Thermal treatments are critical in controlling food-borne pathogens in ready-to-eat (RTE) meat and poultry products.

Factors Affecting Heat Resistance

Microbe
- Gram-negative vs. Gram-positive
- Differences within same genus
- Growth phase, growth conditions, injury status

Food composition
- Fats/oil, carbohydrates/sugars, proteins
- Moisture, salt concentration, water activity ($a_w$)
- pH: less resistance at acid ($<5$) and alkaline ($>9$) pH

Dry vs. moist heat

Validation Support for Thermal Processes

USDA, FSIS Appendix A
"Compliance Guidelines For Meeting Lethality Performance Standards For Certain Meat And Poultry Products."

Peer reviewed scientific journal articles
- Validation of Pepperoni Processes for Control of Escherichia coli 0157:H7 (Hinkens et al., J. Food Prot. 59:1260-1266).

North American Meat Institute Process Lethality Spreadsheet
- Use of D-, z-, and F-values to determine process lethality

Validated Process

Thermal Process Expectations

Ready-To-Eat (RTE) meats
- 6.5-7.0 log Salmonella
- 5 log E. coli 0157:H7 and other STECS
- 4 log Listeria monocytogenes

Dry sausages
- 5 log E. coli 0157:H7 and other STECS
- Batter testing + 2 log reduction

Jerky
- 6.5-7.0 log Salmonella
- Humidity requirement

Thermal Process Tools

D-value
- Time in minutes needed kill 90% of the selected organism at a given temperature
- $D_{145}$ for L. monocytogenes = 1.2 min
- $D_{155}$ for E. coli 0157:H7 = 0.7 min

z-value
- Change in temperature needed to alter the D-value by a factor of 10
- L.m. z-value = 30 °F
- $D_{145}$ = 1.2 minutes
- $D_{155}$ = 0.12 minutes
- $D_{135}$ = 12 minutes
**Thermal Process Tools**

F-value = Process Lethality

Required F-value is the D-value times the number of logs of an organism you want to eliminate

- $D_{145}$ for *E. coli* O157:H7 = 0.7 min
- Target reduction for *E. coli* O157:H7 = 5 logs

Need to heat at 145°F for 3.5 minutes to achieve a 5 log reduction of *E. coli* O157:H7

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**So...What's the Problem?**

Limited science-based support for pathogen destruction during thermal processing

- Product type and process impact not always accounted for
- Difficult to translate into industry tools

NAMI Process Lethality Spreadsheet challenges

- Must use available D- and z-values from literature
- May not match product or process

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**Objectives**

Develop the effect of thermal processing interventions on the survival of *Listeria monocytogenes*, *Salmonella*, and shiga-toxin producing *E. coli* (STEC) in roast beef, turkey deli-breast, and boneless hams

Develop time-temperature tables as tools for assuring regulatory compliance and pathogen destruction for ready-to-eat roast beef, turkey deli-breast, and boneless hams

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Excerpt from O’Bryan et al., Journal of Food Science; 73 (3) 23-30.
Phase I Experimental Approach

- D- and z- value generation

Phase II
- Validation in commercial products
- Integrated lethality investigation

Experimental Approach

Three meat systems
- Turkey breast (ground; 1.5% salt, 1.5% dextrose, 20% water),
- Roast beef (ground; 2.0% salt, 0.35% sodium phosphates, 0.75% sugar, 20% water)
- Boneless ham (ground; 2.5% salt, 1.65% sugar, 0.35% sodium phosphates, 547 ppm sodium erythorbate, 200 ppm sodium nitrite, 20% water)

Microbiological Procedures
- Inoculated with 8 log CFU/g L. monocytogenes, Salmonella (5-strain mixes) or STEC (7-strain mix)

Phase I Experimental Approach

- One g portions
- Heated at one of four temperatures (54.4°C/130°F, 60°C/140°F, 65.6°C/150°F, or 71.1°C/160°F)
- Triplicate samples removed when meat reached target temperature (ca. 6-12 sec) and at 5-7 additional hold times
- Sampled for L. monocytogenes, Salmonella, or STEC

Results: Calculating D-values

Linear regression for a ham/Salmonella treatment combination at 60°C (140°F).

Results: D-value Summary

D-values for Salmonella, L. monocytogenes, and STEC in roast beef, turkey deli-breast, and boneless ham.

Results: Calculating z-values

Z-Values (°F)
Phase II Experimental Approach

Validation of Phase I D-values in commercial products
- Same formulations as for Phase I

<table>
<thead>
<tr>
<th>Product</th>
<th>Pathogen</th>
<th>Final Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turkey</td>
<td>Salmonella</td>
<td>71.1 (160°F)</td>
</tr>
<tr>
<td>Roast beef</td>
<td>Salmonella</td>
<td>54.4 (130°F)</td>
</tr>
<tr>
<td>Roast beef</td>
<td>Salmonella</td>
<td>62.8 (145°F)</td>
</tr>
<tr>
<td>Roast beef</td>
<td>Salmonella</td>
<td>71.1 (160°F)</td>
</tr>
<tr>
<td>Roast beef</td>
<td>STEC</td>
<td>54.4 (130°F)</td>
</tr>
<tr>
<td>Roast beef</td>
<td>STEC</td>
<td>62.8 (145°F)</td>
</tr>
<tr>
<td>Roast beef</td>
<td>STEC</td>
<td>71.1 (160°F)</td>
</tr>
<tr>
<td>Ham</td>
<td>Listeria</td>
<td>62.8 (145°F)</td>
</tr>
<tr>
<td>Ham</td>
<td>Listeria</td>
<td>71.1 (160°F)</td>
</tr>
</tbody>
</table>

Phase II Experimental Approach

Phase II Experimental Approach

Manufacture commercial meat products at UW Meat Lab
- Inoculated with 8 log CFU/g of designated pathogen cocktail
- Stuffed into appropriate casing
  - 4.25” plastic (roast beef, turkey) or fibrous (ham)
- Temperature recording devices inserted
  - Surface, mid-point, geometric center

Sample Collection

Phase II Experimental Approach

Thermal processed using typical industry thermal processing schedule
- Steam cook for roast beef and turkey
- Dry-bulb/wet-bulb cook for ham

Triplicate 25-g samples removed at pre-determined time points
- 54.4°C/130°F Cook: sampled at 54.4, 54.4 +1 h, 54.4 +2 h, and 4°C
- 62.8°C/145°F Cook: sampled at 54.4, 62.8, and 62.8 +5 min, and 4°C
- 71.1°C/160°F Cook: sampled at 54.4, 62.8, and 71.1, and 4°C
Phase II Validation Results

<table>
<thead>
<tr>
<th>Product</th>
<th>Pathogen</th>
<th>Final Temperature (°F)/Hold Time</th>
<th>Total Reduction During Cooking (Log CFU/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turkey</td>
<td>Salmonella</td>
<td>160/0 sec</td>
<td>&gt;7.00</td>
</tr>
<tr>
<td>Roast beef</td>
<td>Salmonella</td>
<td>140/5 min</td>
<td>&gt;7.00</td>
</tr>
<tr>
<td>Roast beef</td>
<td>Salmonella</td>
<td>160/0 sec</td>
<td>&gt;7.00</td>
</tr>
<tr>
<td>Roast beef</td>
<td>STEC</td>
<td>130/2 hr</td>
<td>3.44 ± 0.64</td>
</tr>
<tr>
<td>Roast beef</td>
<td>STEC</td>
<td>145/5 min</td>
<td>&gt;7.00</td>
</tr>
<tr>
<td>Roast beef</td>
<td>STEC</td>
<td>160/0 sec</td>
<td>6.95 ± 0.08</td>
</tr>
<tr>
<td>Ham</td>
<td>Listeria</td>
<td>145/5 min</td>
<td>5.01 ± 1.63</td>
</tr>
<tr>
<td>Ham</td>
<td>Listeria</td>
<td>160/0 sec</td>
<td>&gt;7.00</td>
</tr>
</tbody>
</table>

Low Temperature Survival Study

Objectives:
1. Verify the accuracy of D- and z-values for Salmonella in RTE roast beef at 130°F generated in a recently completed American Meat Institute Foundation (AMIF) study;
2. Measure D- and z-values of thermally-adapted Salmonella in RTE roast beef at 130°F and;
3. Validate 130°F thermal process of roast beef after holding times of 2, 3, 5, and 6 hours.

Study Design

Treatments
- TRT 1 "Thermal Adapted"
  - 70-130°F over 2.5 hr (following come-up time of commercial chub)
- TRT 2 "Cold Adapted"
  - Samples for 3 hr >40°F then added to 130°F water bath
- TRT 3 "Not Adapted"
  - Immediately added to 130°F water bath
  - Samples removed at 0, 10, 20, 30, 40, 60, and 90 min
  - D-values were calculated from linear regression on log reduction from the beginning of the 130°F cook process

Heat Adaptation Results

D-values: Thermal-adapted = 23.4 min; Cold adapted = 15.2 min and; Non-adapted = 13.0 min
Integrated average temperatures and Salmonella lethality from the center of 4" diameter chubs of roast beef steam cooked to a final internal temperature of 130°F.

Experimental Approach

Part 1
- Investigate the impact of compositional, physical, and intrinsic factors on pathogen kill
  - D- and z-value generation and validation

Part 2
- Investigate the use of wet bulb as a more suitable measurement than relative humidity for surface lethality
  - 2 thermal process schedules with varying relative humidity/wet-bulb/times

Salmonella D-values

<table>
<thead>
<tr>
<th>Formulation</th>
<th>Temperature [°C/°F]</th>
<th>D-values (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frankfurter (28% Fat)</td>
<td>54.4/130</td>
<td>20.48, 1.74, 0.26, 0.06, 6.60</td>
</tr>
<tr>
<td>Beef Patty (27% Fat)</td>
<td>60/140</td>
<td>7.48, 0.48, 0.2, 0.07, 5.58</td>
</tr>
<tr>
<td>Chicken Patty (17% Fat)</td>
<td>55.6/150</td>
<td>16.31, 1.36, 0.15, 0.08, 6.70</td>
</tr>
<tr>
<td>Chicken Tender (3% Fat)</td>
<td>65.6/150</td>
<td>14.08, 0.83, - , 0.05, 6.70</td>
</tr>
</tbody>
</table>

- In high fat products: lower pH leads to decreased thermal tolerance at lower temperatures
- In products with similar pH: increase in thermal tolerance as fat content increases

Part 1 Experimental Approach

Four products
- Frankfurters/bologna (high fat, representing small diameter/fast cook and large diameter/slow cook)
- Chicken strips (low fat, thin, fast cook)
- Chicken patties (high fat, thin, fast cook)
- Beef patties (high fat, thin, fast cook)

Two cooking methods
- Impingement oven
- Steam/convection oven

Microbiological Procedures
- 8 log CFU/g L. monocytogenes (7-strain mix) or Salmonella (5-strain mix)

Higher pH vs. Lower pH: High fat content

Salmonella survival at 54.4°C vs Time
**Fat Content**

Turkey (3%) vs Frankfurter (27%)

**End Products**

New data for thermal processing validation inclusive of many different products with varying attributes affecting thermal pathogen lethality

Development of industry developed, scientifically supported and easy to use thermal processing tools

- Appendix A style time/temperature tables
- Specific parameter guidance
- Modeling systems
- Other tools

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ALKAR-RapidPak

**Questions?**