Final Report – Summary
January 20, 2006

Antimicrobial Intervention and Process Validation in Beef Jerky Processing

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Beef jerky is classified by the USDA as a heat-treated, shelf stable ready to eat meat product. Small and very small commercial processors of meat jerky products are currently under pressure to show their processes are sufficient to provide a finished product that is safe. Foodborne pathogens related to jerky of concern to the industry and regulators include *Salmonella*, *Escherichia coli* O157:H7, and *Listeria monocytogenes*. Marination, which is an optional step, can involve the use of ingredients that can affect the survival of foodborne pathogens on jerky products. Jerky processors may use a variety of marinade ingredients and methods for application. In addition, processors may opt to use chemical antimicrobial treatments prior to the drying process. Many small processors use dehydrators, rather than smokehouses to process their product. The issue of humidity control during drying and its effect of pathogen survival has been raised. Humidity in a dehydrator is more difficult to control compared to a smokehouse.

This project evaluated several variations in the production of beef jerky to produce quality products that can satisfy needs of small and very small meat processors for development of their HACCP plans to address concerns with *Salmonella* spp, *E. coli* O157:H7, and *L. monocytogenes*. Challenge studies using all three pathogens were done. We evaluated the use of a marination step, chemical pretreatment, and drying procedures using either a dehydrator or smokehouse. The chemical pretreatments involved using chlorine dioxide (500 and 1200 ppm) and acidic calcium sulfate (1:2 and 1:3 water: calcium sulfate ratios). Attempts were also made to use ozone as a pretreatment. The temperature conditions in the dehydrator and smokehouse were similar to allow for comparison. The relative humidity in the smokehouse was maintained at 33%.

Beef jerky strips were made using a horizontal-flow dehydrator set at 62^{o}C (143.6^{o}F) and a commercial-type smokehouse with a dry-bulb/wet-bulb setting of 63^{o}C/43^{o}C (145^{o}F/110^{o}F) (33% relative humidity) in combination with calcium sulfate and chlorine dioxide pretreatments to determine the effectiveness of the treatments in the inactivation of *Salmonella*, *E. coli* O157:H7, and *L. monocytogenes* for whole strip beef jerky. Calcium sulfate and chlorine dioxide were used in concentrations recommended by the manufacturers. Inoculated strips were marinated overnight in a marinade containing water (3.0 liters), salt (171.00 g), sugar (57.00 g), nitrite (3.56 g), garlic powder (5.68 g), sodium erythorbate (14.20 g), MSG (7.90 g), vinegar (4%, 171.00 g), Worchestershire sauce (14.20 g), and thyme (7.10 g) before drying. Trials were conducted separately with three replications on three different days for each experiment.

Enumeration of the pathogens used in the study was done using selective plating media. The data were compared statistically to determine if each combination of pretreatment and drying method could reduce the populations of *E. coli* O157:H7 and *L. monocytogenes* by at least 5 logs

and *Salmonella* populations by at least 6.5 logs. The effectiveness of the different pretreatments was also compared.

Statistical analysis showed the populations of *E. coli* O157:H7 were reduced by at least 5 logs cfu/strip for all of the treatments except for jerky pretreated with the lower concentration of chlorine dioxide and dried in the dehydrator. For *L. monocytogenes*, 5 log reductions were noted for all the treatments regardless of the drying method. *Salmonella* populations were reduced by more than 6.5 logs on jerky strips that were pretreated with the higher concentration of calcium sulfate and dried in the dehydrator and jerky pretreated with the 1200 ppm concentration of chlorine dioxide and dried in the smokehouse. Populations were reduced almost as well on jerky pretreated with calcium sulfate, both concentrations, and dried in the smokehouse.

There was no statistical difference in the effectiveness of the pretreatments in contributing to the reduction of *E. coli* and *L. monocytogenes* populations, although it is possible to rank them with the higher concentration of calcium sulfate being more effective and the lower concentration of chlorine dioxide being least effective. For *Salmonella*, both concentrations of the calcium sulfate were the most effective in reducing the populations while the lower concentration of chlorine dioxide was least effective.

Pretreatments with ozone were unsuccessful due to difficulties in generating sufficient levels of ozone in pretreatment waters that were to be used. After repeated attempts to correct the situation, desired levels could not be attained.

While effective treatments may be attained using a dehydrator coupled with an antimicrobial pretreatment, processing jerky in the smokehouse with similar temperature conditions was more effective. In general, the acidic calcium sulfate was a more effective pretreatment than chlorine dioxide. Small processors using dehydrators with little control over maintaining consistent relative humidity conditions within the drying chamber may find the use of these antimicrobial treatments beneficial in achieving the desired level of pathogen reduction.

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This project evaluated several variations in the production of beef jerky to produce quality products that can satisfy needs of small and very small meat processors for development of their HACCP plans to address concerns with *Salmonella* spp., *E. coli* O157:H7, and *L. monocytogenes*. Challenge studies using all three pathogens were done. We evaluated the use of a marination step, chemical pretreatment, and drying procedures using either a dehydrator or smokehouse. The chemical pretreatments involved using chlorine dioxide (500 and 1200 ppm) and acidic calcium sulfate (1:2 and 1:3 water: calcium sulfate ratios). Attempts were also made to use ozone as a pretreatment. The temperature conditions in the dehydrator and smokehouse were similar to allow for comparison. The relative humidity in the smokehouse was maintained at 33%.

Approach:

Beef jerky strips were made using a horizontal dehydrator and a commercial-type smokehouse in combination with calcium sulfate and chlorine dioxide pretreatments to determine the effectiveness of the treatment in the inactivation of *Salmonella*, *E. coli* O157:H7, and *L. monocytogenes* for whole strip beef jerky. Inoculated strips were marinated overnight in a marinade containing water (3 liters), salt (171.00 g), sugar (57.00 g), nitrite (3.56 g), garlic powder (5.68 g), sodium erythorbate (14.20 g), MSG (7.90 g), vinegar (4%, 171.00 g), Worchestershire sauce (14.20 g), and thyme (7.10 g) before drying. Trials were conducted separately with three replications on three different days for each experiment. In addition, we tried to use ozone as a pretreatment.

Jerky Processing Using a Dehydrator:
Microbial inactivation data for beef jerky strips that were either treated or not treated with calcium sulfate (Mionix $Safe_2O^{™}$, Mionix Corporation, Rocklin, CA) before marinating and

drying in a horizontal-flow dehydrator 62°C (143.6°F) are in Tables 1 and 2. Table 1 contains bacterial enumeration data at various stages of processing using plate count agar (PCA) as the plating medium. This medium will allow the inoculated pathogens on the product to grow, as well as, the naturally occurring bacteria present on the strips. More detailed descriptions of the effects the treatments have on pathogen survival are described below focusing on pathogen enumeration on selective plating media.

The manufacturer's recommended levels of 1:2 and 1:3 mixtures of Mionix $Safe_2O^{TM}$ with water were used as a 30 sec product dip. Treatment of the inoculated strips prior to drying with the 1:2 mix and the 1:3 mix reduced the *E. coli* O157:H7 populations as determined using selective plating medium by 0.97 to 1.23 logs, with the higher concentration yielding the greatest reduction. In comparison, the water control treatment reduced the populations by only 0.1 log cfu/strip (Table 2). Marination reduced the populations slightly, with a greater reduction occurring on the water control. After drying, the *E. coli* O157:H7 populations were reduced to levels below the detection limit for the plating method (>6.68 log reduction). However, when samples were enriched there was still some viable *E. coli* O157:H7 present on the strips after processing. Stored product was sampled over a 3 month period. After 1 month, no *E. coli* O157:H7 was detected on strips that were pretreated with the calcium sulfate treatments. Only the water treated samples yielded positive samples. Thus the calcium sulfate pretreatment was more effective in eliminating the pathogen than water alone. No *E. coli* O157:H7 was detected by enumeration or after enrichment from any of the samples after 2 and 3 months. There was no noticeable changes in the product's a_w or pH during storage. The relative humidity in the dehydrators for the calcium sulfate experiments at the start of the drying process was 72.5%.

For strips that were inoculated with *L. monocytogenes* before either treating or not treating with calcium sulfate and dehydration, population reductions and patterns were similar to that seen with *E. coli* O157:H7 (Table 2). *L. monocytogenes* appears to be slightly more resistant to the chemical pretreatment and the drying than *E. coli* O157:H7. However, the population of *L. monocytogenes* on these strips was reduced by >6 logs. Use of the greater concentration of the calcium sulfate reduced the populations to a greater degree than did the lower concentration. When sampled before product storage, enrichment of the samples recovered viable *L. monocytogenes* from most of the samples even if the enumeration of the pathogen was not possible. When sampled at monthly intervals during storage, no *L. monocytogenes* positive samples were detected by enumeration or enrichment regardless of the pretreatment. As with the *E. coli* O157:H7 samples, there was no noticeable change in the product a_w or pH. The relative humidity in the dehydrators for the calcium sulfate experiments at the start of the drying process was 61.1%.

Salmonella appears to be more resistant to the chemical pretreatment and the drying process than the other two pathogens (Table 2). While the greater concentration of calcium sulfate reduced the populations of *Salmonella* by at least 7.18 logs, there was a reduction of 6.78 and 4.91 for the 1:3 calcium sulfate mix and the water control, respectively. As was the case prior to drying with the other two pathogens, pretreatment with the 1:2 calcium sulfate mix was more effective in reducing the pathogen populations compared to the 1:3 mix. During storage, positive *Salmonella* samples were detected from all or some of the replications that received the water pretreatment. One replication that was treated with the 1:3 calcium sulfate pretreatment after 1 month was

positive for *Salmonella*, but no samples receiving this treatment were positive after 2 or 3 months. All samples treated with the 1:2 mix were negative for *Salmonella* at all monthly sampling times. The a_w or pH of the product was not changed during storage. The relative humidity in the dehydrators for the calcium sulfate experiments at the start of the drying process was 55.4%.

Microbial inactivation data for beef jerky strips that were either treated or not treated with chlorine dioxide (Keeper®, Bio-Cide International, Inc., Norman, OK) before marinating and drying in the dehydrator are in Tables 3 and 4. Table 3 contains bacterial enumeration data at various stages of processing using plate count agar (PCA) as the plating medium. More detailed descriptions of the effects the treatments have on pathogen survival are described below focusing on pathogen enumeration on selective plating media.

Trials using chlorine dioxide and the dehydrator were completed with all 3 pathogens (Table 4). A 5 log reduction of *E. coli* O157:H7 was achieved with the chlorine dioxide pretreatments and the water control in this experiment, but the reduction was greatest on strips exposed to the higher calcium sulfate concentration. Since populations on the control strips for the chlorine dioxide treatments were not reduced to the same degree as those on the controls in the calcium sulfate experiments (>6.68 compared to 6.11), it is possible that there is some additive or synergistic effect from the calcium sulfate that was not present with the chlorine dioxide. After 1 month, no *E. coli* O157:H7 was recovered by enumeration methods, but enrichment of the samples pretreated with both concentrations of chlorine dioxide did recover the pathogen from samples for most of the replications. Enrichment of the water pretreated samples was negative for *E. coli* O157:H7. The relative humidity in the dehydrators for the chlorine dioxide experiments at the start of the drying process was 80.3%. This was approximately 8% higher than that for the dehydrators for the calcium sulfate experiments.

There was little difference in the effectiveness of the two chlorine dioxide pretreatments. In fact the magnitude of population reduction was less than a log different than the control water treatment. After drying, the log reduction in the *L. monocytogenes* populations for the chlorine dioxide pretreated samples and the control was 6.55 or higher. A reduction of 4.18 was noted on the control strips. After 1 month storage, the populations were not detected by enumeration (at least a 6.68 log reduction) or by enrichment. The relative humidity in the dehydrator at the start of the drying process was 59.3%.

Salmonella populations decreased by 5.34, 4.94, and 4.75 logs cfu/strip on strips treated with 1,200 ppm chlorine dioxide, 500 ppm chlorine dioxide, and water (control), respectively. The pretreatment alone decreased the population by 0.6 log cfu/strip or less regardless of the concentration. There was a further decrease in the population for a total reduction of at least 6.68 logs during the first month of product storage. Except for 1 of the control water pretreated samples, *Salmonella* was not recovered from any of the samples by enrichment after 1 month of product storage. The relative humidity in the dehydrator was 57.0%.

Jerky Processing Using a Smokehouse:
To establish a possible worst-case situation, we used wet-bulb/dry-bulb temperatures that would not typically be recommended. The dry-bulb temperature was 63°C (145°F) and the wet-bulb

temperature was 43.3°C (110°F). The relative humidity was 33%. In using the low relative humidity and temperature conditions, we were trying to minimize the effect of chamber relative humidity and to allow us to compare a questionable smokehouse practice to the dehydrator conditions we evaluated.

Tables 5-8 contain enumeration data for total aerobic bacteria and for *Salmonella*, *E. coli* O157:H7, and *L. monocytogenes*. In all cases, the populations were decreased by more than 6 logs cfu/strip. Even though the relative humidity was low in the smokehouse, the minimal temperature condition used was effective in reducing the bacterial populations.

Water Activity and pH:
Tables 9-12 contain the water activity and pH values for the products that were processed in the dehydrator and the smokehouse.

Ozone Pretreatments:
We experienced difficulty in getting enough ozone captured in the pretreatment waters. We modified our ozone generator to correct the problem but could not obtain suitable levels. Thus, we could not evaluate this pretreatment.

Summary

Enumeration of the pathogens used in the study was done using selective plating media. The data were compared statistically to determine if each combination of pretreatment and drying method could reduce the populations of *E. coli* O157:H7 and *L. monocytogenes* by at least 5 logs and *Salmonella* populations by at least 6.5 logs. The effectiveness of the different pretreatments was also compared.

Statistical analysis showed the populations of *E. coli* O157:H7 were reduced by at least 5 logs cfu/strip for all of the treatments except for jerky pretreated with the lower concentration of chlorine dioxide and dried in the dehydrator. For *L. monocytogenes*, 5 log reductions were noted for all the treatments regardless of the drying method. *Salmonella* populations were significantly reduced ($p<0.05$) by more than 6.5 logs on jerky strips that were pretreated with the higher concentration of calcium sulfate and dried in the dehydrator and jerky pretreated with the 1200 ppm concentration of chlorine dioxide and dried in the smokehouse. Similar results were obtained for jerky pretreated with either concentration of calcium sulfate and dried in the smokehouse ($p=0.055$).

There was no statistical difference in the effectiveness of the pretreatments in contributing to the reduction of *E. coli* and *L. monocytogenes* populations, although it is possible to rank them with the higher concentration of calcium sulfate being more effective and the lower concentration of chlorine dioxide being the least. For *Salmonella*, both concentrations of the calcium sulfate were the most effective in reducing the populations while the lower concentration of chlorine dioxide was least effective.

Additional Comments:

Most jerky processors who have contacted us over the years use dehydrators rather than smokehouses to process their product. Ingram, et al. (Interim Report, Wisconsin Study) showed the percent relative humidity (%RH) control in smokehouses during jerky processing is important. No such data using dehydrators is available. Humidity control in dehydrators presents challenges that cannot be addressed using a smokehouse. For instance, the %RH in dehydrators is influenced by the %RH of the room air, which can widely vary. This is especially true for the initial operating period during the drying process.

Table 1. Survival of *Salmonella*, *E. coli* O157:H7, and *L. monocytogenes* (log cfu/strip) on marinated, whole strip beef jerky pretreated with Mionix $Safe_2O^{TM}$ (calcium sulfate) or not pretreated and dried in a horizontal dehydrator at 62°C (143.6°F). Enumeration was on plate count agar (PCA).

	1:2[a]				1:3[b]				Control[c]			
	Inoculated pretreated	After pretreated	After marinated[d]	After drying[e]	Inoculated pretreated	After pretreated	After marinated[d]	After drying[e]	Inoculated pretreated	After pretreated	After marinated[d]	After drying[e]
Salmonella	8.79	6.81	6.23	<1.6[f]	8.79	7.18	6.93	2.89	8.79	8.49	7.69	4.29
E. coli O157:H7	8.39	7.33	7.24	<1.6	8.39	7.62	7.41	<1.6	8.39	8.36	7.25	<1.6
L. monocytogenes	8.54	8.04	7.57	<1.6	8.54	8.25	7.93	<1.6	8.54	8.38	7.86	2.31

[a] 1 part Mionix concentrate with 2 parts water, dipped for 30 sec
[b] 1 part Mionix concentrate with 3 parts water, dipped for 30 sec
[c] Dipped in tap water for 30 sec
[d] Marinade composed of: water, salt, sugar, vinegar, Worcestershire sauce, sodium erythrobate, MSG, thyme, garlic powder, sodium nitrite
[e] Drying time approx 8-9 h; no humidity control
[f] Enumeration below detection level; positive identification of organisms after enrichment

Table 2. Survival of *Salmonella*, *E. coli* O157:H7, and *L. monocytogenes* (log cfu/strip) on marinated, whole strip beef jerky pretreated with Mionix $Safe_2O^{TM}$ (calcium sulfate) or not pretreated and dried in a horizontal dehydrator at 62°C (143.6°F). Enumeration of *Salmonella*, *E. coli* O157:H7, and *L. monocytogenes* was on bismuth sulfite agar (BSA), sorbitol MacConkey agar (SMAC) and *Listeria* selective agar (LSA), respectively.

	1:2[a]				1:3[b]				Control[c]			
	Inoculated pretreated	After pretreated	After marinated[d]	After drying[e]	Inoculated pretreated	After pretreated	After marinated[d]	After drying[e]	Inoculated pretreated	After pretreated	After marinated[d]	After drying[e]
Salmonella	8.78	6.56	6.15	1.6	8.78	7.09	6.85	2.06	8.78	8.43	7.62	3.87
E. coli O157:H7	8.28	7.05	7.02	<1.6[f]	8.28	7.31	7.22	<1.6	8.28	8.16	7.50	<1.6
L. monocytogenes	8.48	7.66	7.27	<1.6	8.48	7.85	7.74	<1.6	8.48	8.25	7.77	2.12

[a] 1 part Mionix concentrate with 2 parts water, dipped for 30 sec
[b] 1 part Mionix concentrate with 3 parts water, dipped for 30 sec
[c] Dipped in tap water for 30 sec
[d] Marinade composed of: water, salt, sugar, vinegar, Worcestershire sauce, sodium erythrobate, MSG, thyme, garlic powder, sodium nitrite
[e] Drying time approx 8-9 h; no humidity control
[f] Enumeration below detection level; positive identification of organisms after enrichment

Table 3. Survival of *Salmonella*, *E. coli* O157:H7, and *L. monocytogenes* (log cfu/strip) on marinated, whole strip beef jerky pretreated with Keeper® (chlorine dioxide) or not pretreated and dried in horizontal dehydrator at 62°C (143.6°F). Enumeration was on plate count agar (PCA).

	Pretreatment A[a]				Pretreatment B[b]				Control[c]			
	Inoculated pretreated	After pretreated	After marinated[d]	After drying[e]	Inoculated pretreated	After pretreated	After marinated[d]	After drying[e]	Inoculated pretreated	After pretreated	After marinated[d]	After drying[e]
Salmonella	8.28	7.77	7.35	3.46	8.28	8.14	7.35	3.61	8.28	8.18	7.40	3.83
E. coli O157:H7	8.57	7.97	7.24	3.38	8.57	8.43	7.55	3.44	8.57	8.29	7.49	3.56
L. monocytogenes	8.28	8.17	7.56	3.59	8.28	8.25	7.79	3.44	8.28	8.39	7.83	3.74

[a] Pretreatment A: 1,200 ppm ClO_2
[b] Pretreatment B: 500 ppm ClO_2
[c] Dipped in tap water for 30 sec
[d] Marinade composed of: water, salt, sugar, vinegar, Worcestershire sauce, sodium erythorbatethrobate, MSG, thyme, garlic powder, sodium nitrite
[e] Drying time approx 8-9 h; no humidity control

Table 4. Survival of *Salmonella, E. coli* O157:H7, and *L. monocytogenes* (log cfu/strip) on marinated, whole strip beef jerky pretreated with Keeper® (chlorine dioxide) or not pretreated and dried in horizontal dehydrator at 62°C (143.6°F). Enumeration of *Salmonella, E. coli* O157:H7, and *L. monocytogenes* was on bismuth sulfite agar (BSA), sorbitol MacConkey agar (SMAC) and *Listeria* selective agar (LSA), respectively.

	Pretreatment A[a]				Pretreatment B[b]				Control[c]			
	Inoculated pretreated	After pretreated	After marinated[d]	After drying[e]	Inoculated pretreated	After pretreated	After marinated[d]	After drying[e]	Inoculated pretreated	After pretreated	After marinated[d]	After drying[e]
Salmonella	8.29	7.68	7.28	2.95	8.29	8.17	7.33	3.35	8.29	8.27	7.37	3.54
E. coli O157:H7	8.49	7.86	7.17	2.08	8.49	8.36	7.38	3.41	8.49	8.26	7.33	2.38
L. monocytogenes	8.15	8.03	7.40	<1.6[f]	8.15	8.11	7.57	1.60	8.15	8.31	7.69	<1.60

[a] Pretreatment A: 1,200 ppm ClO_2
[b] Pretreatment B: 500 ppm ClO_2
[c] Dipped in tap water for 30 sec
[d] Marinade composed of: water, salt, sugar, vinegar, Worcestershire sauce, sodium erythorbatethrobate, MSG, thyme, garlic powder, sodium nitrite
[e] Drying time approx 8-9 h; no humidity control
[f] Enumeration below detection level; positive identification of organisms after enrichment

Table 5. Survival of *Salmonella, E. coli* O157:H7, and *L. monocytogenes* (log cfu/strip) on marinated, whole strip beef jerky pretreated with Mionix $Safe_2O^{TM}$ (calcium sulfate) or not pretreated and dried in a smokehouse at 62°C (143.6°F). Enumeration was on plate count agar (PCA).

	1:2[a]				1:3[b]				Control[c]			
	Inoculated pretreated	After pretreated	After marinated[d]	After drying[e]	Inoculated pretreated	After pretreated	After marinated[d]	After drying[e]	Inoculated pretreated	After pretreated	After marinated[d]	After drying[e]
Salmonella	8.50	6.71	6.26	<1.60[f]	8.50	7.02	6.46	<1.60	8.50	8.48	7.21	<1.60
E. coli O157:H7	8.36	7.01	6.37	<1.60	8.36	7.14	6.87	<1.60	8.53	8.25	7.25	<1.60
L. monocytogenes	8.55	7.44	6.81	<1.60	8.55	7.58	7.23	<1.60	8.55	8.47	7.28	<1.60

[a] 1 part Mionix concentrate with 2 parts water, dipped for 30 sec
[b] 1 part Mionix concentrate with 3 parts water, dipped for 30 sec
[c] Dipped in tap water for 30 sec
[d] Marinade composed of: water, salt, sugar, vinegar, Worcestershire sauce, sodium erythorbatethrobate, MSG, thyme, garlic powder, sodium nitrite
[e] Drying time approx 8-9 h; no humidity control
[f] Enumeration below detection level; positive identification of organisms after enrichment

Table 6. Survival of *Salmonella, E. coli* O157:H7, and *L. monocytogenes* (log cfu/strip) on marinated, whole strip beef jerky pretreated with Mionix $Safe_2O^{TM}$ (calcium sulfate) or not pretreated and dried in a smokehouse at 63°C (145°F). Enumeration of *Salmonella, E. coli* O157:H7, and *L. monocytogenes* was on bismuth sulfite agar (BSA), sorbitol MacConkey agar (SMAC) and *Listeria* selective agar (LSA), respectively.

	1:2[a]				1:3[b]				Control[c]			
	Inoculated pretreated	After pretreated	After marinated[d]	After drying[e]	Inoculated pretreated	After pretreated	After marinated[d]	After drying[e]	Inoculated pretreated	After pretreated	After marinated[d]	After drying[e]
Salmonella	8.43	6.67	6.32	<1.6[f]	8.43	6.79	6.51	<1.6	8.43	8.48	7.10	<1.6
E. coli O157:H7	8.31	6.62	6.14	<1.6	8.31	6.75	6.61	<1.6	8.31	8.20	7.11	<1.6
L. monocytogenes	8.52	7.16	6.52	<1.6	8.52	7.19	6.98	<1.6	8.52	8.44	7.18	<1.6

[a] 1 part Mionix concentrate with 2 parts water, dipped for 30 sec
[b] 1 part Mionix concentrate with 3 parts water, dipped for 30 sec
[c] Dipped in tap water for 30 sec
[d] Marinade composed of: water, salt, sugar, vinegar, Worcestershire sauce, sodium erythorbatethrobate, MSG, thyme, garlic powder, sodium nitrite
[e] Drying time approx 8-9 h; no humidity control
[f] Enumeration below detection level; positive identification of organisms after enrichment

Table 7. Survival of *Salmonella, E. coli* O157:H7, and *L. monocytogenes* (log cfu/strip) on marinated, whole strip beef jerky pretreated with Keeper® (chlorine dioxide) or not pretreated and dried in a smokehouse at 63°C (145°F). Enumeration was on plate count agar (PCA).

	Pretreatment A[a]				Pretreatment B[b]				Control[c]			
	Inoculated pretreated	After pretreated	After marinated[d]	After drying[e]	Inoculated pretreated	After pretreated	After marinated[d]	After drying[e]	Inoculated pretreated	After pretreated	After marinated[d]	After drying[e]
Salmonella	8.54	7.77	7.10	<1.6[f]	8.54	8.17	7.31	2.23	8.54	8.38	7.37	2.98
E. coli O157:H7	8.53	7.73	7.05	<1.6	8.53	8.12	7.15	<1.6	8.53	8.19	7.10	<1.6
L. monocytogenes	8.52	8.21	6.94	<1.6	8.52	8.32	7.31	<1.6	8.52	8.50	7.15	<1.6

[a] Pretreatment A: 1,200 ppm ClO_2
[b] Pretreatment B: 500 ppm ClO_2
[c] Dipped in tap water for 30 sec
[d] Marinade composed of: water, salt, sugar, vinegar, Worcestershire sauce, sodium erythorbatethrobate, MSG, thyme, garlic powder, sodium nitrite
[e] Drying time approx 8-9 h; no humidity control
[f] Enumeration below detection level; positive identification of organisms after enrichment

Table 8. Survival of *Salmonella, E. coli* O157:H7, and *L. monocytogenes* (log cfu/strip) on marinated, whole strip beef jerky pretreated with Keeper® (chlorine dioxide) or not pretreated and dried in a smokehouse at 63°C (145°F). Enumeration of *Salmonella, E. coli* O157:H7, and *L. monocytogenes* was on bismuth sulfite agar (BSA), sorbitol MacConkey agar (SMAC) and *Listeria* selective agar (LSA), respectively.

	Pretreatment A[a]				Pretreatment B[b]				Control[c]			
	Inoculated pretreated	After pretreated	After marinated[d]	After drying[e]	Inoculated pretreated	After pretreated	After marinated[d]	After drying[e]	Inoculated pretreated	After pretreated	After marinated[d]	After drying[e]
Salmonella	8.57	7.90	6.94	<1.6[f]	8.57	8.24	7.13	1.86	8.57	8.38	7.24	2.79
E. coli O157:H7	8.49	7.59	6.87	<1.60	8.49	8.02	7.01	<1.60	8.49	8.23	6.95	<1.60
L. monocytogenes	8.49	7.79	6.83	<1.60	8.49	8.27	7.19	<1.60	8.49	8.40	7.31	<1.60

[a] Pretreatment A: 1,200 ppm ClO_2
[b] Pretreatment B: 500 ppm ClO_2
[c] Dipped in tap water for 30 sec
[d] Marinade composed of: water, salt, sugar, vinegar, Worcestershire sauce, sodium erythorbatethrobate, MSG, thyme, garlic powder, sodium nitrite
[e] Drying time approx 8-9 h; no humidity control
[f] Enumeration below detection level; positive identification of organisms after enrichment

Table 9. Average a_w and pH value of marinated beef jerky that were pretreated with Mionix $Safe_2O^{™}$ (acidic calcium sulfate) or not pretreated and dried in horizontal dehydrator at 62°C (143.6°F).

		1:2[a]		1:3[b]		Control[c]	
		a_w	pH	a_w	pH	a_w	pH
Before pretreat.	1[d]	0.992	5.68	0.992	5.68	0.992	5.68
	2[e]	0.995	5.85	0.995	5.85	0.995	5.68
	3[f]	0.994	5.90	0.994	5.90	0.994	5.90
After pretreated	1	0.994	4.55	0.995	4.74	0.994	5.72
	2	0.992	4.56	0.993	4.73	0.993	5.85
	3	0.994	4.63	0.994	4.76	0.995	5.94
After marinated[g]	1	0.982	4.55	0.982	4.70	0.982	5.30
	2	0.984	4.80	0.983	4.83	0.983	5.25
	3	0.983	4.63	0.984	4.78	0.983	5.09
After drying[h]	1	0.683	4.54	0.690	4.74	0.697	4.83
	2	0.680	4.61	0.683	4.68	0.681	4.90
	3	0.678	4.58	0.684	4.73	0.676	5.12
Stored 1 mo.	1	0.678	4.97	0.686	5.15	0.679	5.50
	2	0.698	4.86	0.669	4.99	0.659	5.38
	3	0.681	4.83	0.706	4.99	0.686	5.37
Stored 2 mo.	1	0.672	4.47	0.691	4.82	0.668	5.06
	2	0.682	4.77	0.668	4.93	0.692	5.46
	3	0.682	5.01	0.696	4.96	0.668	5.29
Stored 3 mo.	1	0.679	4.80	0.692	4.95	0.694	5.22
	2	0.691	4.92	0.677	5.02	0.698	5.39
	3	0.678	4.88	0.693	4.96	0.675	5.38

[a] 1 part Mionix concentrate with 2 parts water, dipped for 30 sec
[b] 1 part Mionix concentrate with 3 parts water, dipped for 30 sec
[c] Dipped in tap water for 30 sec
[d] Result from the experiment with *Salmonella*
[e] Result from the experiment with *E. coli* O157:H7
[f] Result from the experiment with *L. monocytogenes*
[g] Marinade composed of: water, salt, sugar, vinegar, Worcestershire sauce, sodium erythorbatethrobate, MSG, thyme, garlic powder, sodium nitrite
[h] Drying time approx 8-9 h; no humidity control

Table 10. Average a_w and pH value of marinated beef jerky that were pretreated with Keeper® (chlorine dioxide) or not pretreated and dried in horizontal dehydrator at 62°C (143.6°F).

		Pretreatment A[a]		Pretreatment B[b]		Control[c]	
		a_w	pH	a_w	pH	a_w	pH
Before pretreat.	1[d]	0.997	5.92	0.997	5.92	0.997	5.92
	2[e]	0.993	5.89	0.993	5.89	0.993	5.89
	3[f]	0.994	5.84	0.994	5.84	0.994	5.84
After pretreated	1	0.995	5.83	0.995	5.81	0.994	5.90
	2	0.993	5.53	0.995	5.57	0.995	5.85
	3	0.996	5.60	0.994	5.74	0.995	5.78
After marinated[g]	1	0.984	5.08	0.982	5.26	0.983	5.19
	2	0.984	5.06	0.984	5.19	0.983	4.98
	3	0.983	5.05	0.984	5.05	0.983	5.01
After drying[h]	1	0.685	5.11	0.681	5.03	0.687	5.36
	2	0.690	5.05	0.683	5.07	0.706	4.99
	3	0.695	5.02	0.674	5.11	0.689	5.11
Stored 1 mo.	1	0.708	5.19	0.698	5.22	0.704	5.38
	2	0.704	5.31	0.692	5.37	0.689	5.68
	3	0.762	5.26	0.656	5.28	0.678	5.33
Stored 2 mo.	1	0.708	5.13	0.704	5.01	0.718	5.25
	2	0.692	5.32	0.674	5.33	0.693	5.27
	3	0.674	5.21	0.659	5.21	0.676	5.14
Stored 3 mo.	1	0.700	5.14	0.704	5.08	0.709	5.22
	2	0.687	5.26	0.710	5.16	0.728	5.05
	3	0.691	5.10	0.605	5.08	0.694	5.14

[a] Pretreatment A: 1,200 ppm ClO_2
[b] Pretreatment B: 500 ppm ClO_2
[c] Dipped in tap water for 30 sec
[d] Result from the experiment with *Salmonella*
[e] Result from the experiment with *E. coli* O157:H7
[f] Result from the experiment with *L. monocytogenes*
[g] Marinade composed of: water, salt, sugar, vinegar, Worcestershire sauce, sodium erythorbatethrobate, MSG, thyme, garlic powder, sodium nitrite
[h] Drying time approx 8-9 h; no humidity control

Table 11. Water activity a_w and pH value of marinated beef jerky that were pretreated with Mionix $Safe_2O^{TM}$ (acidic calcium sulfate) or not pretreated and dried in smokehouse at 63°C (145°F).

	1:2[a]		1:3[b]		Control[c]	
	a_w	pH	a_w	pH	a_w	pH
Before pretreat.	0.990	5.52	0.990	5.52	0.990	5.52
After pretreated	0.990	4.39	0.991	4.63	0.993	5.52
After marinated[d]	0.979	4.45	0.982	4.55	0.981	5.03
After drying[e]	0.677	4.58	0.697	4.81	0.667	5.08
Stored 1 mo.	0.695	4.62	0.677	4.83	0.647	4.88
Stored 2 mo.	0.647	4.72	0.657	4.75	0.657	4.94
Stored 3 mo.	0.676	4.89	0.652	4.75	0.657	5.03

[a] 1 part Mionix concentrate with 2 parts water, dipped for 30 sec
[b] 1 part Mionix concentrate with 3 parts water, dipped for 30 sec
[c] Dipped in tap water for 30 sec
[d] Marinade composed of: water, salt, sugar, vinegar, Worcestershire sauce, sodium erythorbatethrobate, MSG, thyme, garlic powder, sodium nitrite
[e] Drying time approx 8-9 h; no humidity control

Table 12. Water activity a_w and pH value of marinated beef jerky that were pretreated with Keeper® (chlorine dioxide) or not pretreated and dried in smokehouse at 62°C (145°F).

	Pretreatment A[a]		Pretreatment B[b]		Control[c]	
	a_w	pH	a_w	pH	a_w	pH
Before pretreat.	0.995	5.94	0.995	5.94	0.995	5.94
After pretreated	0.997	5.76	0.997	5.96	0.998	5.76
After marinated[d]	0.985	5.07	0.984	5.08	0.985	5.05
After drying[e]	0.661	5.04	0.665	5.13	0.675	5.09
Stored 1 mo.	0.676	5.03	0.671	5.15	0.658	5.24
Stored 2 mo.	0.655	5.01	0.664	5.32	0.661	5.22
Stored 3 mo.	0.651	5.24	0.642	5.27	0.649	5.40

[a] Pretreatment A: 1,200 ppm ClO_2
[b] Pretreatment B: 500 ppm ClO_2
[c] Dipped in tap water for 30 sec
[d] Marinade composed of: water, salt, sugar, vinegar, Worcestershire sauce, sodium erythorbatethrobate, MSG, thyme, garlic powder, sodium nitrite
[e] Drying time approx 8-9 h; no humidity control