Predicting the shelf life of chilled products

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International Workshop
Quality Management of the Chill Chain
Athens 2005
Predicting the shelf life of chilled products

Shelf life of chilled foods

Spoilage

Organoleptically accepted by consumers

Safety

Provide an appropriate level of protection - ALOP
Predicting the shelf life of chilled products

Models for shelf life prediction. Why?

- Is there a problem today?
- Profit for Industry?
- Benefits for consumers?
Predicting the shelf life of chilled products

➢ Is there a problem today?

$1 billion in the United States and $200 million in Canada are lost each year as a result of beef spoilage.

Source: The National Cattlemen's Beef Association

4 billion EUROS per year annual health care costs, traced to few selected foodborne pathogens in meat products.

Source: WHO 7th report covering 1993-1998 period
Predicting the shelf life of chilled products

Models for shelf life prediction. Why?

- Identification and quantification of factors affecting shelf life
- Shelf life extension
- Effective “expiration dating”
- Development of effective chill chain management systems (decision support)
Predicting the shelf life of chilled products

Profit for Industry?

- Decrease “external failure cost” of quality (minimizing spoiled products before expiration date)
- Increase “value” of products (providing higher quality, increased safety)
- Lower production cost (exploiting the total shelf life of products)
Predicting the shelf life of chilled products

- Benefits for consumers?
  - Higher quality
  - Increased level of safety
  - Better price?
Predicting the shelf life of chilled products

Presentation Outline

- Spoilage of chilled food products
- Microbial spoilage models
- Applications of spoilage models
- Spoilage modeling in risk assessment
ONLY A FRACTION OF THE TOTAL MICROFLORA IS RESPONSIBLE FOR SPOILAGE (Specific Spoilage Organisms: SSO)

THIS FRACTION (SSO) IS RESPONSIBLE FOR SPOILAGE ONLY WITHIN A CERTAIN RANGE OF ENVIRONMENTAL CONDITIONS (Spoilage Domain: SD)

SPOILAGE IS CAUSED BY THE PRODUCTION OF A CERTAIN AMOUNT OF METABOLIC PRODUCTS (Chemical Spoilage Index: CSI)

SPOILAGE IS OBSERVED WHEN THE SSO REACH A CERTAIN LEVEL (Spoilage level: SL)
Principles of chilled products

Spoilage

Outline
- Spoilage
- Spoilage modeling
- Applications
- Spoilage modeling vs Risk Assessment
- Spoilage modeling vs Risk Assessment

Spoilage process

Graph showing:
- Log (cfu/g)
- Total microflora
- SSO
- Metabolites
- Time (days)
- Concentration of metabolites
- Shelf life
- Spoilage level
- Chemical Spoilage Index

Shelf life is indicated by the horizontal line between the log (cfu/g) and concentration of metabolites axes.
Modeling microbiological spoilage

Steps in development of spoilage models

- IDENTIFICATION OF SSO
- DETERMINATION OF SPOILAGE LEVEL
- DEVELOPMENT OF A PREDICTIVE MODEL FOR SSO GROWTH
- VALIDATION OF THE MODEL
Step 1&2: Identification of SSO and determination of spoilage level

- Studies with natural contaminated products
- Studies with sterile products inoculated with spoilage bacteria isolated from natural contaminated products

Outline

Spoilage

Spoilage modeling

Applications

Spoilage modeling vs Risk Assessment

Microbiological analysis

Sensory analysis

Chemical analysis
**Step 1 & 2: Identification of SSO and determination of spoilage level**

**Microbiological Analysis**

**Ground pork stored at 5 °C**

- PCA
- CFC
- STAA
- MRS
- VRBG

- Total Plate Count
- Pseudomonads
- B. thermosphacta
- Lactic acid bacteria
- Enterobacteriaceae

**Outline**

- Spoilage
- Spoilage modeling
- Applications
- Spoilage modeling vs Risk Assessment
Step 1 & 2: Identification of SSO and determination of spoilage level

Microbiological Analysis

Ground pork stored at 15 °C

- PCA
- CFC
- STAA
- MRS
- VRGB

Total Plate Count
Pseudomonads
B. thermosphacta
Lactic acid bacteria
Enterobacteriaceae
Step 1 & 2: Identification of SSO and determination of spoilage level

Sensory Analysis

Ground pork

Score

Time (hours)

Rejection Point

Spoilage

Spoilage modeling

Applications

Spoilage modeling vs Risk Assessment

Outline
### Step 1&2: Identification of SSO and determination of spoilage level

**Combining results from microbiological and Sensory Analysis**

<table>
<thead>
<tr>
<th>T (°C)</th>
<th>Shelf life (hours)</th>
<th>CFC Pseudomonads (Log₁₀ cfu/g)</th>
<th>STAA B. thermosphacta (Log₁₀ cfu/g)</th>
<th>MRS L.A. bacteria (Log₁₀ cfu/g)</th>
<th>VRBG Enterobacteria (Log₁₀ cfu/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>267.2±5.1</td>
<td>9.2±0.2</td>
<td>8.4±0.2</td>
<td>4.9±0.1</td>
<td>5.1±0.1</td>
</tr>
<tr>
<td>5</td>
<td>146.7±9.7</td>
<td>9.1±0.3</td>
<td>8.2±0.1</td>
<td>5.5±0.1</td>
<td>6.4±0.2</td>
</tr>
<tr>
<td>10</td>
<td>79.4±3.4</td>
<td>8.8±0.3</td>
<td>8.0±0.2</td>
<td>6.0±0.4</td>
<td>7.0±0.3</td>
</tr>
<tr>
<td>15</td>
<td>53.7±6.0</td>
<td>9.0±0.2</td>
<td>8.1±0.1</td>
<td>7.1±0.3</td>
<td>8.0±0.4</td>
</tr>
</tbody>
</table>
Step 1&2: Identification of SSO and determination of spoilage level

Combining results from microbiological and Sensory Analysis

Spoilage level

Ground pork stored at 5 °C

Sensory rejection

Outline

Spoilage

Spoilage modeling

Applications

Spoilage modeling vs Risk Assessment

Log CFU/g

Time (hours)

0 50 100 150 200 250 300 350

2.00 4.00 6.00 8.00 10.00 12.00

PCA CFC STAA MRS VRBG

Sensory rejection

Spoilage level

Spoilage modeling vs Risk Assessment
Step 1&2: Identification of SSO and determination of spoilage level

**SSO:** pseudomonads

**SPOILAGE DOMAIN:** Aerobic storage from 0 to 20 °C

**SSO SPOILAGE LEVEL:** $10^9$ cfu/g
Step 3: Development of a model for SSO growth

Experimental Design

Factors:

1. Storage temperature
2. Meat pH

Experimental Design

Factors:

1. Storage temperature
2. Meat pH

- Temperature (°C)
- pH

<table>
<thead>
<tr>
<th>Storage Temperature</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5.00</td>
</tr>
<tr>
<td></td>
<td>5.30</td>
</tr>
<tr>
<td></td>
<td>5.60</td>
</tr>
<tr>
<td></td>
<td>5.90</td>
</tr>
<tr>
<td></td>
<td>6.20</td>
</tr>
<tr>
<td></td>
<td>6.50</td>
</tr>
</tbody>
</table>

- A
- B
- C
- D
- E
- F
Step 3: Development of a model for SSO growth

Modified Arrhenius model for the combined effect of temperature and meat pH

\[
\ln(\mu_{\text{max}}) = \ln(\mu_{\text{ref}}) - d_\mu \ast (pH_{\text{ref}} - pH) + \frac{E_{A\mu}}{R} \ast \left( \frac{1}{T} - \frac{1}{T_{\text{ref}}} \right)
\]

\[
\ln(1/\lambda) = \ln(1/\lambda_{\text{ref}}) - d_\lambda \ast (pH_{\text{ref}} - pH) + \frac{E_{A\lambda}}{R} \ast \left( \frac{1}{T} - \frac{1}{T_{\text{ref}}} \right)
\]
Step 3: Development of a model for SSO growth

Modified arrhenius model for the combined effect of temperature and meat pH

![Graph showing the modified Arrhenius model for the combined effect of temperature and meat pH.](graph.png)
Step 4: Validation of the model

Performance of the model in predicting SSO growth under dynamic temperature conditions

Profile T1

Profile T2
Step 4: Validation of the model

Performance of the model in predicting shelf life under dynamic temperature conditions

Shelf life prediction

TIME REQUIRED BY THE SSO TO MULTIPLY FROM THE INITIAL TO SPOILAGE LEVEL
**Step 4: Validation of the model**

**Performance of the model in predicting shelf life under dynamic temperature conditions**

<table>
<thead>
<tr>
<th>Temperature profile</th>
<th>SL observed (h)</th>
<th>SL predicted (h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>85.3</td>
<td>85.5</td>
</tr>
<tr>
<td>T2</td>
<td>98.0</td>
<td>66.8</td>
</tr>
<tr>
<td>T3</td>
<td>68.8</td>
<td>53.6</td>
</tr>
<tr>
<td>T4</td>
<td>71.5</td>
<td>70.5</td>
</tr>
</tbody>
</table>
Components of a “ready to use” Spoilage Model

**PRODUCT:** Ground meat (beef and pork)

**CONDITIONS**

**OF APPLICABILITY:**
- Aerobic storage from 0 to 20 °C,
- Meat pH: 5.3-6.2

**SSO:** Pseudomonads

**SSO SPOILAGE LEVEL:** $10^9$ cfu/g

**PREDICTIVE MODEL:** Modified arrhenius model for the effect of temperature and pH

**VALIDATION:** Static and Dynamic conditions

**APPLICATION:** User-friendly software
Components of a “ready to use” Spoilage Model

Tertiary Model

Application of spoilage models by the Food Industry using a user-friendly computer software

SPOILAGE MODEL

Shelf life prediction

user-friendly computer software

Outline

- Spoilage
- Spoilage modeling
- Applications
- Spoilage modeling vs Risk Assessment
Components of a “ready to use” Spoilage Model

Application of spoilage models by the Food Industry using a user-friendly computer software

®MicroSPred v 1.0-pro

MICROBIAL SPOILAGE PREDICTOR

- Models targeted to specific food products (fish, meat, poultry, dairy)
- Lag is included
- Organoleptic data
- Information on the relation microbial growth vs shelf life (SSO, Spoilage level)
- Application of the rapid method for SSO enumeration
- Applicable and well validated models at static and dynamic conditions
Use of spoilage modeling for effective expiration dating

“Expiration Dating”

Current method for expiration dating: Challenge tests

Problems with Challenge tests

Estimation of shelf life based on Challenge tests is valid only for the conditions tested while any changes to these conditions require the repetition of the test.

Furthermore, no information is provided on the magnitude of influence of the controlling factors on microbial growth and product shelf life.
Use of spoilage modeling for effective expiration dating

Challenge Experiments on ground pork

<table>
<thead>
<tr>
<th>Storage Temperature °C</th>
<th>Shelf life (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>11.1</td>
</tr>
<tr>
<td>5</td>
<td>6.1</td>
</tr>
<tr>
<td>10</td>
<td>3.3</td>
</tr>
<tr>
<td>15</td>
<td>2.2</td>
</tr>
</tbody>
</table>

Expiration date?
Use of spoilage modeling for effective expiration dating

Temperature in Retail Stores

[Bar chart showing temperature distribution in °C with corresponding percentage of refrigerators.]
Use of spoilage modeling for effective expiration dating

Challenge Experiments on ground pork

**Challenge Experiment 1**
Temperature: 5 °C  
Initial pseudomonads level: 2.5 log cfu/g  
pH: 5.7

Self life: 7.0 days

**Challenge Experiment 2**
Temperature: 5 °C  
Initial pseudomonads level: 5.8 log cfu/g  
pH: 6.4

Self life: 2.8 days

Expiration date?
Use of spoilage modeling for effective expiration dating

Ground pork

Initial pseudomonads level

pH

![Graph showing initial pseudomonads level and pH for ground pork.](image)
Use of spoilage modeling for effective expiration dating

“Expiration Dating”

Current method for expiration dating: Challenge tests

Disadvantages:

- Ignores variations in initial Quality (level of SSO)
- Ignores variations in product characteristics ($pH$, $a_w$, etc)
- Ignores chill chain characteristics

Shelf life loss

Spoiled products

Significant economic losses for Food Industry
“Quantitative Spoilage Assessment (QSA): a probabilistic approach for effective “expiration dating” of chilled products”

QSA components

**Spoilage Characterization**
- SSO identification
- Determination of Spoilage domain
- Determination of Spoilage level

**Spoilage Quantification**
- Model development for SSO
- Model Validation

**Chill Chain Mapping**
- Databases of temperature characteristics of the chill chain

**Self life Assessment**
- Estimation of self life distribution
- Establishment of expiration date
“Quantitative Spoilage Assessment (QSA)

**QSA algorithm**

- **Product characteristics** (Initial quality SSO, pH)
- **Chill chain characteristics**

**Applications**

- Self life
- Assessment
- and
- Expiration Date

**Spoilage level**

**Monte Carlo Simulation**

**Spoilage model**

**Outline**

- Spoilage
- Spoilage modeling
- Applications
- Spoilage modeling vs Risk Assessment
“Quantitative Spoilage Assessment (QSA)

QSA algorithm

Chill chain characteristics

<table>
<thead>
<tr>
<th>Temperature °C</th>
<th>%Refrigerators</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>18</td>
</tr>
<tr>
<td>2</td>
<td>16</td>
</tr>
<tr>
<td>4</td>
<td>14</td>
</tr>
<tr>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>8</td>
<td>10</td>
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<td>6</td>
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<td>14</td>
<td>4</td>
</tr>
<tr>
<td>16</td>
<td>2</td>
</tr>
<tr>
<td>18</td>
<td>0</td>
</tr>
</tbody>
</table>

Temperatures range from 0°C to 18°C.

Outline

Spoilage

Spoilage modeling

Applications

Spoilage modeling vs Risk Assessment
"Quantitative Spoilage Assessment (QSA)"

QSA algorithm

Spoilage Level

Normal(9.025; 0.17)

Probability

Ns spoilage log cfu/g

Outline

Spoilage

Spoilage modeling

Applications

Spoilage modeling vs Risk Assessment
“Quantitative Spoilage Assessment (QSA)

QSA output

Distribution of Shelf life

Self life (h) vs % Products

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

0 3 6 9 12 15 18 21 24
Quantitative Spoilage Assessment (QSA)

Application of QSA on ground pork

Batch characteristics
SSO initial level: 3.5 log cfu/g
pH=6.0

Self life distribution

- 4 days: 0% spoiled
- 5 days: 6% spoiled
“Quantitative Spoilage Assessment (QSA)

Application of QSA on ground pork

Batch characteristics
SSO initial level: 3.5 log cfu/g
pH=6.0

Application of QSA on ground pork

Challenge exp1

Challenge exp2
“Quantitative Spoilage Assessment (QSA)

QSA as the basis of effective shelf life management systems
Application of QSA on ground pork

**Batch characteristics**

- **batch 1**
  - pH: 5.6
  - No: 1.5 log cfu/g

- **batch 2**
  - pH: 6.0
  - No: 3.5 log cfu/g

- **batch 3**
  - pH: 6.4
  - No: 5.5 log cfu/g

Shelf life based on Challenge test: 3 days
"Quantitative Spoilage Assessment (QSA)"

Application of QSA on ground pork

Self life distribution

Batch characteristics

- **batch 1**
  - pH: 5.6
  - No: 1.5 log cfu/g

- **batch 2**
  - pH: 6.0
  - No: 3.5 log cfu/g

- **batch 3**
  - pH: 6.4
  - No: 5.5 log cfu/g

Challenge exp

Self life (days)

Shelf life based on QSA
“Quantitative Spoilage Assessment (QSA)

Application of QSA on ground pork

Batch characteristics

<table>
<thead>
<tr>
<th>Batch</th>
<th>pH</th>
<th>No: log cfu/g</th>
<th>Shelf life based on QSA</th>
</tr>
</thead>
<tbody>
<tr>
<td>batch 1</td>
<td>5.6</td>
<td>1.5</td>
<td>2 days</td>
</tr>
<tr>
<td>batch 2</td>
<td>6.0</td>
<td>3.5</td>
<td>3 days</td>
</tr>
<tr>
<td>batch 2</td>
<td>6.4</td>
<td>5.5</td>
<td>5 days</td>
</tr>
</tbody>
</table>
“Quantitative Spoilage Assessment (QSA)

Application of QSA on ground pork

Batch characteristics

\[
\begin{align*}
\text{pH: } & 6.0 \\
\text{No: } & 3.5 \text{ log cfu/g}
\end{align*}
\]

Super market chain

Various Retail stores

Outline

Spoilage

Spoilage modeling

Applications

Spoilage modeling vs Risk Assessment
“Quantitative Spoilage Assessment (QSA)"

Application of QSA on ground pork

Results from Retail Temperature Survey

<table>
<thead>
<tr>
<th>Temperature °C</th>
<th>% Refrigerators</th>
</tr>
</thead>
<tbody>
<tr>
<td>-2</td>
<td>Super Market chain</td>
</tr>
<tr>
<td>-1</td>
<td>Various Retail stores</td>
</tr>
<tr>
<td>0</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
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<td>5</td>
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<td>6</td>
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<td>7</td>
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<tr>
<td>11</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td></td>
</tr>
</tbody>
</table>

- Super Market chain
- Various Retail stores
Application of QSA on ground pork

Expiration date based on QSA

Various Retail Stores
Super Market chain

%Products
Self life (days)
"Quantitative Spoilage Assessment (QSA)"

- Estimates the distribution of product self life within the chill chain
- Allows establishment of expiration date targeted to specific batch units based on their characteristics (initial SSO level, pH, etc)
- Allows establishment of expiration date targeted to specific chill chains (retail companies)
- Exploitation of total self life of products
- Minimization of spoiled products before expiration date
"Quantitative Spoilage Assessment (QSA)"

Appropriate level of protection (ALOP)

Microbiological Risk Assessment (MRA)

Food Safety Objectives (FSO)

- Assure safety
- Improve quality
- Reduce cost due to spoilage and self life losses
Spoilage modeling vs Risk Assessment

The need of introducing spoilage modeling in Risk Assessment
Spoilage modeling vs Risk Assessment

The need of introducing spoilage modeling in Risk Assessment

- In most Microbial Risk Assessment studies published up till now spoilage is not taken into account.

- As a product approaches the spoilage point the probability to be consumed decreases.

- A realistic estimation of safety risk must include the identification of products with acceptable quality at the time of consumption.
Quantitative risk assessment for *Escherichia coli* O157:H7 in ground beef hamburgers


**Retail Storage Scenario**

**Retail Time**

Triang(4, 48, 96)

**Retail Temperature**

Triang(4, 10, 15)
Spoilage modeling vs Risk Assessment

Quantitative risk assessment for *Escherichia coli* O157:H7 in ground beef hamburgers


Retail Storage Scenario

Days of Storage in Retail vs Temperature in Retail
Retail Storage Scenario

When spoilage is not taken into account, risk is calculated based on all possible time-temperature scenarios. **Pitfall !!!**

Some products will not be consumed due to spoilage.
Spoilage modeling vs Risk Assessment

Quantitative Spoilage Assessment

Level of pseudomonads in fresh ground beef

Spoilage model

Time
Retail

Temperature
Retail

Remaining shelf life at the time of consumption

%Products

9.26% of products are spoiled before cooking

Remaining Self life at 5 °C

Remaining shelf life at the consumption time

Spoilage Level
Table 6. Mean values of consumer responses in a scale of 1 to 10.

<table>
<thead>
<tr>
<th>Knowledge and opinion of fresh packaged meat</th>
<th>Swe</th>
<th>IE</th>
<th>NL</th>
<th>GR</th>
</tr>
</thead>
<tbody>
<tr>
<td>I always find the information I need on a meat package</td>
<td>6.9a</td>
<td>8b</td>
<td>7.9b</td>
<td>7.7b</td>
</tr>
<tr>
<td>I always look at the use-by (or best before) date label</td>
<td>9.5a</td>
<td>9.5a</td>
<td>9.7a</td>
<td>9.6a</td>
</tr>
<tr>
<td>I want to able to visually check the visual freshness of the meat</td>
<td>9.5a</td>
<td>9.5a</td>
<td>9.3a</td>
<td>9.2a</td>
</tr>
<tr>
<td>I always store fresh meat in a fridge</td>
<td>8.7a</td>
<td>9.5a</td>
<td>8.2a</td>
<td>9.2a</td>
</tr>
<tr>
<td>I often freeze my meat at home</td>
<td>6.5a</td>
<td>8.2b</td>
<td>6.9a</td>
<td>8.0b</td>
</tr>
<tr>
<td>Fresh meat left out of the refrigerator loses its freshness</td>
<td>9.4a</td>
<td>9.3a</td>
<td>9.7a</td>
<td>9.3a</td>
</tr>
<tr>
<td>I always smell the meat to assess the freshness before use</td>
<td>6.6a</td>
<td>6.2a</td>
<td>4.9b</td>
<td>8.4c</td>
</tr>
<tr>
<td>I believe that temperature conditions in the chill chain</td>
<td>7.3a</td>
<td>7.2a</td>
<td>5.4b</td>
<td>8.2c</td>
</tr>
<tr>
<td>often deviate from the recommended ones</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I care about the health aspect of fresh meat</td>
<td>9.6a</td>
<td>9.3a</td>
<td>9.3a</td>
<td>9.5a</td>
</tr>
</tbody>
</table>
Spoilage modeling vs Risk Assessment

The need of taking into account spoilage in Risk Assessment

Combining data and models for both spoilage and pathogenic bacteria
Quantitative risk assessment for *Escherichia coli* O157:H7 in ground beef hamburgers


Contamination of fresh ground beef

**E. coli 157:H7**

SSO (pseudomonads)

Fig. 3: Predicted total log CFU of *E. coli* O157:H7 in a contaminated package of fresh ground beef.
Contamination of fresh ground beef

Spoilage modeling vs Risk Assessment

E. coli log cfu/g

Pseudomonads log cfu/g

-4 -2 0 2 4 6 8
Contamination of ground beef at the time of consumption (before cooking)
Containment of ground beef at the time of consumption (before cooking)

E. coli O157:H7 log cfu/g

Probability

Spoiled products
Unspoiled products
Spoilage modeling vs Risk Assessment

The need of taking into account spoilage in Risk Assessment

Ignoring spoilage in risk assessment may lead to significant overestimation of risk
Predicting the shelf life of chilled products

Kostas Koutsoumanis
Aristotle University of Thessaloniki,
Dpt. Of Food Science and Technology

thank you

Ευχαριστώ

International Workshop
Quality Management of the Chill Chain
Athens 2005