Listeria monocytogenes: Risks, recall and intervention

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Introduction of *Listeria*

- **Species in *Listeria* genus**
  - *L. monocytogenes*
    - Highly virulent
      - Causing the food-borne illness, listeriosis, in susceptible persons.
    - Is intracellular parasite
      - Survive and multiply inside host cells
  - *L. innocua*
    - Highly similar (95%) to *L. monocytogenes* but not virulent
    - Use as a surrogate for *L. monocytogenes*
  - **Other pathogenic strains**
    - *L. seeligeri, L. welshimeri, L. grayi, L. ivanovii*
  - **Other non-pathogenic strains**
    - *L. floridensis, L. aquatic, L. cornellensis, L. riparia, L. grandensis*
**Listeria monocytogenes**

- Serotyping is a universally accepted subtyping method for *L. monocytogenes*
  - Serotype: strain can be recognized by surface proteins such as somatic (O) antigen and flagellar (H) antigen.
  - 14 serotypes
    - 1/2a, 1/2b, 1/2c, 3a, 3b, 3c, 4a, 4b, 4bX, 4c, 4d, 5, 6a, 6b
  - 3 serotypes (1/2a, 1/2b, and 4b) → the majority of human cases.
Table 3. Serotypes of *L. monocytogenes* isolated from invasive cases reported to the *Listeria* Initiative, 2013 (n=500).

<table>
<thead>
<tr>
<th>Serotype</th>
<th>n</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>4b</td>
<td>261</td>
<td>52</td>
</tr>
<tr>
<td>1/2a</td>
<td>148</td>
<td>30</td>
</tr>
<tr>
<td>1/2b</td>
<td>61</td>
<td>12</td>
</tr>
<tr>
<td>Other serotypes</td>
<td>21</td>
<td>4</td>
</tr>
<tr>
<td>Untypeable</td>
<td>9</td>
<td>2</td>
</tr>
</tbody>
</table>

National Enteric Disease Surveillance: *Listeria* Annual Summary, 2013, CDC
L. monocytogenes

It is widespread (ubiquitous) in the environment

- Soil, water, sewage
- Silage for animal feed
- The intestinal tract of infected animals
- On vegetables contaminated from soil or manure
- Food processing environments and catering facilities

Zhu et al., 2005. Comprehensive Reviews in Food Science and Food Safety, 4: 34-42
History of L. monocytogenes

- Isolated from diseased rabbit in 1926
- Named after Lord Lister
- Has been recognized as a foodborne pathogen since 1980s.
**L. monocytogenes**

Causes the food-borne illness, listeriosis, in susceptible persons

- **Listeriosis**
  - Outbreaks
  - Sporadic cases
Listeriosis is rare, but deadly

<table>
<thead>
<tr>
<th>Pathogen</th>
<th>Illnesses</th>
<th>Deaths</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Listeria</em></td>
<td>1,600</td>
<td>260</td>
</tr>
<tr>
<td><em>Campylobacter</em></td>
<td>1,300,000</td>
<td>120</td>
</tr>
<tr>
<td><em>Salmonella</em></td>
<td>1,230,000</td>
<td>450</td>
</tr>
<tr>
<td><em>Escherichia coli</em> O157* toxin-producing*</td>
<td>96,000</td>
<td>30</td>
</tr>
</tbody>
</table>

Scallan E et al, 2011. *Emerging Infectious Diseases*

→ Has a high mortality rate (~30%)
Listeriosis

Susceptible populations

The elderly, neonates and infants
Impaired immune systems
- Persons with HIV/AIDS
- Cancer patients
- Organ transplant patients
- Predisposing illness (alcoholism, diabetes etc.)

Pregnant women
- $20\times$ more likely to get listeriosis
- $1/3$ *Listeria* cases occur during pregnancy.

http://www.cdc.gov/nczved/dffmd/disease_listing/listeriosis_gi.html
Incidence by Risk Group, 2004–2009

Illnesses per 100,000 people

Pregnancy-associated

Adults ≥65 years old

Overall incidence
Patients with invasive listeriosis not associated with pregnancy, by age group and sex, Listeria Initiative, 2013 (n=562)
Symptoms of listeriosis

Mild flu-like illness

Nausea or diarrhea

Headache

Persistent fever

Severe cases:

- Meningoencephalitis: an infection of the brain and the surrounding tissues

- Septicemia: where the bacteria is present in the blood

http://www.cdc.gov/nczved/dfbmd/disease_listing/listeriosis_gi.html
Symptoms of Listeriosis

Infected pregnant women
- Themselves only mild, flu-like illness
- Infection during pregnancy
  - Spontaneous abortion
  - Lead to miscarriage
  - Premature delivery
  - Fetal death or stillbirth
  - Infection of newborns such as meningitis.

http://www.cdc.gov/nczved/dfbmd/disease_listing/listeriosis_gi.html
The incubation time
– Time that between ingestion and onset of symptom
– 3~70 days, and averages 21 days

Symptoms of Listeriosis

3 Deaths, 10 Illnesses: *Listeria* Outbreak Linked to Single-Serving Blue Bell Ice Cream
Foodborne through contaminated foods
- Raw and undercooked meats
- Processed foods: deli meats and hot dogs
- Unpasteurized dairy products
- Cantaloupes, apples
- Other produces

A major food safety concern of ready-to-eat (RTE) food
- Historically, RTE meats
- Produces

*monocytogenes transmission mode*
Outbreak in RTE meats

1998 - 1999 outbreak (CDC, 1999)
– Frankfurters and deli meats
– 101 cases and 21 deaths (CDC, 1999)

2000 outbreak (CDC, 2000).
– Deli turkey meat
– 29 cases, 4 deaths and 3 still births
– Recalled 16 million pounds

2002 outbreak (CDC, 2002)
– Sliceable turkey deli meat
– 54 cases, 8 deaths and 3 still births
– Recall > 30 million pounds of products
Outbreak in RTE meats

2008 Canadian listeriosis outbreak
- Deli meats by Maple Leaf Foods plant in Toronto
- 20 death, 56 cases
- The recall cost $20 million

http://www.mahalo.com/canada-listeriosis-outbreak
Outbreak in RTE meats

Why is *L. monocytogenes* a big issue to RTE meat?

- Where does contamination come from?
- Is it heat resistant?
- ....?
characteristics of *L. monocytogenes*

Gram-positive, non-sporeforming, rod shaped
Motile at 20-25°C but not at 37°C.
Facultative anaerobe
→ Grow in vacuum packaged foods

Temperature
– Can grow from 0 to 42 °C
– Optimal T: 30-37°C
– Is killed by pasteurization

Growth of *Listeria monocytogenes* CFA 433 in chicken broth when incubated at 47.7, 38.3, 34.7, and 33.4°F. Adapted from S.J. Walker et al. (1990).
Characteristics of *L. monocytogenes*

**Acidity**
- Growth pH range is 4.4–9.6
- Can survive in hard salami at pH 4.3 to 4.5

**Water activity (a\(_w\))**
- Optimal a\(_w\) = 0.97; can multiply at a\(_w\) = 0.90.
- Can survive at a\(_w\) of <0.90
  - Was isolated from salami with a\(_w\) of 0.79-0.86

**Salt: Halo-tolerant**
- Grow at 6.5% NaCl
- Capable of surviving 10-12% of NaCl,
- Some even survive 25.5% NaCl

Tolerates nitrite
characteristics of *L. monocytogenes*

Form biofilm

- Attach to solid surface of processing facilities
  - Stainless steel
  - Glass
  - Polypropylene and rubber
- Create a microenvironment
- Extremely difficult to remove

- Are ubiquitous in the environment
- Can persist for many years
Characteristics of *L. monocytogenes* important to RTE meats

- Due to its ubiquity and persistence in the environment
  - It is difficult to avoid contamination in RTE meats during slicing and packaging.
- Growth at refrigerated temperature and vacuum condition, and resistant to salt and nitrite
  - Once contaminated, it can grow in vacuum packaged RTE meat during refrigerated storage.
- RTE meats usually have long shelf-life and consume without further heating.
  - Grow to a hazardous level
Regulation about *L. monocytogenes* in RTE meats?

2003, Oct 6, USDA-FSIS Implementation of new regulation

RTE meat is adulterated if

- It contains *L. monocytogenes*
- It contacts surfaces contaminated with *L. monocytogenes*.

Zero tolerance of *L. monocytogenes* in RTE meats.

In order to meet this requirement, an establishment producing RTE meats must comply with one of three alternatives.  

Three alternatives to control of *L. monocytogenes* in RTE meats/foods?

Alternative 1

- Post-Lethality treatment of product
- **AND**
  - Antimicrobial/Process that Suppresses/limits growth

*Listeria monocytogenes* Control
Three alternatives to control of *Listeria monocytogenes* in RTE meats/foods?

**Alternative 2**

- Post-Lethality treatment of product
  - OR
  - *Listeria monocytogenes* Control
  - OR
  - Antimicrobial/Process that Suppresses/limits growth
    - AND
    - Sanitation Program
Three alternatives to control of *Listeria monocytogenes* in RTE meats/foods?

**Alternative 3**

*Listeria monocytogenes* Control

Use of sanitation procedures

Risk?

Alternative 3 > Alternative 2 > Alternative 1
### Control *Listeria* in RTE products?

<table>
<thead>
<tr>
<th>Alternative 1</th>
<th>USDA</th>
<th>FDA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post-exposure lethality treatment AND antimicrobial agent.</td>
<td>2 food contact sites / line / 6 months (Voluntary.)</td>
<td>5 food contact sites / line / week. Test all identified FCS / month.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Alternative 2</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Post-exposure lethality treatment OR antimicrobial agent.</td>
<td>2 food contact sites / line / quarter (Mandatory.)</td>
<td>No differentiation between product type/category.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Alternative 3</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(Initiation only to control <em>L. monocytogenes.</em> )</td>
<td>1-4 food contact sites / line / month, depending on product and size of operation. (Mandatory.)</td>
<td>(Voluntary.)</td>
</tr>
</tbody>
</table>
### RTE meat *L. monocytogenes* outbreaks, 1998–2015

<table>
<thead>
<tr>
<th>Years</th>
<th>No. cases</th>
<th>No. deaths/fetal losses</th>
</tr>
</thead>
<tbody>
<tr>
<td>1999</td>
<td>101</td>
<td>21</td>
</tr>
<tr>
<td>2000</td>
<td>30</td>
<td>4/3</td>
</tr>
<tr>
<td>2001</td>
<td>28</td>
<td>0</td>
</tr>
<tr>
<td>2002</td>
<td>54</td>
<td>8/3</td>
</tr>
<tr>
<td>2003</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2004</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2005</td>
<td>13</td>
<td>1</td>
</tr>
<tr>
<td>2009</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2010</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>2011</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2012</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2013</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2014</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

**A regulatory success**
U.S. Listeriosis Incidence, 1986-2011

New regulatory policies and industry efforts begin targeting meat processing

Advent of PulseNet

Lack of progress

Healthy People 2020 Goal
Foodborne outbreak linked to fresh produces
2011 Outbreaks in cantaloupes

A widespread outbreak across 28 states

Contaminated cantaloupes
2011 Outbreaks in cantaloupes

The first recorded case on July 31, 2011

→ linked to Jensen Farms of Holly, Colorado.
→ 33 deaths and 147 total confirmed cases

Source?

– Soil: clear of the bacteria
– Equipment: four *L. monocytogenes* strains
– Water: contaminated with *L. monocytogenes*
– ???
2015 Multistate Outbreak of Listeriosis Linked to Commercially Produced, Prepackaged Caramel Apples

34 hospitalizations and 7 deaths

Cases infected with the outbreak strains of *Listeria monocytogenes*, by state of December 20, 2014 (n=30)
Caramel Apples Listeria outbreak

Two strains of *L. monocytogenes* found in California Apple Processing Facility

- *Bidart Brothers apple processing plant*
- Same strains were found on outbreak apples

A devastating and sad news

IS THIS ALONE?
RECENT APPLE RECALLS DUE TO POTENTIAL CONTAMINATION OF *LISTERIA*

November 14, 2013
Crunch Pak® of Cashmere, Washington recalled 5,471 cases of Apple Slices due to a possible risk from *L. monocytogenes*.

December 8, 2012
Freshway Foods recalled 6,671 pounds of sliced apples, which may have been contaminated with *L. monocytogenes*.

August 10, 2012
Missa Bay of Swedesboro, New Jersey recalled a total of 293,488 cases fresh produce containing apples...

# Listeria Outbreaks in Produce

<table>
<thead>
<tr>
<th>Implicated food vehicle</th>
<th>Year</th>
<th>No. cases</th>
<th>No. deaths /fetal losses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coleslaw</td>
<td>1981</td>
<td>41</td>
<td>18</td>
</tr>
<tr>
<td>None</td>
<td>1998-2007</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Sprouts</td>
<td>2008</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>Pre-cut celery</td>
<td>2010</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>Whole cantaloupe</td>
<td>2011</td>
<td>147</td>
<td>33</td>
</tr>
<tr>
<td>Caramel apples</td>
<td>2014</td>
<td>35</td>
<td>7</td>
</tr>
</tbody>
</table>
A total of 695 boxes containing 8 “Granny Smith”

67 clear plastic bags containing 6 “Granny Smith”

States affected include CO, KS, MO, NE, NM, OK, SD, UT and WY.
Listeria in Green Beans

POSTED BY BILL MARLER ON OCTOBER 4, 2015

General Mills is recalling 60,000 bags of its Cascadian Farm frozen green beans after one package tested positive for Listeria. It is the second time this year that the bacteria were found in the company’s green beans.
Listeria Positive Test Prompts Corn Recall

Bonduelle USA Inc. of Brockport, NY is recalling 9,335 cases of frozen corn because it has the potential to be contaminated with Listeria monocytogenes, an organism which can

Good Seed Soybean and Mung Bean Sprouts Recalled for Listeria

Good Seed Inc. of Springfield, Va. is recalling all packages of bean sprouts and mung bean sprouts for potential Listeria contamination. The recalled products were distributed to retail stores in Virginia, Maryland and New Jersey.

In the third such recall this year. 1st: May, 2nd: June
Today’s Harvest Brand Peas, Corn, and Broccoli Recalled for Listeria Risk

By NEWS DESK | APRIL 24, 2015

Today’s Harvest Field Peas with Snaps, Silver Queen Corn, and Broccoli Florets with the sell-by dates 04/21/16 are being recalled by manufacturer Greystone Foods LLC and Publix Supermarkets because of possible Listeria contamination.
Rio Tex Wholesale Meats

Texas Firm Recalls RTE Beef Products for Possible Listeria Contamination

NEWS DESK | MARCH 7, 2015

Rio Tex Wholesale Meats of Mercedes, TX, is recalling approximately 58,180 pounds of ready-to-eat beef products that may be contaminated with Listeria monocytogenes, the U.S. Department of Agriculture’s Food Safety and Inspection Service (FSIS) announced Friday. The beef products were produced on various dates between March 25, 2014, and Feb. 19, 2015. The following products...
Listeriosis outbreaks linked with other foods

- Pasteurized milk – 1983 (14 deaths/62 cases)

- Mexican style soft cheese - 1985 (64 deaths/145 cases)
  - Contamination was due to inadequate pasteurization and contamination of equipment

<table>
<thead>
<tr>
<th>Year</th>
<th>No. cases</th>
<th>No. deaths/fetal losses</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1999</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2000</td>
<td>13</td>
<td>0</td>
</tr>
<tr>
<td>2003</td>
<td>12</td>
<td>1</td>
</tr>
<tr>
<td>2005</td>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td>2008</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>2009</td>
<td>26</td>
<td>0</td>
</tr>
<tr>
<td>2010</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>2011</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

Cartwright et al, 2013. *Emerging Infectious Diseases*
Outbreaks in cheese

2012, imported Frescolina Marte Brand Ricotta Salata cheese
- 4 deaths
- Total 22 cases

2013, Crave Brothers Farmstead cheese
- 1 death
- 1 miscarriage
- Total 6 cases
Outbreaks in cheese

2014, March 3, *L. monocytogenes* cheese outbreak
- 8 cases
- Cheese products by Roos Foods, Delaware

http://www.fda.gov/Food/RecallsOutbreaksEmergencies/Outbreaks/ucm386726.htm
Outbreaks in cheese

2015, Oct. 23, *L. monocytogenes* cheese outbreak
- 30 cases, 3 deaths, 28 hospitalizations
- Soft cheese distributed by Karoun Dairies
- On Sept. 16, 2015, Karoun Dairies, Inc. voluntarily recalled 15 types of soft cheeses.
Multistate Outbreak of Listeriosis Linked to Blue Bell Creameries Products

10 cases, 10 hospitalizations and 3 deaths
monocytogenes in produce-a unique challenge

Fresh produces grow in an open environment
- Soil, water, compost
- Bird, wild life and human
→ Potentially high frequency in pre-harvest environments

Listeria spp. is ubiquitous and persistent in the environment
- Contamination during packing and through-out the chain
monocytogenes in produce-a unique challenge

Kill steps?
– Heat/thermal treated?
  ▪ Blanching
  ▪ Can be an effective mitigation to control *Listeria* on clean product contact surfaces and equipment.
– Washing
  ▪ Depends on water quality
  ▪ Microbial reduction?
– Antimicrobial washing
  ▪ Limited efficacy (<2 Log reduction)
  ▪ Regulatory approval
Can frozen eliminate *L. monocytogenes*?

Survival of *L. monocytogenes* on Strawberries frozen with or without 20% sucrose plated onto TPAPN

<table>
<thead>
<tr>
<th>Storage Day</th>
<th>0% sucrose</th>
<th>20% Sucrose</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>6.7 ± 0.2</td>
<td>6.4 ± 0.3</td>
</tr>
<tr>
<td>1</td>
<td>6.0 ± 0.2</td>
<td>6.5 ± 0.1</td>
</tr>
<tr>
<td>7</td>
<td>5.8 ± 0.3</td>
<td>6.6 ± 0.2</td>
</tr>
<tr>
<td>14</td>
<td>5.1 ± 0.7</td>
<td>6.5 ± 0.2</td>
</tr>
<tr>
<td>21</td>
<td>5.5 ± 0.4</td>
<td>6.4 ± 0.4</td>
</tr>
<tr>
<td>28</td>
<td>5.5 ± 0.7</td>
<td>6.3 ± 0.3</td>
</tr>
</tbody>
</table>

Values are the average log CFU/g ± standard deviation of triplicate samples from each of two experiments (n=6). Flessa, S. 2005. Int J Food Micro, 101:255-262

Survive on frozen strawberries for at least 4 weeks.
monocytogenes in produce—a unique challenge

Growth is possible in some products and/or under certain conditions

Centralized processing and packing
– Strives for low bacterial counts
– Extended refrigeration shelf-life
– Listeria grow at refrigerated T
  → Creates environment for Listeria to grow to dangerous levels.

“Zero tolerance”

Control in processing and packaging facilities is critical!
Can low pH prevent *L. monocytogenes* grow in fruits?

<table>
<thead>
<tr>
<th>Fruit</th>
<th>pH (FDA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apple</td>
<td>3.30 - 4.00</td>
</tr>
<tr>
<td>Apricots</td>
<td>3.30 - 4.80</td>
</tr>
<tr>
<td>Cherries, red, Water pack</td>
<td>3.25 - 3.82</td>
</tr>
<tr>
<td>Blackberries, Washington</td>
<td>3.85 - 4.50</td>
</tr>
<tr>
<td>Blueberries, frozen</td>
<td>3.11 - 3.22</td>
</tr>
<tr>
<td>Grapes, Seedless</td>
<td>2.90 - 3.82</td>
</tr>
<tr>
<td>Raspberries</td>
<td>3.22 - 3.95</td>
</tr>
</tbody>
</table>
The water activity of the caramel coating (<0.80) are too low to support *Listeria* growth???
Prevention strategies: Hurdle approach

Pre-harvest

- Produce without pathogen contamination
  - Good agricultural practice
  - Irrigation water
  - Soil
  - Manure and compost

Post-harvest intervention
**TABLE 1** *Salmonella* and *L. monocytogenes* prevalence in water samples collected from irrigation and nonirrigation water sources

<table>
<thead>
<tr>
<th>Category</th>
<th>No. of samples</th>
<th>% prevalence (frequency) of samples with:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td><em>Salmonella</em></td>
</tr>
<tr>
<td>Not used for irrigation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pond</td>
<td>17</td>
<td>12 (2)</td>
</tr>
<tr>
<td>Ditch</td>
<td>13</td>
<td>23 (3)</td>
</tr>
<tr>
<td>River/creek/stream</td>
<td>21</td>
<td>10 (2)</td>
</tr>
<tr>
<td>Used for irrigation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engineered</td>
<td>14</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Pond</td>
<td>8</td>
<td>13 (1)</td>
</tr>
<tr>
<td>River/creek/stream</td>
<td>1</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Total</td>
<td>74</td>
<td>11 (8)</td>
</tr>
</tbody>
</table>

*a* Water samples not used for irrigation were collected within 50 m from a sampled field.

*b* A ditch was defined as either a roadside ditch (located between road and field) or a runoff ditch (located between landscape feature [e.g., a pasture] and field, often part of a buffer zone).

*c* Engineered water was defined as water from a well or municipal source (i.e., a potable water source).
Univariate analyses of management practices that influence the likelihood of *L. monocytogenes* being detected in a produce field (based on soil and drag swab samples)

<table>
<thead>
<tr>
<th>Description</th>
<th>β coefficient</th>
<th>SE</th>
<th>OR</th>
<th>95% CI</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Last time manure was applied to field</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Within 365 days</td>
<td>1.9</td>
<td>0.4</td>
<td>7.0</td>
<td>3.1, 15.4</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Over 365 days</td>
<td>−0.4</td>
<td>0.5</td>
<td>0.6</td>
<td>0.2, 1.7</td>
<td>0.381</td>
</tr>
<tr>
<td>Not applied</td>
<td>0</td>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Last time wildlife was observed in field</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Within 3 days</td>
<td>1.5</td>
<td>0.6</td>
<td>4.4</td>
<td>1.2, 15.6</td>
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<tr>
<td>4 to 7 days</td>
<td>−0.2</td>
<td>0.7</td>
<td>0.8</td>
<td>0.2, 3.1</td>
<td>0.725</td>
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<tr>
<td>8 to 30 days</td>
<td>0</td>
<td>1.0</td>
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</tr>
<tr>
<td>Last time workers were in field</td>
<td></td>
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<tr>
<td>Within 3 days</td>
<td>2.4</td>
<td>0.8</td>
<td>10.5</td>
<td>2.3, 47.5</td>
<td>0.003</td>
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<td>1.9</td>
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<tr>
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<td>0.9</td>
<td>2.6</td>
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<td>Over 30 days</td>
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<tr>
<td>Last time field was irrigated</td>
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<tr>
<td>Within 3 days</td>
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<td>0.4</td>
<td>5.3</td>
<td>2.4, 12.0</td>
<td>&lt;0.001</td>
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<td>0.8</td>
<td>0.3, 2.2</td>
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<td>0.3</td>
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<td>Over 14 days/not irrigated</td>
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<td>Last time soil in field was cultivated</td>
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<td>Within 7 days</td>
<td>2.1</td>
<td>0.5</td>
<td>8.1</td>
<td>3.3, 19.6</td>
<td>&lt;0.001</td>
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<td>8 to 14 days</td>
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<td>0.6</td>
<td>1.8</td>
<td>0.6, 5.7</td>
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<tr>
<td>15 to 30 days</td>
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<td>0.2, 2.2</td>
<td>0.540</td>
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<td>Over 30 days</td>
<td>0</td>
<td>1.0</td>
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<tr>
<td>Does field have a buffer zone</td>
<td></td>
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<td>Yes</td>
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<td>0.4</td>
<td>0.5</td>
<td>0.2, 0.9</td>
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<tr>
<td>No</td>
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</table>

* a = Question 4 (never) was not selected in the questionnaire; therefore, it was excluded from analysis.
* b = worker refers to a man or woman in the field, not in the cab of farm equipment (e.g., tractor).
* c = all dates are based on the calendar.
Rules regulating cow manure
Proposed produce rule under FSMA

FSMA

- Food Safety Modernization Acts
- New federal food safety law passed January 4, 2011

Manure and compost application intervals

- 9 month interval between application of manure and harvest
- 45 day interval between application of compost and Microbial Standards for Ag Water
Prevention strategies

Pre-harvest

Post-harvest intervention

- Eliminate pathogens from fruits, facility and environments
  - Good manufactory practice
  - Antimicrobial and other intervention strategies
Prevention strategies

- Chlorine
- Per-acetic acid
- Ozone treatment
- Natural antimicrobial
- Biological control
  - Bacteriophage: Listex P100
  - Bacteriocins: Nisin
- UVC surface intervention
- High pressure processing
- Irradiation?
Go Cougs!

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School of Food Science

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