FARMER VETERAN COALITION

USDA United States Department of Agriculture
Risk Management Agency

AgriLogic CONSULTING, LLC

FOOD SAFETY

WITH DR. MATTHEW TAYLOR, TEXAS A&M UNIVERSITY

Microbial Hazards in Foods

Matthew Taylor
College of Agriculture and Life Sciences
June 4, 2024

AgVersity

June • 2024

Farmer Veteran Coalition Webinar

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Microbial Hazards in Foods

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Presentation Objectives

- Significance of microbes in foods (meat, dairy, produce) and food safety
- Key microbial pathogens in foods
- Factors impacting microbial growth in foods
- How microbes get into our food supply
- Preventing contamination and transmission

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Foodborne Disease and Microbial Pathogens

- Pathogens – Agents that have capacity to cause disease, illness, injury
- Microbes that cause human disease are a type of hazard
  - Most *severe* class of hazard
  - High costs! (money and quality of life)

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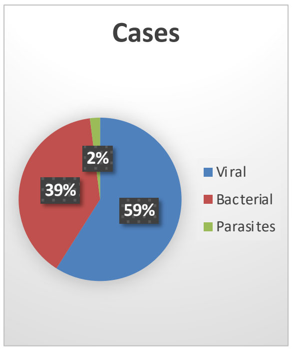
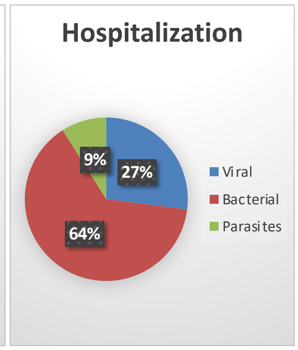
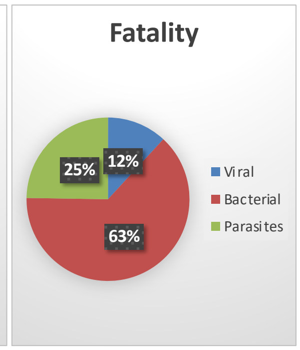
U.S. Foodborne Disease Estimates







Scallan et al. 2011. Emerg. Infect. Dis. 17:7-15

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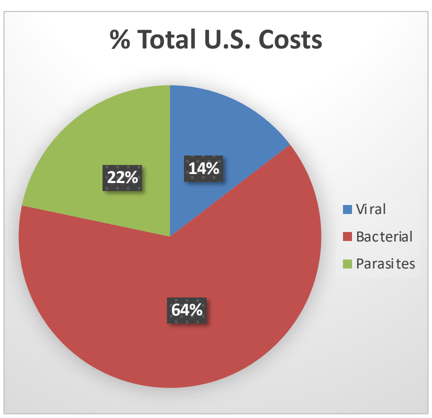
Financial Costs of U.S. Foodborne Disease (2018 Data)



Pathogen Category	Annual U.S. Costs ($)
Viruses	$2,566,984,171
Bacteria	$11,199,833,944
Parasites	$3,804,974,577

ers.usda.gov

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Foodborne Disease by Food Category

Estimates U.S. Foodborne Illness (Percent of Total by Pathogen Type)		
Food Category	**Bacteria**	**Parasites**
Dairy Products	656,951 (18.0)	
Eggs	179,421 (4.9)	
Meat (Beef, Pork, Game)	1,497,628 (41.1)	156 (0.1)
Poultry	653,622 (17.9)	
Fruits & Nuts	230,636 (6.3)	60,573 (25.9)
Vegetables	755,171 (20.7)	8,450 (3.6)
Seafood	142,415 (3.9)	77,795 (33.3)

Painter et al. 2013. Emerg. Infect. Dis. 19:407-415.

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Foodborne Disease Affects **People**

- Numbers are abstract; people are not!
- It affects our loved ones, our community, our nation, our globe.

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KEY PATHOGENS IN MEAT & PRODUCE

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Foodborne Pathogens and Disease Syndromes

- Foodborne Infection: Consumption, attachment, colonization, growth, and release virulence factors
  - *Salmonella enterica*, Noroviruses
- Foodborne intoxication: Consumption of microbially produced, pre-formed toxin (meaning present in food at point of consumption)
  - Examples: Staphylococcal enterotoxin, Clostridial neurotoxin, Fungal aflatoxins
- Foodborne Toxico-infection: Consumption of the viable microbe, with subsequent release of a toxin into the gut; sometimes may follow acute disease
  - Examples: *E. coli* O157:H7 and Shiga toxin release

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Bacillus cereus and Human Disease

- A spore-forming bacterial pathogen (spores can survive many forms of food processing)
- Isolates capable of producing 1 or 2 key toxins
  - Emetic toxin (Intoxication)
  - Enterotoxin/diarrheal toxin (Toxico-infection)
- Commonly associated with starchy foods and/or high protein foods (milk, fish, meats)
  - Contamination of animal or milk
  - Spores survive pasteurization
  - Some psychrotolerant strains identified - milk safety during refrigeration (Growth at $\geq$4°C)

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B. cereus Foodborne Disease

Characteristic	Enterotoxin	Emetic Toxin
# Cells Needed for Illness	10^5 - 10^7 CFU total	10^5 - 10^8 CFU/g food
Toxin production?	Small intestine	Pre-formed in food
Incubation period	8 - 16 hr (typical)	0.5 - 6 hr
Duration	12 - 24 hr (or longer)	6 - 24 hr
Symptoms	Abdominal pain, watery diarrhea, nausea	Nausea, vomiting

Granum & Lindbäck. 2013. Ch. 19 in: *Food microbiology: fundamentals and frontiers*, 4th edt. ASM Press: Washington, DC.

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Clostridium botulinum

- First described in connection to consumption of raw, undercooked blood sausages
- Anaerobe, sporeforming rod
- *C. botulinum* possess both psychrotrophic and mesophilic strains
- Disease is an intoxication in the adult from toxin production in food
- Intoxicating dose: 0.4 ng per kg of body weight

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Symptoms of Disease

- Symptoms
  - Nausea, abdominal pain, vomiting
  - Descending paralysis
    - Droopy eyelids
    - Slurred speech, loss of motor control in face
  - Can have respiratory failure, inability to breathe (leading cause of botulism-derived fatality)
  - Abdominal pain follows, constipation (typically infant botulism)

Image of 14 year old suffering drooping facial muscle, flaccid paralysis

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Clostridium perfringens

- Similar to other *Clostridium* species: rod-shaped, sporeformer
- Optimal growth: 40-45°C
- Common food vehicles are high protein-containing
- Often foods undercooked or are properly cooked but cooled too slowly
- Vegetative cells destroyed; spores survive

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Foodborne Perfringenosis

- Diarrheal disease (Toxico-infection): Commonly associated with Type A toxin-producing *C. perfringens* (sometimes also Type E)
  - Acute (explosive) diarrheal with cramping (12-24 hr symptoms) - symptoms painful but short-lived
  - Incubation period 8-12 hr.
- *CDC estimated 3rd leading cause of bacterial foodborne human disease!*

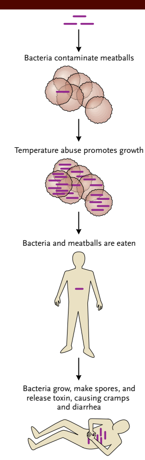

Figure 11.1

Schematic representation of *C. perfringens* food poisoning. Vegetative cells or spores contaminate a meat product and multiply rapidly when food is "incubated." A person consumes the vegetative cells, which then multiply rapidly in the small intestine (producing lots of gas) and sporulate, releasing the toxin at the same time as the spores. The victim is very sick with gas, cramps, and diarrhea but recovers in 24 to 48 h.

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Listeria monocytogenes

- Gram-positive cocco-bacillus facultatively anaerobic
- Foodborne **infection**; primarily affects the immuno-compromised (adults, children)
- Can grow at refrigeration conditions; can grow at low pH conditions
- Resides for long times in biofilms in food processing areas

Image: www.sample6.com (Used w/o permission)

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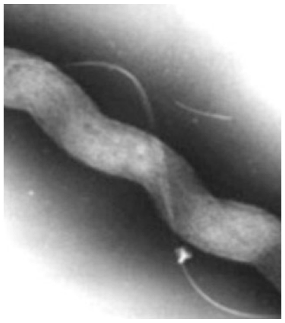
Human *Campylobacter* Disease



- Typically self-limiting/acute disease: up to 2-10 days clinical symptoms
  - Clinical symptoms resolve without medical treatment (self-limiting)
  - Relapse/severe disease sequelae: 5-20% of cases
  - Fever, diarrhea (heavy, frequent, contain undetected blood [occult]), abdominal pain, vomiting (violent, repeated)
- Infectious dose is low: $\leq$500 CFU (generally around 10^4)
- Incubation Period: 2-5 days post-exposure
- Low frequency of chronic sequelae (post-acute disease) onset
  - Bacteremia: Bacteria in blood stream
  - Inflammation: meningitis, pancreatitis, endocarditis
  - Auto-immune disorders: Guillain-Barré Syndrome (GBS), reactive arthritis

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Foodborne Campylobacteriosis

- Incubation period can be up to 10 days
- Duration may be 21 days in extreme cases (generally 2-10 days)
- Gastroenteritis symptoms, infection
  - Colonization of GI tract
  - Inflammation
- Fresh poultry and red meat are most frequent vehicles

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Non-typhoidal *Salmonella*

- Mesophilic rod (most serovars do not grow at <10°C)
- Human foodborne infection
- Multiple food vehicles identified as transmitting:
  - Meat, poultry, dairy
  - Produce, nuts
  - Confections, chocolate
  - *Pretty much every food category…*

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Salmonella and Food Vehicles, Disease

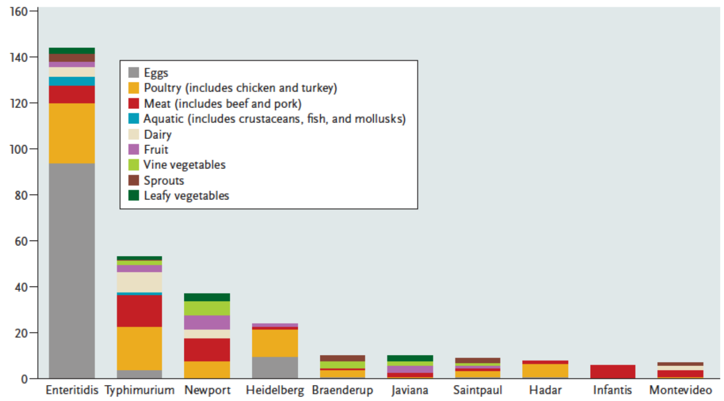

Figure 14.1

Number of *S. enterica* serotypes attributed to specific food commodities for outbreaks from 1998 to 2008 in the United States.

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Foodborne Salmonellosis

- Infection: Invasion of cells, replication with epithelial cells (vacuoles)
- Invasion stimulates cell damage with water release (diarrhea)
- Symptoms: fever, abdominal pain, nausea, vomiting
- Incubation: 8-72 hr

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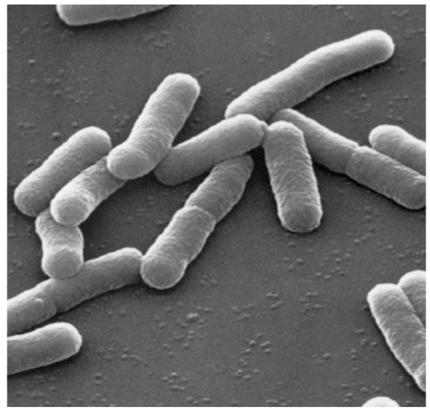
Pathogenic *Escherichia*

- *E. coli*
  - Pathogenic groupings: EPEC, EIEC, EAEC, ETEC, EHEC
  - **O157 STEC & non-O157 STEC**
- *E. hermanii*
- *E. albertii*
- *E. fergusonii*



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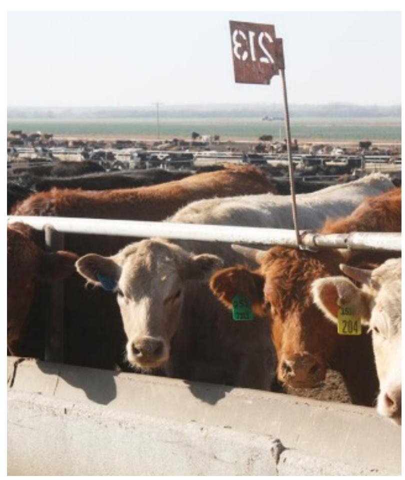
STEC in Foods

- Animal-derived foods: *E. coli* maintain reservoirs in bovine GI tract (commensal)
  - Beef, dairy
  - Calves have higher carriage rates
  - Dairy breeds of greater concern for carriage, likely conversion of carcass meat into ground beef
- Recovered from game animal carcasses, feces
- Fecal matter cross-contamination of produce-irrigating waters
- Human-human; fecal/oral transmission



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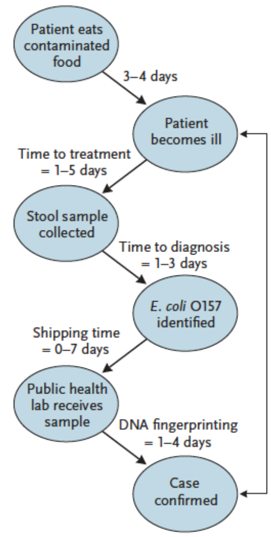
Hemorrhagic Colitis STEC Disease

- Mild diarrhea (non-bloody) to severe bloody diarrhea
- Abdominal pain, cramps is common; symptoms resolve typically within 7-10 days
- Hemolytic uremic syndrome (HUS): common in young children but can affect teens, young and older adults
- Disease dose: ~10 CFU has been reported (generally thought <100 CFU)
- Fatality in rare, but can occur in severe cases: estimated rate: 1%



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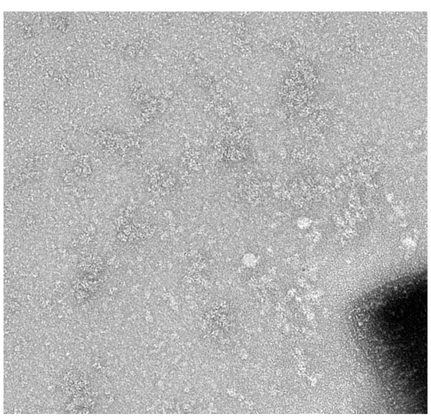
Enteric Viruses



- Human Noroviruses
- Hepatitis A
- Adenoviruses
- Diarrheal infections, typically spread via fecal contamination by shedders (feces)
- NO growth outside the host (You and I)!

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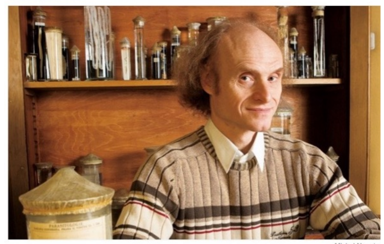
Foodborne Protozoa

- Parasites: Organisms that live off of a host (definitive, intermediary) – host suffers harm
- Protozoal parasites commonly transmitted via foods:
  - *Cryptosporidium parvum*
  - *Toxoplasma gondii*
  - *Giardia intestinalis*
  - *Cyclospora cayatenensis*
- Single-celled microbes capable of forming cysts, oocysts
- Like viruses, no growth outside host

How Your Cat Is Making You Crazy

Jaroslav Flegr is no kook. And yet, for years, he suspected his mind had been taken over by parasites that had invaded his brain. So the prolific biologist took his science-fiction hunch into the lab. What he's now discovering will startle you. Could tiny organisms carried by house cats be creeping into our brains, causing everything from car wrecks to schizophrenia?



The Atlantic Magazine, March 2012 Issue

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SOURCES OF PATHOGENS

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Environmental Transmission to Foods

Feces (animal, human) plays central role in pathogen opportunity for cross- or direct-contamination.

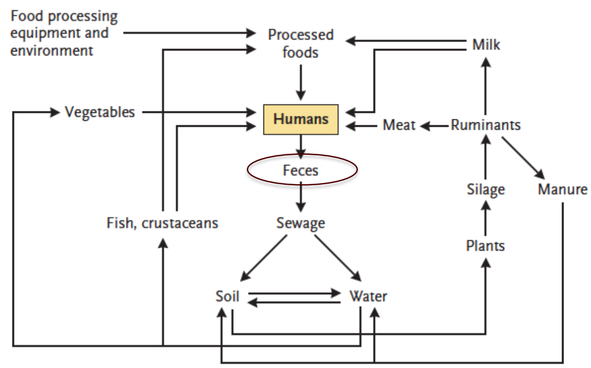

Figure 13.3

Potential routes of transmission of *L. monocytogenes.* (Based on Swaminathan B, p. 383–409, *in* Doyle MP, Beuchat LR, Montville TJ, ed, *Food Microbiology: Fundamentals and Frontiers*, 2nd ed, ASM Press, Washington, DC, 2001.)

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Red Meat and Poultry Animal Sources

- Hides, hooves, feet, mouths, GI tracts, anal openings all sources of contaminating microorganisms
- Teat canals (lactating mammals)
- Enteric bacteria are typically commensals

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Animal Harvest and Processing Sources

- Process environment sanitary condition will contribute to reduced microbiota on meat, poultry products
- Workers play key role in limiting cross-contamination of carcasses and products
- Sanitation of facility

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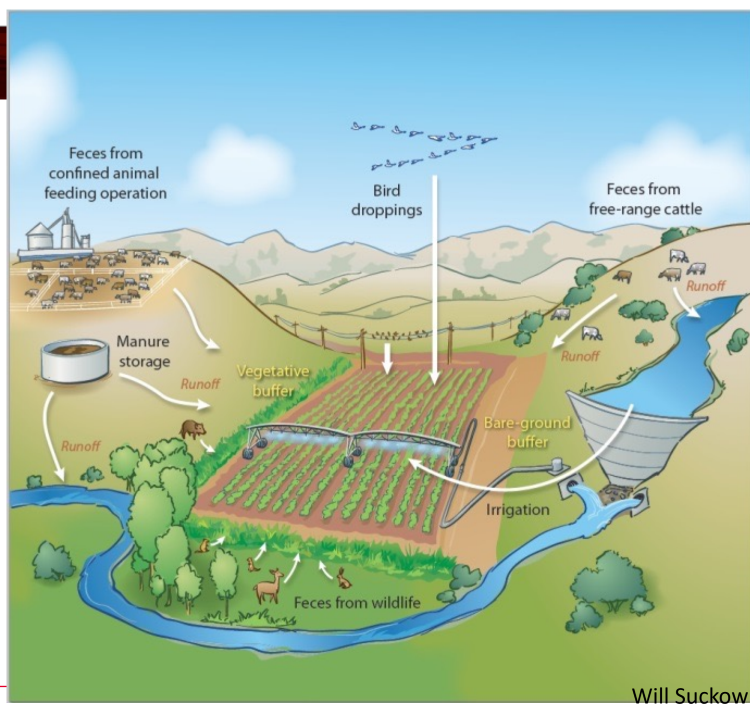

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Produce-Contaminating Microbes: Post-Harvest

- Surfaces of packing equipment
- Wash waters, flume/dump tank waters
- Fresh-cut produce surfaces (cutting equipment, packing surfaces)
- Facility employees and sanitary design

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FACTORS AFFECTING BACTERIAL GROWTH

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Key Considerations

- Bacterial microbes can grow inside and outside host
- Growth is observed as increased numbers of the microbe
- Rates of growth and population increase linked to intrinsic, extrinsic factors

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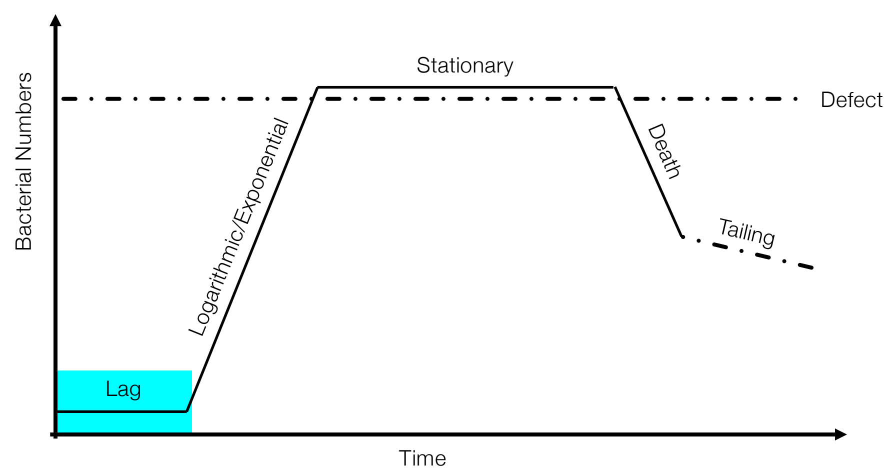
Bacterial Population Growth Phases



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Factors Affecting Bacterial Growth

Intrinsic

Inherent to the **physico-chemistry** of the food

- Physical structure/state, presence of barriers to microbial penetration/internalization
- pH and acidity
- Bulk/free water, bound water, and the water activity (a_w)
- Presence and types of antimicrobials
- Availability and usefulness of nutrients
- Oxygenation status, the REDOX potential (E_h), and reducing/oxidizing agents

Extrinsic

Process, external environment-related

- Temperature, duration of product storage
- Product packaging and transmission of humidity, gases, light
- Atmospheric conditions of stored food

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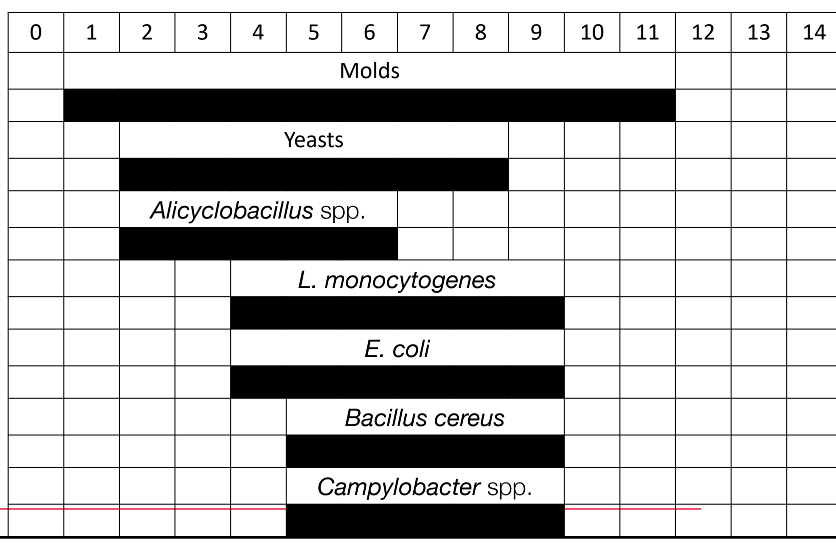
pH-Specific Growth of Microbes



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a_w and Microbial Growth

- a_w measures water availability, NOT water content
- Can change with:
  - Air temperature
  - Air humidity
  - Both should thus be kept constant, allowed to equilibrate

Approximate a_w lower limit for selected microbes' growth	
C. botulinum Type E: 0.97	*Pseudomonas* spp.: 0.97
E. coli: 0.96	*C. botulinum* Type A: 0.94
L. monocytogenes: 0.93	*S. aureus*: 0.86

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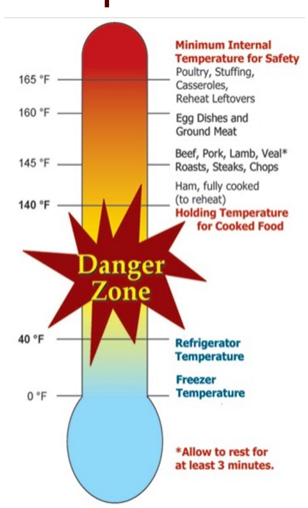
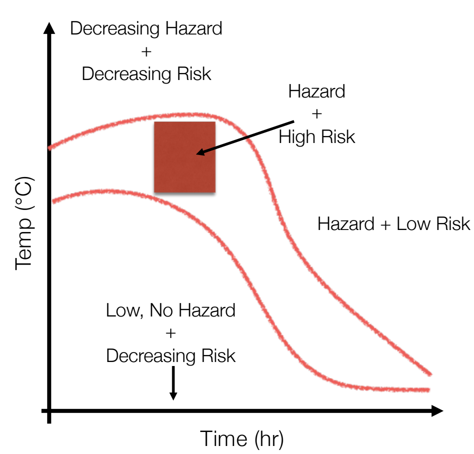
Temperature vs. Duration





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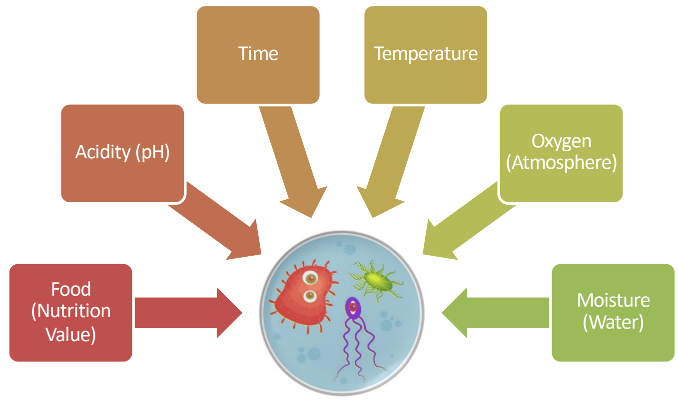
FAT TOM



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PERAL & MICROBES

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Controlling Microbes – Protecting Food Safety

- Chemical preservatives
- Processing
  - Heat
  - Non-thermal
  - Low-temperature holding
- Sanitation and Sanitization

P = Prevent

E = Eliminate

Ral = Reduce to acceptable level

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Chemical Preservatives

- Most preservatives slow or prevent microbe growth!
- Work by differing mechanisms
- Differences in regulations surrounding their approval for use!
  - GRAS
  - Labeling requirements based on use
  - FDA, USDA, and/or state jurisdictions

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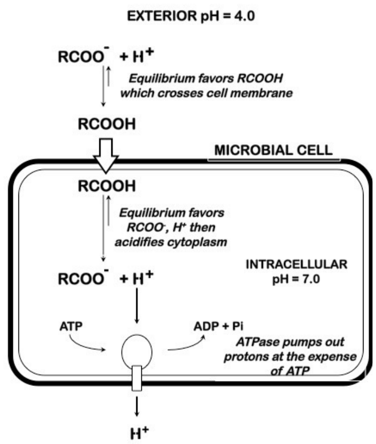
Weak Organic Acids

- Many bear value for various uses, according to Current Good Manufacturing Practices (CGMPs)
- Microbes may develop tolerance to these over repeated exposures



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Key Organic Acids

- Benzoic acid and benzoates
- Acetic acid and acetates
- Lactic acid and lactates
- Sorbic acid and sorbates
- Citric acid and citrates

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Nitrates, Nitrites

- Used primarily in cured meat, poultry foods (components of curing salt)
- In combination with reducing agents, functions to modulate E_H (Erythorbate, ascorbate)
- Approvals
  - USDA: 9CFR§424.21 (156 ppm max. finished product content NO_2^-; 120 ppm in bacons)
  - FDA: 10-200 ppm in smoked fish (tuna, shad) final concentration
- Various plants/vegetables serve as natural source of nitrites in use of various meat/poultry foods
- Prevent toxigenic clostridia spores from completion of germination process

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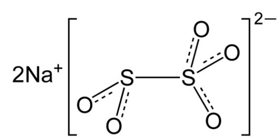
Sulfites



- Typically applied to solid food surfaces as surface sanitizer but can be added into some foods as additive
- USDA does not allow use in meat/poultry
- FDA does not allow use for fruits/vegetables to be marked as fresh (§182.3766) but can be used on other foods
- Enzyme denaturant activity (reduction of disulfide bonds) as well as weak acid mechanisms (sulfurous acid, H_2SO_3); most functional at pH<4.0
- SO_2: antifungal agent in various produce applications
- Used in processed, dried produce items to help prevent microbial spoilage/discoloration

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Refrigeration: Define, Regulate

- FDA Food Code: Foods should be refrigerated at 41°F (5°C) (Part 3-501.14, 16)
  - Exception: Eggs (45°F/7.2°C)
  - Time/temperature control for safety (TCS) foods require refrigeration/cooling
- USDA-FSIS: Cooked meats must be chilled to $\leq$40°F post-lethality and raw meat/poultry stored cold
- Rate of cooling and achieving desired cold storage temperature a function of:
  - Food chemistry and mass
  - Impacts of packaging (if packaged) on heat loss
  - Cooling technology and efficiency at heat stripping
    - Still versus blast air cooling, IQF
    - Cooler temperature

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Meat Product Storage Periods for Safety Preservation

Class	Refrigerator – Unopened	Refrigerator – After Opening	Freezing
Fresh, uncooked	1-2 days	1-2 days	1-2 months
Fresh, cooked	NA	3-4 days	2-3 months
Hard/dry	Whole, 6 weeks in pantry; indefinite if refrigerated	3 weeks	1-2 months
Frankfurters, cooked sausages	2 weeks	7 days	1-2 months
Summer sausages (semi-dry)	3 months	3 weeks	1-2 months

USDA-FSIS

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Refrigeration Impacts on Foodborne Microbes

- Cold storage slows, halts enzymatic, chemical reactions
- Inhibitory to microbial growth through limitations on reaction kinetics
- Psychrotrophic pathogens continue to exhibit slow growth/replication
- Many spoilage microbes will grow well under cold temperatures, including psychrotrophic *Lactobacillus* spp. and Pseudomonads

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Food Freezing

- Foods typically frozen to < -18°C must remain frozen until ready for thawing, preparation for consumption
- Long preservation of food safety, though quality may not be indefinitely preserved
- May result in inactivation of some pathogens
  - Helminths
- Food chemistry can retard freezing rate, allow longer microbial survival

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Thermal Processing of Food: Defining

- Pasteurization: Process designed to eliminate/reduce **most process-resistant non-sporulating pathogen of concern** to non-threatening numbers during post-process handling, as well as significantly reduce non-pathogenic spoilage
  - FDA, NACMCF 2004
- Commercial Sterility: Absence of pathogens and other microbes **capable of replication under shelf storage conditions post-processing**
  - Low acid canned foods (LACF): pH >4.6; a_w >0.85
  - Acid, acidified canned foods: pH $\leq$4.6 (a_w >0.85)
- Blanching: Application of moderate heating to foods to inactivate enzymes carrying enzymatic spoilage (most frequently applied to plants/produce)
- Hot Fill: Non-sterilized container is filled with sufficiently hot food to render final product commercially sterile

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Cooking, Chilling and Meat/Poultry Safety (FDA)

- Comminuted meat, fish, game meat: Cook to minimum internal temperature of 155°F, hold 15 sec. (USDA-FSIS: 160°F, min 10 sec)
- Poultry: cook to 165°F (15 sec.) internal temp. (USDA-FSIS: 165°F, min 10 sec)
- Oven min temp (still air): 350°F (dry); can be lower if air is humidified (250°F)
  This is guidance, NOT guarantee.
- Must validate proper oven temperature for your process to achieve prescribed PRODUCT internal temperature
- Maintain frozen foods as frozen until ready to thaw and re-heat/serve
- If foods are chilled, not frozen, post-cooking, cool to 41°F (5°C) in not more than 6 hr
  135°F → 70°F in 2 hr. (USDA-FSIS: 130°F → 80°F in 1.5 hr)
  70°F → 41°F in 4 hr. (USDA-FSIS: 80°F → 40°F in 5.0 hr)

FDA. 2013. Food Code. (www.fda.gov)

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Cleaning and Sanitization

- Cleaning: Removing of soils (food residues) from food contact, process, environment surfaces
  - Heated, pressurized water
  - Detergents to dislodge protein, fat, etc.
- Sanitization: Treatment of food process environment with heat and/or chemical treatments to inactivate pathogens and reduce numbers of other microbes significantly
- Cleaning ≠ Sanitation

Image: www.hershey.com (Used w/o permission).

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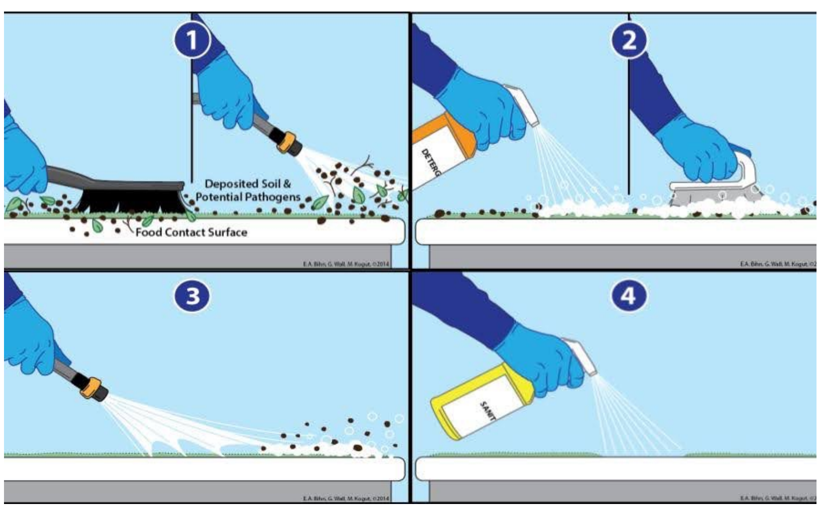
Cleaning, Sanitization Process



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Sanitizers for Kitchen & In-Home Equipment

Recommended:
- Chlorine
- Quaternary Ammonium Compound (e.g., Lysol)
- Vinegar
- Ethyl alcohol

Sanitizer	Concentration	Appy Temp.	Contact Time (min)	Shelf Life
Bleach (Household, 6% NaOCl)	1 tbsp per gal. H_2O (pH 6.5-7.5)	77°F (25°C)	1.0	1 week
H_2O_2 (3%)	Non-diluted	130°F (55°c)	1.0	Manufacturer Expiration
Ethyl Alcohol (95%)	70% v/v in H_2O	Ambient	10.0 min (submerge)	4 months

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Sanitary Design

Approach food process facility, and equipment installation, maintenance, and use to:
- Minimize harborage sites for microorganisms
- Eliminate opportunity for pest entry into facility
- Minimize/prevent food contamination

Schmidt & Erickson, 2008

Image: J. Miller, 2009 (Used w/o permission)

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Sanitation Standard Operating Procedures (SSOPs)

- Provide specific procedures, sequence of events to complete task to ensure sanitary conditions
- Must be written and maintained by establishment
- Procedures to be used during pre- and post-operational facility sanitation
- If SSOPs prove ineffective for sanitary condition maintenance, corrective actions taken to re-establish sanitary conditions

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