < 0.05$).

[1]n = 20 measurements for each mean value.

0.1% NaD was similar ($P > 0.05$) to the control steaks (Table 4) and higher ($P < 0.05$) than steaks treated with either 1.5 or 2.0% NaL alone or in combination with NaD. Steaks treated with 2.0% NaL had lower ($P < 0.05$) a_w than all steaks. The ability of NaL to lower product a_w has been well documented (Chirife and Fontan, 1980; De Wit and Rombouts, 1990; Shelef and Yang, 1991; Weaver and Shelef, 1993; Maca et al., 1997). Chen and Shelef (1992) observed that potassium and calcium lactate also functioned to decrease a_w in food systems. In all treatments in this study, a_w was greater than 0.9, which suggested a favorable environment for spoilage bacteria to grow in the product.

TBA Analysis

The significant differences revealed for TBA values were due to overall mean effects. Steaks treated with either NaD or NaL alone or in combination had higher ($P < 0.05$) TBA values when compared with control steaks (Table 4). Rhee et al. (1998) observed that aerobically stored ground beef at 4°C when mixed with 3.0% NaL had higher TBA values than the untreated samples. Other researchers have also reported that a disadvantage of using NaL is its prooxidant properties (Krahl et al., 1995; Kulshrestha and Rhee, 1996) when used in aerobically packaged beef patties stored at 4°C.

The addition of 0.1% NaD to steaks in combination with NaL resulted in higher ($P < 0.05$) TBA values than the control steaks and steaks treated with NaD alone and NaL alone (Table 4). Reddy and Reddy (1994) observed that cockerel meat treated with 0.5% acetic acid resulted in increased TBA values. Although TBA values for steaks treated with NaD or NaL, or both, were higher ($P < 0.05$) than the control, the TBA values were less than 1 mg of malonaldehyde/kg for all treatments during 3 mo of frozen storage. Tarladgis et al. (1964) reported that a TBA value of 1 mg of malonaldehyde/kg is the accepted human threshold for detection of rancidity.

Thaw Loss and Cooking Yield

Initially (mo 0), thaw loss was similar for all treatments and ranged from 1.50 to 3.66% (Table 5). After 1 mo and through 3 mo of storage, all steaks treated with NaL alone or in combination with NaD had lower ($P < 0.05$) thaw loss when compared with control steaks and steaks treated with NaD only. Steaks treated with NaD had higher ($P < 0.05$) thaw loss than the control steaks after 1 and 2 mo of storage. The higher thaw loss was attributed primarily to slight protein denaturation caused by shrinkage of meat myofibrils. Mendonca et al. (1989) reported that fresh pork chops treated with lactic and acetic acids had an increased purge loss. Lower intracellular pH of meat caused shrinkage of meat myofibrils, thus causing drip loss (Offer and Trinick, 1983). This study revealed that NaL alone or in combination with NaD minimized ($P < 0.05$) thaw loss when compared with the control steaks. Similar findings were reported

Table 5. Thaw loss percentage for restructured turkey breast steaks manufactured with Fibrimex (FX Technology, Fremont, NE) and treated with sodium lactate and sodium diacetate and stored for up to 3 mo at −30°C

	Storage time (mo)			
Treatment[1]	0	1	2	3
Control	2.96[a]	3.98[b]	4.69[b]	5.65[a]
1.5% NaL	1.91[a]	2.82[c]	2.80[c]	4.09[b]
2.0% NaL	1.50[a]	2.75[c]	2.70[c]	3.08[b]
0.1% NaD	3.66[a]	5.74[a]	7.34[a]	6.86[a]
1.5% NaL + 0.1% NaD	3.36[a]	2.74[c]	3.85[c]	3.84[b]
2.0% NaL + 0.1% NaD	1.70[a]	2.72[c]	3.20[c]	3.05[b]

[a–c]Means within the same column with no common superscript differ significantly ($P < 0.05$).

[1]NaL = sodium lactate; NaD = sodium diacetate. n = 4 measurements for each mean value.

Table 6. Slope a* values for restructured turkey breast steaks manufactured with Fibrimex (FX Technology, Fremont, NE) and treated with sodium lactate and sodium diacetate and stored for up to 3 mo at −30°C

		Sodium lactate (%)		
Month[1]	Sodium diacetate (%)	0	1.5	2.0
0	0	−0.271*	−0.199*	−0.133*
	0.1	−0.168*	−0.195*	−0.243*
1	0	−0.309*	−0.235*	−0.301*
	0.1	−0.290*	−0.288*	−0.272*
2	0	−0.249*	−0.281*	−0.290*
	0.1	−0.269*	−0.247*	−0.275*
3	0	−0.295*	−0.248*	−0.254*
	0.1	−0.268*	−0.281*	−0.273*

[1]n = 16 measurements for each mean value.
*$P < 0.05$.

in this study for a_w wherein steaks treated with NaL alone or in combination with NaD resulted in decreased ($P < 0.05$) a_w.

Cooking yields were similar ($P > 0.05$) for all treatments during 3 mo of storage (data not shown). Cooking yields ranged from approximately 80% for control steaks and steaks treated with NaD to approximately 83% for steaks treated with NaL alone or in combination with NaD. Although researchers have reported that NaL significantly increased cooking yields in beef top rounds (Papadopoulos et al., 1991), seafood (Williams et al., 1995), and broiler meat (Williams and Phillips, 1998), no significant increase ($P > 0.05$) in cooking yields was determined for the turkey steaks in this study when NaL was used. However, it is important to note that a 3.0% increase in cooking yield was revealed for steaks treated with NaL in this study.

Objective Color Measurement

L* Color Values. The L* values were similar ($P > 0.05$) for all treatments through 3 mo of frozen storage (data not shown). The values ranged from 46.7 to 49.6 for all treatments and were similar to those reported in the literature for fresh turkey breast meat (Werner et al., 2008). Werner et al. (2008) measured color of 120 turkey breast meat samples and reported average L* values of 50.96 ± 2.43.

a* Color Values. The a* values for all treatments were similar ($P > 0.05$; data not shown). The slopes for a* values demonstrated a decreasing trend in degree of redness for all treatments through 8 d of retail storage and 3 mo of frozen storage (Table 6). Initially, at 0, 1, 2, and 3 mo, a* values for the steaks were in the range of 5.8 to 6.4, but at d 8 of storage, the a* values were in the range of 3.4 to 3.7. The decrease in a* values over time of storage was similar among all treatments. Boles and Shand (1999) observed that the redness of restructured beef made with Fibrimex decreased with retail storage. Banks et al. (1998) observed that the red color that is due to oxymyoglobin decreased with increasing NaL concentration in fresh pork longissimus muscle. Werner et al. (2008) reported average a* values of 3.68 ± 0.90 for 120 turkey breast meat samples, which were similar to d 8 a* values for the turkey breasts in this study.

b* Color Values. The b* values for all treatments ranged from 4.8 to 5.9 and were similar ($P > 0.05$; data not shown). The slopes for b* values demonstrated an increasing trend in degree of yellowness for all treatments through 8 d of retail storage and 3 mo of frozen storage (Table 7). However, the amount of change in b*

Table 7. Slope b* values for restructured turkey breast steaks manufactured with Fibrimex (FX Technology, Fremont, NE) and treated with sodium lactate and sodium diacetate and stored for up to 3 mo at −30°C

		Sodium lactate (%)		
Month[1]	Sodium diacetate (%)	0	1.5	2.0
0	0	0.069*	0.026	0.059*
	0.1	0.024	0.087*	0.064*
1	0	0.121*	0.081*	0.101*
	0.1	0.097*	0.103*	0.098*
2	0	0.099*	0.093*	0.100*
	0.1	0.075*	0.092*	0.096*
3	0	0.149*	0.124*	0.141*
	0.1	0.105*	0.126*	0.126*

[1]n = 16 measurements for each mean value.
*$P < 0.05$.

Table 8. Panelist responses for off-flavor in restructured turkey breast steaks manufactured with Fibrimex (FX Technology, Fremont, NE) and treated with sodium lactate and sodium diacetate and stored for up to 3 mo at −30°C[1]

	Storage time (mo)			
Treatment[2]	0	1	2	3
Control	5.46[a]	5.73[a]	5.73[a]	5.76[a]
1.5% NaL	4.57[b]	5.43[ac]	5.23[ab]	5.20[ac]
2.0% NaL	4.23[b]	4.43[bc]	4.80[bc]	4.56[bc]
0.1% NaD	5.36[a]	5.69[a]	5.35[ab]	5.63[a]
1.5% NaL + 0.1% NaD	4.46[b]	4.73[bc]	4.66[bc]	4.93[bc]
2.0% NaL + 0.1% NaD	4.26[b]	3.97[bc]	4.93[bc]	4.56[bc]

[a–c]Means within the same column with no common superscript differ significantly ($P < 0.05$).

[1]Scoring scale for off-flavor: 6 = none detected; 5 = threshold, barely detected; 4 = slightly off-flavor; 3 = moderate off-flavor; 2 = strong off-flavor; 1 = extreme off-flavor.

[2]NaL = sodium lactate; NaD = sodium diacetate. n = 20 measurements for each mean value.

values for each increase in storage time was minimal. Banks et al. (1998) observed that yellowness in pork loin containing 1.0 to 2.0% NaL increased after 14 d of storage. Maca et al. (1997) observed that raw ground beef patties became brighter, lighter, and more yellow with storage. The b* values recorded in this study were similar to those reported in the literature for fresh turkey breast meat (Werner et al., 2008). Werner et al. (2008) measured the color of 120 turkey breast meat samples and reported average b* values of 3.89 ± 1.09.

Sensory Evaluations

There were no significant differences ($P > 0.05$) in juiciness, flavor intensity, and tenderness among all treatments through 3 mo of storage (data not shown). The data demonstrated that treating the steaks with NaD or NaL had no adverse effect on turkey flavor intensity, juiciness, and tenderness. The panelists' scores for off-flavor were between 3.97 and 5.76, which were indicative of "slight" and "barely detected" off-flavor, respectively (Table 8). The panelists "barely detected" off-flavor in the control steaks and steaks treated with NaD only and 1.5% NaL only. "Slight off-flavor" was detected in steaks treated with 2.0% NaL only and a combination of NaD and NaL (1.5 and 2.0%). Sodium lactate has been associated with off-flavor notes such as metallic, bitter, chemical, medicinal, sour, astringent, sodium, and salty (Papadopoulos et al., 1991; Williams et al., 1995; Maca et al., 1997). In general, researchers have reported that the off-flavor increases with increased usage levels of NaL. In this study, 34.38 and 53.13% of panelists detected off-flavor notes in steaks treated with 1.5 and 2.0% NaL, respectively. When steaks were treated with a combination of 0.1% NaD and 1.5 and 2.0% NaL, 54.17 and 51.04% of the panelists detected off-flavor, respectively. Approximately 14.58 and 5.21% of the panelists detected off-flavor in the control steaks and steaks treated with 0.1% NaD only, respectively. The off-flavor detected in the steaks was described primarily as "slightly bitter aftertaste."

Conclusions

The data in this study revealed the significance of NaD alone and in combination with NaL as an antimicrobial agent in the restructured turkey product when stored under retail conditions and during frozen storage. Sodium diacetate treatments alone or in combination with 1.5 or 2.0% NaL reduced ($P < 0.05$) growth of psychrotrophic organisms. However, the reduction in psychrotrophic organisms was not observed when NaL was used alone. Treating steaks with NaD resulted in lower pH values, which might have contributed to the lower psychrotrophic counts recorded for steaks treated with NaD alone or in combination with NaL.

Sodium lactate alone and in combination with NaD treatments imparted a slight off-flavor to the steaks. Sodium diacetate used alone or in combination with NaL had no adverse effects on water activity, cooking yield, fat, moisture, protein, objective color and the sensory characteristics juiciness, turkey flavor intensity, and tenderness. Increased ash content for steaks treated with NaL alone and in combination with NaD suggested the possibility of increased sodium content in the steaks. The data in this study suggested that the practice of maintaining chubs frozen and removing them as needed for retail storage to achieve maximum shelf life should have no adverse effect on the product when treated with NaL alone and in combination with NaD because these treatments functioned to minimize thaw loss and retard the onset of rancidity in the frozen product and may result in extended retail shelf life of the restructured steak product.

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