DRYING AND FOOD SAFETY

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Quality

From consumer/industry point of view
- Organoleptic quality
- Functional properties
- Shelf life
- Freshness
- Nutritional values
- Safety
- Value of money

From public health point of view
- Safety
- Nutritional values
- Compliance with regulations
Assurance that food will not cause harm to the consumers when it is prepared and/or eaten according to its intended use.
At different levels

- Farm
- Preparation
- Production
- Consumption

Where to control hazards
Food safety assurance

- **HACCP** (Hazard analysis critical control point)
- **GMP** (Good Manufacturing Practice)
- **GAP** (Good Agricultural Practice)
Control at farm

Control of production environment

Control of process
Hazards in foods

Physical hazard

Chemical hazard

Biological hazard
Physical hazard

- Button
- Glass fragment
- Wooden chip
- Insect fragment
- Bones
- Jewelry
- Finger nail/False nail
- Stone
- Toothpick
- Bandage
Hepatitis A
Norwalk virus group
Rotavirus

Cryptosporidium parvum
Trichinella spiralis
Biological concerns

- Survival
- Toxin production
- Growth
- Contamination
- Post-process contamination
Sources of contamination

- Plants
- Animals
- Soil
- Air
- Food handling & processing
- Sewage
- Water

Sources of contamination
*Listeria monocytogenes* can attach and form biofilm on stainless steel

Source: faculty.piercecollege.edu/pregersb/microbiology/006industrialbiofilms.html
*Escherichia coli* on wooden cutting board

Microorganisms on plastic cutting board

Microorganisms on kitchen sponge

Source: visualsunlimited.photoshelter.com/gallery/
Bacteria on cabbage leaf

Bacteria on kitchen mint
Microbial contamination from air
Microbial contamination from insects
Microbial contamination from hair
Microbial contamination from coughing
Microbial contamination from hand

- Unwashed hand
- After washing with water for 20 sec
- After washing with soap for 20 sec
- After spraying with 70% ethanol

*Microbial contamination from hand*
<table>
<thead>
<tr>
<th>Bacteria</th>
<th>Food</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Clostridium botulinum</em></td>
<td>Low acid canned foods</td>
</tr>
<tr>
<td><em>Bacillus cereus</em></td>
<td>Starchy foods</td>
</tr>
<tr>
<td><em>Escherichia coli</em> O157:H7</td>
<td>Raw milk, undercooked beef</td>
</tr>
<tr>
<td><em>Listeria monocytogenes</em></td>
<td>Raw meats, dairy products, vegetables</td>
</tr>
<tr>
<td><em>Salmonella</em> spp.</td>
<td>Meats, poultry, milk, egg</td>
</tr>
<tr>
<td><em>Staphylococcus aureus</em></td>
<td>Cooked ready-to-eat foods</td>
</tr>
<tr>
<td><em>Vibrio parahaemolyticus</em></td>
<td>Seafoods</td>
</tr>
</tbody>
</table>

**Examples of foodborne pathogenic bacteria**
Aim of safe food production

- Control growth
- Destroy/ inhibit/ reduce numbers to the safe levels

Need to understand factors affecting microbial growth
Bacterial growth curve
Factors affecting microbial growth

- Food
- Acidity
- Temperature
- Time
- Oxygen
- Moisture
Food

Microorganisms require

Source of energy, nitrogen, minerals, vitamins and growth factors

To grow and function normally
Acidity

pH scale

Acidic

Neutral

Alkaline

Bacteria

Yeast and Molds
pH affects microbial growth rate and survival during processing and storage

Max cell numbers produced drops
Length of stationary phase shortens
Growth rate decreases
Length of lag phase increases
Death rate increases

(Source: Garbutt, 1997)
<table>
<thead>
<tr>
<th>Food</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lemon</td>
<td>2.2-2.4</td>
</tr>
<tr>
<td>Tomato</td>
<td>3.1-3.9</td>
</tr>
<tr>
<td>Banana</td>
<td>4.5-4.7</td>
</tr>
<tr>
<td>Meats</td>
<td>5.4-6.9</td>
</tr>
<tr>
<td>Milk</td>
<td>6.3-6.6</td>
</tr>
<tr>
<td>Shrimp</td>
<td>6.8-7.0</td>
</tr>
<tr>
<td>egg white</td>
<td>8.6-9.6</td>
</tr>
</tbody>
</table>

**pH of different foods**
Enzyme-catalyzed reactions occur at maximum rate when growth rate is at its optimum temperature. Growth rate increases as the rate of enzyme-catalyzed reactions increases. Growth rate decreases as enzymes become denatured and membranes are damaged.
# Grouping of microorganisms according to temperature growth range

<table>
<thead>
<tr>
<th>Group</th>
<th>Minimum (°C)</th>
<th>Optimum (°C)</th>
<th>Maximum (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Psychrophiles</td>
<td>-5</td>
<td>12-15</td>
<td>20</td>
</tr>
<tr>
<td>Mesophiles</td>
<td>5</td>
<td>30-45</td>
<td>47</td>
</tr>
<tr>
<td>Thermophiles</td>
<td>40</td>
<td>55-75</td>
<td>60-90</td>
</tr>
</tbody>
</table>
Time

Bacteria

Increase in numbers by binary fission
Bacterial numbers

- >1,000,000
- >1,000
- 16
- 4
- 2
- 1

Time (in minutes and hours):
- 15 min
- 30 min
- 1 h
- 3 h
- 5 h
Temperature Danger Zone (TDZ)
5-60 °C
(41-140 °F)

- Most microorganisms grow well in TDZ
- Some survive and grow outside TDZ
Obligate aerobic bacteria

Obligate anaerobic bacteria

Facultative anaerobic bacteria

Microaerophiles

Aerotolerant bacteria

Oxygen
Water activity ($a_w$) - a measure of the availability of water for biological function and relates to water present in food in free form

$$a_w = \frac{P}{p_0}$$

$P$ = Vapor pressure of solution

$p_0$ = Vapor pressure of solvent (usually water)

$$A_w \times 100 = \text{Equilibrium relative humidity (ERH, %)}$$
Food pick up moisture

Food loses moisture

Relative humidity

Water activity

Bacterial growth

High humidity

Low humidity

Food with low $a_w$

Food with high $a_w$
## Limits of bacterial growth

<table>
<thead>
<tr>
<th>Organism</th>
<th>Minimal $a_w$</th>
<th>pH range</th>
<th>Temperature range (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Bacillus cereus</em></td>
<td>0.970</td>
<td>4.3-9.3</td>
<td>4-52</td>
</tr>
<tr>
<td><em>Clostridium botulinum</em></td>
<td>0.935</td>
<td>4.6-9.0</td>
<td>10-48</td>
</tr>
<tr>
<td><em>Listeria monocytogenes</em></td>
<td>0.920</td>
<td>4.4-9.4</td>
<td>-0.4-45</td>
</tr>
<tr>
<td><em>Salmonella spp.</em></td>
<td>0.940</td>
<td>3.7-9.5</td>
<td>5-46</td>
</tr>
<tr>
<td><em>Staphylococcus aureus</em></td>
<td>0.830</td>
<td>4.0-10</td>
<td>7-50</td>
</tr>
</tbody>
</table>

Source: Forsythe (2000)
Barriers controlling growth of microorganisms

- High quality of raw materials
- Process by using high or low temperature
- Lessen the time in TDZ
- Lower water activity
- Make food more acidic
# Effects of food processing on microorganisms

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Factors influencing growth/survival</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooling, chilling</td>
<td>Retard growth by low temperature</td>
</tr>
<tr>
<td>Freezing</td>
<td>Retard/prevent growth by low temperature and reducing $a_w$</td>
</tr>
<tr>
<td>Drying/curing</td>
<td>Delay/prevent microbial growth by reducing $a_w$</td>
</tr>
<tr>
<td>Addition of acid</td>
<td>Reduce pH</td>
</tr>
<tr>
<td>Pasteurization/sterilization</td>
<td>Delivery heat sufficient to inactivate target microorganism to the desired extent</td>
</tr>
<tr>
<td>Vacuum/modified atmosphere packaging</td>
<td>Low oxygen content to inhibit aerobes and delay growth of facultative anaerobes</td>
</tr>
</tbody>
</table>

Source: Adams & Moss (2008)
A number of low-level hurdles can be used in combination

The lower $a_w$ e.g. salt content, acid content and preservative content may improve product quality and make the product more acceptable.
Contamination in dried foods
Foodborne pathogens contaminated in dried foods

- *Bacillus cereus*
- *Clostridium perfringens*
- *Salmonella* spp.
- Cereals, grains, nuts, beans
- Spices and herbs
- Dried fruits and vegetables

Contamination of mycotoxin in dried foods
Mycotoxins frequently reported in dried foods

- Aflatoxins
- Ochratoxins
- Fumonisins
- Zearalenone
High humidity + warm temperature

Production of mycotoxin

Poor storage after harvesting
# Mycotoxin contamination in dried foods

<table>
<thead>
<tr>
<th>Products</th>
<th>Contaminated mycotoxin</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apricots</td>
<td>Ochratoxin</td>
<td>Bircan (2009)</td>
</tr>
<tr>
<td>Figs</td>
<td>Aflatoxin, Fumonisin, Ochratoxin</td>
<td>Iamanaka et al. (2007)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Juan et al. (2008a)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Trucksess &amp; Scott (2008)</td>
</tr>
<tr>
<td>Raisin</td>
<td>Ochratoxin</td>
<td>Sugita-Konishi et al. (2006)</td>
</tr>
<tr>
<td>Okra</td>
<td>Aflatoxin</td>
<td>Hell et al. (2009)</td>
</tr>
<tr>
<td>Smoked-dried fish</td>
<td>Aflatoxin</td>
<td>Adebaya-Tayo et al. (2008)</td>
</tr>
<tr>
<td>Milk powder</td>
<td>Aflatoxin</td>
<td>Ghanem &amp; Orfi (2009)</td>
</tr>
<tr>
<td>Infant formula</td>
<td>Aflatoxin</td>
<td>Rastogi et al. (2004)</td>
</tr>
<tr>
<td>Rice</td>
<td>Aflatoxin, Ochratoxin, Fumonisin, Zearalenone</td>
<td>Binder et al. (2007)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Nguyen et al. (2007)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Juan et al. (2008b)</td>
</tr>
<tr>
<td>Wheat</td>
<td>Ochratoxin, Fumonisin, Zearalenone</td>
<td>Zinedine et al. (2006)</td>
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<td></td>
<td></td>
<td>Binder et al. (2007)</td>
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<td></td>
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<td>Magan &amp; Aldred (2007)</td>
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<tr>
<td>Maize</td>
<td>Aflatoxin, Fumonisin, Ochratoxin, Zearalenone</td>
<td>Zinedine et al. (2006)</td>
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<tr>
<td></td>
<td></td>
<td>Binder et al. (2007)</td>
</tr>
<tr>
<td>Breakfast cereals</td>
<td>Aflatoxin, Ochratoxin</td>
<td>Villa and Markaki (2009)</td>
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<tr>
<td>Pitachios</td>
<td>Alfatoxin</td>
<td>Schatzki &amp; Pan (1996)</td>
</tr>
<tr>
<td>Chilli</td>
<td>Alfatoxin</td>
<td>Russell &amp; Paterson (2007)</td>
</tr>
<tr>
<td>Garlic powder</td>
<td>Fumonisin</td>
<td>Boonzaaijer et al. (2008)</td>
</tr>
<tr>
<td>Onion powder</td>
<td>Fumonisin</td>
<td>Boonzaaijer et al. (2008)</td>
</tr>
<tr>
<td>Pepper</td>
<td>Aflatoxin</td>
<td>Boonzaaijer et al. (2008)</td>
</tr>
<tr>
<td>Gingseng root</td>
<td>Aflatoxin</td>
<td>D’ovidio et al. (2006)</td>
</tr>
<tr>
<td>Cocoa beans</td>
<td>Aflatoxin, Ochratoxin</td>
<td>Sánchez-Hervás et al. (2008)</td>
</tr>
<tr>
<td>Coffee beans</td>
<td>Aflatoxin, Ochratoxin</td>
<td>Bokhari &amp; Aly (2009)</td>
</tr>
<tr>
<td>Patulin</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Black tea</td>
<td>Aflatoxin</td>
<td>Hasan &amp; Abdel-Sater (1993)</td>
</tr>
<tr>
<td>Pet foods</td>
<td>Aflatoxin, Ochratoxin</td>
<td>Leung et al. (2006), Peña et al. (2008)</td>
</tr>
</tbody>
</table>
Drying

Removal of water

Reduction of water activity

Negative effects on growth and survival of microorganisms
- Dry heat is less effective than moist heat
- Some microorganisms can survive in low water activity
- Microbial cells attached to a surface are more heat resistant than those unattached or are in dispersed state in liquid food
Time required to destroy 90% of microbial cells (Decimal reduction time)
Heated at 60 °C

Time (min) | No. of survivors (cells/ml) | log no. of survivors
---|---|---
0 | 1.00E+06 | 6.00
2 | 3.01E+05 | 5.48
4 | 3.19E+04 | 4.50
6 | 4.18E+03 | 3.62
8 | 1.70E+02 | 2.23
10 | 1.30E+02 | 2.11
log no. of survivors vs. Time (min)
Viable cells, log % of initial

- 100
- 10
- 1
- 0.1

Time

- 50°C
- 60°C
- 70°C

Decimal reduction time
Degrees Celsius or Fahrenheit change in temperature
Required to achieve a tenfold reduction in the $D$-value

**Thermal death time curve**
Survival curves of Salmonella Krefeld (a) in TSB adjusted $a_w$ by addition of sucrose and heating at 60°C and (b) on rawhide surface at drying temperature of 60°C.

Mild process

New technology

Pretreatment

Good raw material

Quality retention + Food safety

Well designed process condition

Good packaging and right storage condition

- Mild process
- New technology
Survival curves of *Salmonella* Anatum attached on cabbage surfaces: (a) hot air drying; (b) vacuum drying; (c) low-pressure superheated steam drying at 50 °C (□), 60 °C (◆) and 70 °C (△).

Evolution of surface temperature of cabbage samples during drying: (a) hot air drying; (b) vacuum drying; (c) low-pressure superheated steam drying at 50 °C (□), 60 °C (◆) and 70 °C (△).

Attachment of *Salmonella* on (a) fresh cabbage surface and after (b) hot air drying for 6 h, (c) vacuum drying for 1 h and (d) low-pressure superheated steam drying for 1 h. Drying temperature was 60 °C.

Examples of typical pretreatments

- **Water/steam blanching**
  - Hot water at 85-100°C
  - Saturated steam
- **Chemical pretreatment**
  - Soaking/dipping in
    - Organic acid, e.g., ascorbic acid, citric acid
    - Calcium chloride
    - Potassium/sodium metabisulfite
    - Blanching in chemical solution
- **Osmotic dehydration**
  - Sugar
  - Sodium chloride
- **Combined pretreatment**
Survival curves of *Salmonella* Anatum onto sliced cabbage having been subjected to (a) 0% and (b) 0.5% acetic acid during drying at 50 (◊), 55(■) and 60°C (Δ).

Packaging and storage condition

- Type of packaging
- Aerobic/anaerobic conditions
- Nitrogen packing
- Storage temperature
Reduce initial contamination

Process control

Prevent post contamination after processing

Reduce/inhibit/eliminate foodborne microorganisms
Quality assurance

Quality → Food product → Food safety

Good Manufacturing Practice (GMP)
Hazard Analysis and Critical Control Point (HACCP)