Microbial Ecology of Foods
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A food is an ecosystem for microbes
- They don't “know” they are in food!
- Bacteria & molds may multiply, survive, or die.

Pathogenic bacteria in food: potential “outcomes”
- Persistence: viable, numbers unchanged (lag or stationary phase or sporulation)
- Growth (multiplication): rate parameter (variable) based on doubling time
### Growth curve biology
- Spores & lag phase cells quiescent; adaptation to environmental conditions = selecting needed enzymes (activating appropriate genes) from broad bacterial repertoire.
- Multiplying (doubling) cells are metabolically active, often adapting; not all metabolically active cells are multiplying.
- Stress causes adaptation or injury.
- Stationary phase may represent quiescence or (more often) growth rate = death rate.
- Some injured cells appear dead (“viable nonculturable”).
- Some dead cells autolyze.
- Broth: “planktonic cells”
- Bacteria tend to aggregate, attach to surfaces, form colonies or biofilms
- Foods = solid matrix, microenvironments
- Pathogens outnumbered

### Bacteria in broth vs food
- Food contaminants (water, air, soil, raw material, feces) have mixed microflora.
- Food ecosystem may select one organism
- At high levels, bacteria signal each other chemically (“consensus”)
- Different species interact competitively, but sometimes beneficially
<table>
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<tr>
<th>Research vs real food</th>
<th>Major factors (interact)</th>
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<tr>
<td>&quot;Programmed&quot; successions</td>
<td>Temperature</td>
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<td>Genetic exchanges among strains or species</td>
<td>available</td>
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<td>Toxigenic agents (including molds) <em>grow</em> under conditions that do not permit toxigenesis.</td>
<td>Physical structure</td>
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<tr>
<th>Temperatures for Thermophiles</th>
<th>Temperatures for Mesophiles</th>
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<tr>
<td>Minimum: 40–45°C</td>
<td>Minimum: 5–15°C</td>
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<tr>
<td>Optimum: 55–75°C</td>
<td>Optimum: 30-45°C</td>
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<tr>
<td>Maximum: 60–90°C</td>
<td>Maximum: 35–47°C</td>
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<tr>
<th>Temperatures for Psychrophiles</th>
<th>Temperatures for Psychrotrophs</th>
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<tbody>
<tr>
<td>Minimum: -5–+5°C</td>
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</tr>
<tr>
<td>Maximum: 15–20°C</td>
<td>Maximum: 30–35°C</td>
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<td>(cf. handout)</td>
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Cold: liquid or solid water?
- Freezing kills some cells, frozen storage preserves
- Psychrotrophs grow slowly in refrigerated food

Warm = near optimum?
- Food spoilage promoted; test of sanitation
- “Danger Zone”: 4–60°C (40–140°F) or 5–57°C (41–135°F)
- Rapid transition from hot to cold or cold to hot

“Danger zone” depicted

DANGER ZONE FOR NEUTRAL FOODS
Averages of Aeromonas hydrophila, Bacillus cereus, E. coli O157:H7, Listeria monocytogenes, Salmonella spp., Shigella spp., Staphylococcus aureus, & Yersinia enterocolitica

Hot—temps > max for growth cause death
- $D$ value: time for decimal reduction at $t^\circ$C; organisms are in log death phase
- $z$ value: temperature change ($^\circ$C) to reduce the $D$ value 10-fold

D value example

$D_{TC} = 5$ min
Heat

- Cooking, blanching, pasteurization not for "commercial sterility"
- Cells in log phase are more heat-sensitive

Heat

- "Heat-shock" proteins aid adaptation; some produced in response to other stresses.
- Mesophiles or psychrotrophs—infected agents must be able to multiply at body temperature.

Tyndallization: boiling on 3 days

- Day 1: vegetative cells killed, spores heat-shocked
- Day 2: veg cells from spores killed, last spores heat-shocked
- Day 3: vegetative cells from final spores killed; endpoint: sterility

Eh

- Aerobic (>0 mV), microaerophiles, facultative, anaerobic (<0 mV)
- "Strict" aerobes $E_h > 0$ mV, "obligate" anaerobes $E_h < -300$ mV

Eh

- Facultative organisms often use available energy more efficiently under aerobic conditions
- *C. perfringens* may not start growing under aerobic conditions, but is not inhibited by oxygen once growth begins.
### Eh

- $E_h$ hard to measure in foods
- Live foods metabolize or bind oxygen
- Packaging, modified atmosphere
- Molds generally strict aerobes

### Water activity—"$a_w$"

Water available for microbial growth, based on water present and on binding by solutes such as salt or sugar; equilibrium relative humidity ÷ 100; range is 0 to 1.00

#### Approximate $a_w$ of some foods

- Fresh fruit or vegetables $\geq 0.97$
- Fresh poultry or fish $\geq 0.98$
- Fresh meats $\geq 0.95$
- Juices, fruit & vegetable 0.97
- Cheese, most types $\geq 0.91$
- Honey 0.54–0.75
- Cereals 0.10–0.20

#### Minimum $a_w$ for some foodborne pathogens

- *Salmonella* 0.93
- *C. botulinum* 0.93
- *Staphylococcus aureus* 0.85
- (Most yeasts) 0.88
- Most molds 0.75

### pH: Hydrogen-ion potential

- Foods range from pH 7 downward.
- Acidification inhibits spoilage & growth of many pathogens.
- “Low acid” (bot) pH $\geq 4.6$

### pH values of some foods

- Egg white 7.6–9.5
- Milk 6.3–6.8
- Chicken 5.5–6.4
- Beef 5.3–6.2
- Cheeses, most 5.0–6.1
- Tomatoes 3.7–4.9
- Apples 2.9–3.5
**Important minimum pH values for growth of microbes in foods**

- *Clostridium botulinum* 4.8–5.0
- *Salmonella* (most types) 4.5–5.0
- *Staphylococcus aureus* 4.0–4.7
- Yeasts & molds 1.5–3.5

- “Organic” acids (e.g., lactic, acetic, etc.) more effective antimicrobials than mineral acids
- Most effective undissociated; at a given pH, molar quantity of organic acid >> than that of a mineral acid.

**Nutrients available**

- C & N sources required, sometimes “growth factors”
- Foods generally good C & N sources
- Other factors, then nutrients decide which organism predominates

**Physical structure**

- Bacteria grow on surfaces when they can.
- Some surfaces (melon rind, eggshell) limit access to nutrients.
- Food matrix: molds often penetrate better than bacteria.

**Physical structure**

- If water & solutes cannot diffuse freely, local variations in $E_h$, $a_w$, and pH are highly possible.
- High viscosity or strongly cellular structure can greatly limit heat transfer (both heating and cooling) in foods.

**Microflora**

- Bacteria in foods: variety & competition
- Microbial growth may lower $E_h$ & pH; molds use organic acids as carbon sources & raise pH.
**Microflora**
- Bacteria may produce acetic, lactic, and other acids as fermentation products.
- Some produce bacteriocins — proteins that have a highly-specific lethal effect on closely related organisms.

**Competing organisms**
- *Staphylococcus aureus*
- *Clostridium botulinum*

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<th>Antimicrobials: preservatives</th>
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<td>Milk: rapid lactic acid producers (lactococci), then&lt;br&gt;Slower acid producers (lactobacilli) that tolerate lower pH's, then&lt;br&gt;Acid-stable putrefactive (proteolytic) bacteria and finally,&lt;br&gt;Molds (metabolite tolerance).</td>
<td>Materials added specifically to inhibit microbial growth&lt;br&gt;Nitrite for “curing” meats, vs <em>C. botulinum</em>.&lt;br&gt;Sorbates, benzoates, &amp; other salts of organic acids bacteriostatic, not bactericidal</td>
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**Antimicrobials: preservatives**
- CO₂ & SO₂ long used in foods; SO₂ is highly toxic to a small segment of the population.<br>Spices — especially those with strong flavors — often viewed as preservatives or disinfectants. Probably bacteriostatic, at best.

**Antimicrobials: radiation**
- UV widely applicable to decontamination of food surfaces, food contact surfaces, & water used in food processing; limited penetration.
Antimicrobials: radiation

- Surface efficiency enhanced by pulsed laser application (some pulsed laser applications use visible light).
- Ionizing radiation discussed earlier in course.

Interactions

- The pH that permits growth of a bacterium near its optimal temperature may be limiting at a less favorable temperature.

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Interactions

- Safe foods “designed” combining slightly unfavorable conditions for several parameters to stop target pathogens and spoilage organisms.

Interactions

- This kind of food design has heavy safety implications; modeling (discussed last time) is used to make choices, then validated by inoculated-pack, product-abuse trials before a new food product is marketed.
- Applied in HACCP.
Pathogen Modeling Program (PMP)

http://www.arserrc.gov/MFS/PATHOGEN.HTM

Summary

- Food ecosystems govern which microorganisms may grow in them.
- Factors, such as temperature, $a_w$, pH, etc., interact to determine the microbiologic safety of a food.
- Food processing takes account of these factors to ensure food safety.