Food Safety: General Principles

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U.S. Foodborne Illness

- CDC ESTIMATES
  - Affects 1 in 4
  - 76 million illnesses per year
  - 325,000 hospitalizations
  - 5,000 deaths
    - 1,500 of those deaths caused by *Salmonella*, *Listeria*, and *Toxoplasma*
- Cost estimates
  - Billions of dollars

Costs of foodborne illness

- Affected person:
  - loss of earnings and productivity
  - cost of medical treatment
  - cost of death
- National costs:
  - cost of investigation
  - medical costs - insurance
- Company involved:
  - destruction of stock
  - loss of production
  - cleaning and renovation
  - in-house investigation
  - staff retraining
  - loss of brand reputation
  - compensation
  - legal costs and fines

Varnam & Evans, 1991

Food Safety Hazards

- A
  - biological,
  - chemical, or
  - physical property

  that is *reasonably likely* to cause

  - cause injury or illness

  in the absence of its control

Chemical Hazards

- If not controlled will cause illness
  - Chemicals
    - Pesticides
    - Sanitizers
  - Allergens
    - Undeclared ingredients
    - Cross contaminants
  - Unapproved additives
  - Natural toxins
    - Mycotoxins
      - E.g., patulin

Chemical Hazards - Mycotoxins

- Toxins produced by fungi
  - Primarily *Aspergillus* spp., *Penicillium* spp., and *Fusarium* spp.
- Long-term chronic toxicity of concern
  - Can be carcinogenic
  - Influence immune response

Examples of major mycotoxins

- Aflatoxin (corn, peanuts, figs, tree nuts)
  - *Aspergillus flavus, Aspergillus parasiticus*
- Patulin (apple juice)
  - *Penicillium expansum*
- Fumonisin (corn)
  - *Fusarium moniliforme*
- Ochratoxin (corn, cereals, coffee beans)
  - *Penicillium verrucosu, Aspergillus ochraceus*

Aflatoxins

- Naturally-occurring fungal metabolites
- Produced by
  - *Aspergillus flavus* & *Aspergillus parasiticus*
- Aflatoxin B1, B2, G1, G2 & M1
- Pre-harvest and post-harvest occurrence
- Greatest concern – mostly tree nuts (ppb)
- Stable to heat and processing procedures
- Associated with human liver cancer

Preventing Aflatoxin Formation

- Pre-harvest
  - Resistant varieties (if practicable)
  - Crop rotation, irrigation
  - Insect management
  - Minimize damage during harvesting
- Post-harvest
  - Dry to <15% moisture
  - Facility with temperature-moisture control
  - Insect and pest management

Patulin

- Mycotoxin produced by molds on rotting apples
  - *Penicillium expansum* *(most common)*
  - *Byssochlamys fulva*
  - *Aspergillus* spp.

- Primarily apple cider/juice products
  - Serious concern in children

Inoculum sources: Contaminated harvest equipment

Physical Hazards

- Foreign objects capable of injuring the consumer
  - Metal
  - Glass
  - Wood
  - Hard plastic
  - Stones

Metal Detection is a (the) Critical Control Point

Food Allergy

- Key components of food allergies:
  - An immunologic response to a food protein
    - (food intolerances usually related to carbohydrates)
  - Exquisitely small amounts may cause a reaction
  - Reactions can be severe and even life-threatening

Food Allergy - Prevalence

- 5 – 7% of young children
- 2 – 3% of adolescents and adults
- At least 11 million Americans affected
- Prevalence has been rising

Allergens

- The "big eight" (90% of allergies in U.S.)
  - cow's milk, peanuts, tree nuts, shellfish, egg, soybean, crustacea, fish, wheat
- Less common
  - cottonseed, sesame seed, poppy seed, sunflower seed, other legumes, mollusks
- Biggest reason for "Class I" recalls
  - Non-declared allergens

Allergen Labeling (1/1/06)

- Must declare in plain language:
  - milk, eggs, fish, crustacean shellfish, peanuts, tree nuts, wheat, and soy
  - Must specify nut or shellfish
    - e.g., almond, walnut, cashew; or tuna, salmon, shrimp, or lobster
  - Must indicate if present in flavor, color, or spice
- Where?
  - In ingredient list
  - After "Contains:"
  - Parenthetically (e.g., albumen (egg))

Biological Hazards

- If not controlled will cause illness
  - Bacteria, e.g., *Salmonella*
    - Or their toxins (e.g., *Clostridium botulinum* toxin)
  - Viruses, e.g., hepatitis A
  - Parasites, e.g., protozoa
    - *Cryptosporidium parvum*

Raw fruits and vegetables from which human bacterial pathogens have isolated

Human pathogen	Produce
Bacillus cereus	Alfalfa, cress, mustard, and soybean sprouts, cucumbers
Campylobacter jejuni	Green onions, lettuce, mushrooms, potatoes, parsley, peppers, spinach
Clostridium botulinum	Cabbage, mushroom, peppers
Escherichia coli O157:H7	Alfalfa sprouts, cabbage, celery, cilantro, coriander
Listeria monocytogenes	Bean sprouts, cabbage, chicory, cucumbers, eggplant, leafy salad greens, lettuce, mushrooms, potatoes, radishes, tomatoes
Salmonella	Alfalfa and mung bean sprouts, raw almonds, artichokes, beet greens, cabbage, cantaloupes, cardoon, cauliflower, celery, chili, cilantro, culantro, eggplant, endive, fennel, green onions, lettuce, mustard cress, parsley, peppers, salad greens, spinach, strawberries, watermelons
Shigella	Celery, cantaloupes, lettuce, parsley, salad vegetables, scallions
Staphylococcus	Alfalfa sprouts, carrots, lettuce, onion sprouts, parsley, radishes, salad vegetables
Yersinia enterocolitica	Carrots, cucumbers, lettuce, salad vegetables, tomatoes, watercress
Vibrio cholerae	Cabbage, lettuce

Surveys of Pathogens Isolated from Produce

- Produce: Large variety (asparagus to zucchini)
- Place: International (Australia to U.S.)
- Proportion: <1 in several hundred to >50% positive
  - e.g., 0/336 *Salmonella* in oranges (Florida 2001)

    82/120 (68%) *Salmonella* in lettuce (Italy 1976)

    (much less common)

Bacterial-Associated Outbreaks

C. botulinum	cabbage salad, garlic in oil
Campylobacter jejuni	salad, lettuce
E. coli O157:H7	lettuce, sprouts, cantaloupe, unpasteurized apple cider
Shigella	green onions, parsley, shredded lettuce
L. monocytogenes	cabbage salad
Salmonella	melons, tomatoes, sprouts,

Viral- and Protozoan-Associated Outbreaks

Virus	
Hepatitis A	lettuce, frozen strawberries and raspberries, diced tomatoes, watercress, green onions
Calicivirus	salad, frozen raspberries
Norwalk	celery, coleslaw, fruit salad, green salad, melon
Protozoa	
Cyclospora	raspberry, basil pesto, lettuce, basil
Cryptosporidium	unpasteurized apple cider
Giardia	lettuce and onions

Produce Increasingly Recognized as Vector

- Proportion of reported outbreaks
- USA
  - 1970s <1% (outbreaks) <1% (cases)
  - 1990s 6% (outbreaks) 12% (cases)
- Australia
  - 4% (2001-2005)
- Europe
  - Increases in past decade

Lynch et al., Epidemiol. Infect. 2009

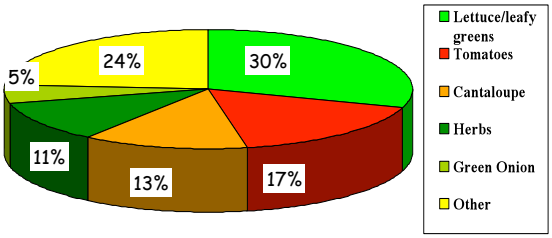
Multinational Outbreaks

Year	Pathogen	Cases	Regions	Food
2008	*Salmonella*	1442	North America	Fresh peppers, tomatoes?
2007	*Salmonella*	51	Europe, North America	Fresh basil
2007	*Shigella*	175	Australia, Europe	Alfalfa sprouts
2007	*Salmonella*	45	Europe	Alfalfa sprouts
2006	*E. coli* O157:H7	206	North America	Fresh spinach
2006	*Salmonella*	20+	Europe	Arugula

Why the increase?

- Increased consumption
  - More raw, less cooked
- Large scale production, widespread distribution
  - Increasing size of outbreak and ability to detect
- Increase in sensitive populations
- Increase in public and scientific awareness
- Greatly improved methodology

1998 – 2006 Produce Outbreaks



Top 5 produce items make up 76% of outbreaks

Recurring Pathogen and Commodity Combinations

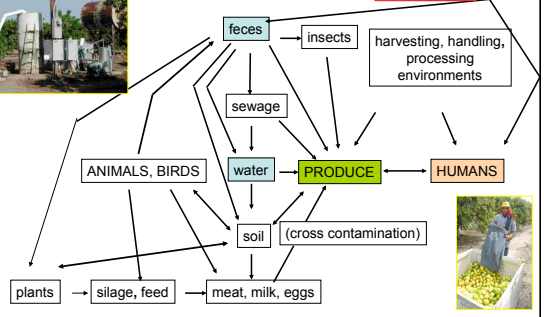
- *Salmonella* Poona and *Salmonella* Anatum
  - cantaloupes
- *E. coli* O157:H7
  - lettuce and leafy greens
- *Salmonella*
  - mangoes, tomatoes, almonds (nuts)
- Hepatitis A
  - green onions
- *Shigella sonnei*
  - parsley, cilantro, and culantro

Enteric (Fecal) Pathogens (partial list)

Pathogen Multiply in Foods?	Enteric Source	Infectious Dose	Sequelae
BACTERIA			
Salmonella spp. **YES**	human animals	10 - 100,000	Reactive arthritis
E. coli O157:H7 **YES**	human animals	10 - 1,000	HUS
Shigella **YES**	Human	10 - 100	Dysentery
PROTOZOA			
Cryptosporidium **NO**	human animals	<20	Severe diarrhea
VIRUS			
Hepatitis A **NO**	human	10 - 100	Jaundice

What are the sources of contamination?

Routes of Contamination



Beuchat, 1996

Contamination/Handling Errors

- Have occurred at:
  - Production
  - Packing
  - Processing
  - Final preparation
- Contamination MOST important factor
- Temperature abuse SOMETIMES contributes
  - Most critical in low-acid fruits and vegetables
    - Pathogens can multiply when fruit or vegetable cut
  - Only critical with bacteria

Survival/Growth of Pathogens in Produce

- Intact fruit/vegetable
  - Survival variable, growth rare
- Cut/wounded fruit/vegetable
  - Survival increases and growth possible
- Temperature
  - Growth slowed at lower temperatures
  - SURVIVAL sometimes increases at lower temperatures
- Humidity
  - Growth and survival enhanced with higher humidity

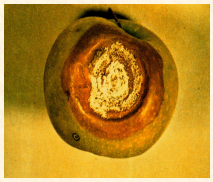
Growth of Pathogens in (cut) Produce

- High pH/low acid products:
  - Growth can be rapid at room temperature
  - examples:
    sprouts, cut melons, chopped parsley, chopped lettuce
- Low pH/high acid products
  - Tomatoes: Under some conditions, chopped tomatoes will support the growth of *Salmonella*
  - Apples: Wound will support the growth of *E. coli* O157:H7

Damaged tissue can support growth

- Higher isolation rates in damaged or decayed produce
- Peppers
  - *E. coli* O157:H7 attaches preferentially to damaged tissue
  - Cells may migrate or flow from sound tissue to damaged tissue during drying of inocula

    (Han et al., 2000)



Innovative Packaging

- Modified atmosphere packaging
- Vacuum packaging
- Shrink-wrap packaging
- Customized films
- Controlled atmosphere storage

Toxin Production by *Clostridium botulinum*

Product	Temp.	Days to Toxin	Product Quality
Romaine	21	14 to 21	Inedible
Shredded cabbage	21	7	Inedible
	22 to 25	4 to 6	Acceptable
Sliced potatoes	22	3	Marginal
Sulfited potatoes	22	4	Acceptable

Washing Doesn't Eliminate Pathogens

- At best 1-3 log (1 to 1000-fold) reductions can be expected under commercial conditions regardless of antimicrobial used
- Issues
  - Complexity
  - Stem scar area
  - Apples
    - Bacteria can enter core through blossom end
    - Stem end difficult access
  - Presume knife can transfer to edible flesh
    - Demonstrated for melons and tomatoes

Infiltration Can Occur in Some Products

Fruit pulp must be < 9ºF warmer than water temperature to prevent infiltration.

Apples
Melons
Peppers
Spinach
Mango

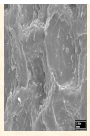
Temp
Pressure
Depth
Water deficit
Vacuum

Maintaining water sanitation critical

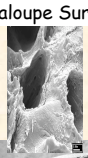
Not all surfaces equal

- Smooth surfaces
  - Honeydew melon, tomato, oranges, apples
- Complex surfaces - hard
  - Netted rind difficult to "clean"
  - Scrubbing with clean brush significant improvement
- Complex surfaces - soft
  - Strawberries, broccoli, lettuce, parsley, sprouts

Honeydew Melon Surface



Cantaloupe Surface



Alfalfa seed

Some surfaces may attract bacteria

- Lettuce
  - *E. coli* O157:H7 found in cut edges and stomata (Seo and Frank, 1999)
  - *L. monocytogenes* and *Salmonella* attach to cut edges (Takeuchi et al., 2000)

Lettuce stomata

Guiding Principles of Food Safety for Fresh Produce

- Once contaminated, removing or killing pathogens is VERY difficult
- THEREFORE
- Prevention of contamination is favored

Approach for risk reduction in fresh produce - proactive

- Integrated farm-to-fork risk reduction
  - Good Agricultural Practices - production
    - FDA/USDA Document 1998
  - Good Packinghouse Practices - harvest/ packing
    - Application of sanitation and hygiene GMPs
  - Good Manufacturing Practices - processing
    - CFR 21 110
- Generating appropriate data

Summary

- Fresh fruits and vegetables can be associated with foodborne illness
- Pathogens associated with fruits and vegetables are associated with human or animal feces
- Prevention of contamination throughout the food chain is preferred
  - washing and temperature control important