Surrogate Organisms for Low Moisture Foods: Tables and References
To repost or cite, please use the following citation: C. Theofel, S. Yada, and L. J. Harris. 2019. Surrogate organisms for low moisture foods – published treatments [Tables and references]. Available at: http://ucfoodsafety.ucdavis.edu/Low_Moisture_Foods/.

Table 1. Studies that compare the survival of surrogate organisms to one or more target pathogens in low moisture foods under different processes

<table>
<thead>
<tr>
<th>Process type</th>
<th>Treatment</th>
<th>Surrogate organism</th>
<th>Target pathogen(s)</th>
<th>Matrix</th>
<th>Summary</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal</td>
<td>Extrusion</td>
<td><em>Enterococcus faecium</em> NRRL B-2354</td>
<td><em>Salmonella</em> strains: Branderup NVSL 96-12528, Oranienburg NVSL 96-12608, Typhimurium ATCC 14028, Enteritidis IV/NVSL 94-13062, Heidelberg/Sheldon 3347-1</td>
<td>Balanced carbohydrate-protein meal</td>
<td>Extrusion lead to a 5-log reduction of <em>Salmonella</em>. <em>E. faecium</em> showed greater heat resistance than <em>Salmonella</em>.</td>
<td>Bianchini et al., 2014</td>
</tr>
<tr>
<td></td>
<td>Stagnant and forced dry air heating (peanuts), hot oil (pecan kernels), hot water (in-shell pecans)</td>
<td><em>Enterococcus faecium</em> ATCC 8459; <em>Enterococcus faecalis</em> ATCC 29212</td>
<td><em>Salmonella</em> strains: Senftenberg 775W ATCC 43845, Enteritidis PT 30 ATCC BAA-1045, Tennessee K4643</td>
<td>Peanuts, pecans</td>
<td><em>E. faecium</em> survived better or not significantly worse than <em>Salmonella</em> in all tested processes.</td>
<td>Brar and Danyluk, 2019</td>
</tr>
<tr>
<td>Heat process</td>
<td><em>Pediococcus acidilactici</em> (from starter culture (Formula 100, Trumark, Linden, N.J.)</td>
<td><em>Escherichia coli</em> O157:H7 strains: ATCC 43894, ATCC 51657, ATCC 51658, ATCC 43895; <em>Salmonella</em> strains: Typhimurium S9, Heidelberg S13, Enteritidis E40, Infantis S20, Hadar S21</td>
<td><em>Beef jerky</em></td>
<td><em>P. acidilactici</em> displayed greater thermal resistance than all pathogens evaluated when reductions could be calculated.</td>
<td>Buege et al., 2006</td>
<td></td>
</tr>
<tr>
<td>Water blanching, steam blanching</td>
<td><em>Pediococcus acidilactici</em> ATCC 8042; <em>Enterococcus faecium</em> NRRL B-2354</td>
<td><em>Salmonella</em> strains: Anatum, Montevideo, Senftenberg 775W, Tennessee, Schwarzengrund, Infantis, Mbandaka</td>
<td><em>Pet food</em></td>
<td>Both <em>P. acidilactici</em> and <em>E. faecium</em> showed greater thermal tolerance than the <em>Salmonella</em> cocktail.</td>
<td>Ceylan et al., 2015</td>
<td></td>
</tr>
<tr>
<td>Process type</td>
<td>Treatment</td>
<td>Surrogate organism</td>
<td>Target pathogen(s)</td>
<td>Matrix</td>
<td>Summary</td>
<td>References</td>
</tr>
<tr>
<td>---------------------------</td>
<td>----------------------------------</td>
<td>-------------------------------</td>
<td>-----------------------------------------------------</td>
<td>---------------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>Heat process</td>
<td><em>Enterococcus faecium</em> ATCC 8459; <em>Saccharomyces cerevisiae</em></td>
<td></td>
<td><em>Salmonella</em> strains: Typhimurium, Newport, Senftenberg 775W</td>
<td>Wheat flour</td>
<td><em>E. faecium</em> was more heat resistant than the <em>Salmonella</em>. <em>S. cerevisiae</em> was less heat resistant than <em>Salmonella</em>.</td>
<td>Channaiah et al., 2016</td>
</tr>
<tr>
<td>Moist-air convection heating</td>
<td><em>Enterococcus faecium</em> NRRL B-2354</td>
<td></td>
<td><em>Salmonella Enteritidis</em> Phage Type (PT) 30</td>
<td>Almond kernels</td>
<td><em>E. faecium</em> is a conservative surrogate for <em>Salmonella</em> Enteritidis PT 30 during moist-air heating.</td>
<td>Jeong et al., 2011</td>
</tr>
<tr>
<td>Heat process</td>
<td><em>Enterococcus faecium</em> NRRL B-2354</td>
<td></td>
<td><em>Salmonella Enteritidis</em> PT 30</td>
<td>Almond kernels</td>
<td><em>E. faecium</em> is a good surrogate for <em>Salmonella</em>, but <em>E. faecium</em> models showed higher error. Methodology, a_w, and process humidity are important parameters to monitor.</td>
<td>Jeong et al., 2017</td>
</tr>
<tr>
<td>Hot water</td>
<td><em>Enterococcus faecium</em> ATCC 8459</td>
<td></td>
<td><em>Salmonella, E. coli O157:H7, Listeria monocytogenes</em></td>
<td>In-shell pecans</td>
<td><em>Salmonella enterica</em> and <em>E. faecium</em> had the highest D-values of all tested strains. <em>E. faecium</em> was overall the most heat resistant.</td>
<td>Kharel et al., 2018</td>
</tr>
<tr>
<td>Heat process</td>
<td><em>Enterococcus faecium</em> NRRL B-2354</td>
<td></td>
<td><em>Salmonella Enteritidis</em> PT 30</td>
<td>Wheat flour</td>
<td><em>E. faecium</em> had similar or higher D and Z values under all parameters tested.</td>
<td>Liu et al., 2018</td>
</tr>
<tr>
<td>Radio frequency heating and subsequent freezing</td>
<td><em>Enterococcus faecium</em> NRRL B-2354</td>
<td></td>
<td><em>Salmonella Enteritidis</em> PT 30</td>
<td>Corn flour</td>
<td><em>E. faecium</em> was a conservative surrogate for <em>Salmonella</em> under the parameters tested.</td>
<td>Ozturk et al., 2019</td>
</tr>
<tr>
<td>Heat process</td>
<td><em>Enterococcus faecium</em> NRRL B-2354</td>
<td></td>
<td><em>Salmonella</em> strains: Enteritidis PT 30, Senftenberg 775W, Typhimurium, Anatum, Montevideo, Tennessee; Listeria strains: ATCC 15313–53 XXIII, DSMZ 20600; ATCC 49594; ATCC 35152–NCTC 7973; ATCC 13932–LMG 21264, DSMZ 27575; FRRB 2542</td>
<td>Confectionery formulation, chicken meat powder, pet food, savory seasoning</td>
<td><em>E. faecium</em> was a suitable surrogate for all products studied except for the confectionery formulation.</td>
<td>Rachon et al., 2016</td>
</tr>
</tbody>
</table>

C. Theofel, S. Yada, and L. J. Harris
<table>
<thead>
<tr>
<th>Process type</th>
<th>Treatment</th>
<th>Surrogate organism</th>
<th>Target pathogen(s)</th>
<th>Matrix</th>
<th>Summary</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vacuum steam pasteurization</td>
<td>Enterococcus faecium NRRL B-2354</td>
<td>Salmonella Enteritidis PT 30, E. coli O157:H7</td>
<td>Quinoa, sunflower kernels, black peppercorns, whole flaxseed, milled flaxseed</td>
<td>Quinoa, sunflower kernels, black peppercorns, whole flaxseed, milled flaxseed</td>
<td>Vacuum steam pasteurizations effectively reduced pathogens on the matrices at the parameters tested. E. faecium was a good surrogate for Salmonella PT 30 and E. coli O157:H7 for the matrices and parameters tested.</td>
<td>Shah et al., 2017</td>
</tr>
<tr>
<td>Heat process</td>
<td>Enterococcus faecium NRRL B-2354</td>
<td>Salmonella Enteritidis PT 30, E. coli O157:H7</td>
<td>Cocoa powder</td>
<td>Cocoa powder</td>
<td>E. faecium was a suitable surrogate at lower aw but not at aw above 0.45.</td>
<td>Tsai et al., 2019</td>
</tr>
<tr>
<td>Radiofrequency heat</td>
<td>Enterococcus faecium NRRL B-2354</td>
<td>Salmonella Enteritidis PT 30, E. coli O157:H7</td>
<td>Wheat flour</td>
<td>Wheat flour</td>
<td>E. faecium was a suitable surrogate for Salmonella.</td>
<td>Villa-Rojas et al., 2017</td>
</tr>
<tr>
<td>Radiofrequency heat</td>
<td>Enterococcus faecium NRRL B-2354</td>
<td>Salmonella Enteritidis PT 30, E. coli O157:H7</td>
<td>Black peppercorns</td>
<td>Black peppercorns</td>
<td>E. faecium was a suitable surrogate for Salmonella.</td>
<td>Wei et al., 2018</td>
</tr>
<tr>
<td>Product formulation: water activity and fat level, heat process</td>
<td>Enterococcus faecium NRRL B-2354</td>
<td>Salmonella Tennessee, Salmonella Typhimurium DT104</td>
<td>Peanut pastes</td>
<td>Peanut pastes</td>
<td>Salmonella survived in all formulations for &gt;12 months. E. faecium survived at higher levels than Salmonella during storage.</td>
<td>Kataoka et al., 2014</td>
</tr>
<tr>
<td>Process type</td>
<td>Treatment</td>
<td>Surrogate organism</td>
<td>Target pathogen(s)</td>
<td>Matrix</td>
<td>Summary</td>
<td>References</td>
</tr>
<tr>
<td>---------------</td>
<td>--------------------</td>
<td>-----------------------------------------</td>
<td>--------------------------------------------------------</td>
<td>-------------------</td>
<td>--------------------------------------------------------------------------------------------</td>
<td>------------------</td>
</tr>
<tr>
<td>Chemical</td>
<td>Peracetic acid</td>
<td><em>Enterococcus faecium</em> NRRL B-2354</td>
<td><em>Salmonella</em> strains: Newport, Senftenberg 775W, Oranienburg, Saintpaul, Typhimurium DT104</td>
<td>Chia seeds, flax seeds</td>
<td><em>E. faecium</em> was an appropriate surrogate for <em>Salmonella</em>.</td>
<td>Hylton et al., 2019</td>
</tr>
<tr>
<td></td>
<td>Propylene oxide (PPO)</td>
<td><em>Enterococcus faecium</em> ATCC 8459; <em>Pediococcus acidilactici</em> ATCC 8042; <em>Staphylococcus carnosus</em> ATCC 51365</td>
<td><em>Salmonella</em> strains: Senftenberg 775W, Montevideo 1449, Tennessee K4643, Johannesburg ARL-SE-013, Ball ARL-SE-085</td>
<td>Cashews, macadamia nuts</td>
<td><em>S. carnosus</em> was not a suitable surrogate under the parameters tested. <em>E. faecium</em> and <em>P. acidilactici</em> were suitable surrogates under the parameters tested.</td>
<td>Saunders et al., 2018</td>
</tr>
<tr>
<td>Non-thermal</td>
<td>High-intensity 405-nanometer light</td>
<td><em>Escherichia coli</em> K-12 ATCC SMG 123; <em>Salmonella</em> Typhimurium Chi 3985</td>
<td><em>E. coli</em> O157:H7 strains: ATCC 35150, C9990, 43894; <em>Salmonella</em> Enteritidis PT 30</td>
<td>Almonds</td>
<td>Surrogates behaved similarly to all pathogenic strains tested. Reductions were under 3 log for all processes.</td>
<td>Lacombe et al., 2016</td>
</tr>
</tbody>
</table>

1 *Enterococcus faecium* ATCC 8459 is a clonal relative of *Enterococcus faecium* NRRL B-2354; they share over 99% sequence identity (Kopit et al., 2014).
Table 2. Studies that use surrogate organisms to study different processes in low moisture foods

<table>
<thead>
<tr>
<th>Process type</th>
<th>Treatment</th>
<th>Surrogate organism</th>
<th>Matrix</th>
<th>Summary</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal</td>
<td>Dry-heat process</td>
<td><em>Enterococcus faecium</em> ATCC 8459, <em>Enterococcus faecium</em> ATCC 35667</td>
<td>Peanuts</td>
<td>5-log reduction of <em>E. faecium</em> was achieved using industrially relevant dry roasting parameters for peanuts.</td>
<td>Poirier et al., 2014</td>
</tr>
<tr>
<td></td>
<td>Oven roasting, microwave roasting, oven and microwave roasting</td>
<td><em>Enterococcus faecium</em> OSY31284</td>
<td>Peanuts</td>
<td>A minimum 3-log reduction of <em>E. faecium</em> was achieved for the parameters tested.</td>
<td>Smith et al., 2014</td>
</tr>
<tr>
<td></td>
<td>Sequential infrared hot air</td>
<td><em>Enterococcus faecium</em> NRRL B-2354</td>
<td>Pistachios</td>
<td>Sequential infrared hot air treatment achieved faster drying of pistachios and &gt;5-log reduction of <em>E. faecium</em>.</td>
<td>Venkitasamy et al., 2017</td>
</tr>
<tr>
<td></td>
<td>Sequential infrared hot air</td>
<td><em>Enterococcus faecium</em> NRRL B-2354</td>
<td>Almonds</td>
<td>Sequential infrared hot air treatment achieved faster drying of almonds and varied reductions of <em>E. faecium</em>.</td>
<td>Venkitasamy et al., 2018</td>
</tr>
<tr>
<td>Thermal and Chemical</td>
<td>Heat with or without controlled atmosphere</td>
<td><em>Escherichia coli</em> ATCC 25922</td>
<td>Almond powder</td>
<td>Heat with controlled atmosphere (low oxygen) showed increased D-values below 1°C/min heating.</td>
<td>Cheng et al., 2017</td>
</tr>
<tr>
<td></td>
<td>Modified atmosphere storage, heat process</td>
<td><em>Escherichia coli</em> ATCC 25922</td>
<td>Almond powder</td>
<td>Long-term storage at 24°C in a modified atmosphere resulted in increased reductions. Holding at 75°C for 50.4 min achieved 4-log reductions.</td>
<td>Cheng et al., 2018</td>
</tr>
<tr>
<td>Non-thermal</td>
<td>Electron beam irradiation</td>
<td><em>Salmonella Typhimurium</em> LT2; <em>Escherichia coli</em> BAA-1427, BAA-1428, BAA-1430</td>
<td>Pecans</td>
<td>Irradiation under modified atmosphere conditions showed similar lethality, but reduced rancidity.</td>
<td>Karagöz et al., 2014</td>
</tr>
</tbody>
</table>

1 *Enterococcus faecium* ATCC 8459 is a clonal relative of *Enterococcus faecium* NRRL B-2354; they share over 99% sequence identity (Kopit et al., 2014).
Validation guidelines and key references

Almond Board of California. 2014. Guidelines for using Enterococcus faecium NRRL B-2354 as a surrogate microorganism in almond process validation. Almond Board of California, Modesto, CA.

- The Almond Board of California’s guidelines for using Enterococcus faecium NRRL B-2354 to validate dry-heat processes for the control of Salmonella Enteritidis PT 30 (the pathogen of concern) on almonds.


- Outlines the steps and requirements for validating heat processes for the control of pathogens in low moisture foods.

Barouei, J., J. Frelka, L. J. Harris, B. Marks, R. Mashiana, and C. Theofel (contributing authors) 2018. Guidelines for using Enterococcus faecium NRRL B-2354 as a surrogate microorganism in pistachio process validation.

- Guidelines for using Enterococcus faecium NRRL B-2354 to validate dry-heat processes for the control of Salmonella Enteritidis PT 30 (the target pathogen of concern) on pistachios.


- Outlines steps in controlling Salmonella in low moisture foods including validation of Salmonella inactivation measures.


- Outlines steps for validating antimicrobial interventions for pathogen control in foods.


- Describes procedures for obtaining a dry inoculum of Enterococcus faecium NRRL B-2354 or Salmonella Tennessee on talc. E. faecium had higher heat resistance than Salmonella under all parameters tested.


- Outlines criteria for selecting a surrogate for process validation and lists surrogates that have been previously validated by pathogen.

- *E. faecium* NRRL B-2354 and clonal relative *E. faecium* ATCC 8459 are devoid of key antibiotic resistance and virulence genes and were considered safe to use in validation studies. The two strains share over 99% sequence identity.
References cited


