Predictive microbiology

Tina Beck Hansen
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• What is it?
• How is it done?
• What is it used for?
• How is it used correctly?
Predictive microbiology

What is it?
Prediction of microbial behaviour in food environments
The idea is not new!

• 1920’s – heat inactivation: D-, z- and F-values

• 1930’s – Scott from Australia: ... if we know the growth rates of the meat spoilage organisms, we can predict when meat is spoiled at different storage temperatures...
But it accelerated in the 1980’s...

Roberts & Jarvis (1983):

• Growth, survival and inactivation of microorganisms in foods are reproducible responses
• A limited number of environmental parameters in foods determine the kinetic responses of microorganisms
  – Temperature
  – Water activity / salt-in-water
  – pH
  – Preservatives
• Mathematical models that quantitatively describe the combined effect of the environmental parameters can be used to predict growth, survival or inactivation of microorganisms
Growth of *Brochothrix* within 10 days in 1989

10 °C

3.5 °C
Predictive microbiology

How is it done?
Using mathematical equations for description of kinetic responses of microorganisms in food
Procedure for building microbial predictive models

Primary modelling

Secondary modelling

Tertiary modelling

\[ \sqrt{\mu} = b (T - T_{\text{min}})(1 - \exp(c(T - T_{\text{max}}))) \]

\[ N = N_0 \cdot e^{\mu t} \]
# Model types

<table>
<thead>
<tr>
<th>Model type</th>
<th>Response</th>
<th>Predictor</th>
<th>Examples</th>
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</thead>
<tbody>
<tr>
<td><strong>Primary model:</strong></td>
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<tr>
<td></td>
<td>A function describing</td>
<td>Time</td>
<td>Exponential</td>
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<td></td>
<td>microbial response over time</td>
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<td>Logistic</td>
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<td></td>
<td>CFU</td>
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<td>Gompertz</td>
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<td></td>
<td>Toxin formation</td>
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<td>Baranyi &amp; Roberts</td>
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<td></td>
<td>Metabolic compounds</td>
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<td>Weibull</td>
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<td>Absorbance</td>
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<td></td>
<td>Impedance</td>
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<tr>
<td><strong>Secondary models:</strong></td>
<td>Growth rate</td>
<td>Environmental parameters (Time)</td>
<td>Polynomial</td>
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<td></td>
<td>Generation time</td>
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<td>Arrhenius</td>
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<td></td>
<td>Lag phase</td>
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<td>Square root</td>
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<td>Max. population</td>
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<td>CPM-models</td>
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<td>D-value</td>
<td></td>
<td>ANN-models</td>
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<td></td>
<td>Growth/no-growth</td>
<td></td>
<td>z-value</td>
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<td>Probability models</td>
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Validation

• Does the developed model work for real life situations?
• Comparison of observed and predicted values
• Graphical and/or mathematical
Graphical validation

Predicted values

Observed values

Fail-safe predictions

Fail-dangerous predictions

Predicted growth rate (log cfu/h)

Observed growth rate (log cfu/h)
Mathematical validation

Secondary models
(growth rates, lag times, D-values)

Bias factor ($B_f$) = 
$$10\left(\frac{\sum \log(\text{pred}/\text{obs})}{n}\right)$$

Accuracy factor ($A_f$) = 
$$10\left(\frac{\sum |\log(\text{pred}/\text{obs})|}{n}\right)$$

Illustration: Furqan Nazeeri
Interpretation of Bias factor

**B_f = 0.93**

- **B_f > 1**, faster growth
- **B_f < 1**, slower growth

**Good**: 0.95-1.11

**Acceptable**: 0.87-0.95 or 1.11-1.43

**Unacceptable**: <0.87 or >1.43
Validation – dynamic temperature profile

![Graph showing time in hours vs. temperature and L. monocytogenes counts for air and chicken.]
Tertiary modelling – available tools

https://foodrisklabs.bfr.bund.de/microbial-modeling-exchange-wiki/
Popular freeware tools

- **Pathogen Modeling Program (PMP)**
  - USA
  - [http://ars.usda.gov/services/docs.htm?docid=6786](http://ars.usda.gov/services/docs.htm?docid=6786)
  - [http://pmp.errc.ars.usda.gov/PMPOnline.aspx](http://pmp.errc.ars.usda.gov/PMPOnline.aspx)
  - >40 models (growth, survival and inactivation)
  - Available as freeware

- **ComBase**
  - UK & USA: [www.combase.cc](http://www.combase.cc)
  - ComBase Predictor: online models for growth and inactivation for mainly pathogens
  - ComBase Perfringens Predictor: online model for evaluation of safe cooling of meat
  - ComBase Browser: data for growth or inactivation of food associated microorganisms
More popular freeware tools

- **Food Spoilage and Safety Predictor (FSSP)**
  - DK: [http://fssp.food.dtu.dk](http://fssp.food.dtu.dk)
  - Time-temperature integration
  - Shelf-life, specific spoilage organisms
  - *Listeria monocytogenes*, histamine formation

- **DMRIpredict**
  - DK: [http://dmripredict.dk](http://dmripredict.dk)
  - Safety models, *L. monocytogenes*, *Clostridium botulinum*, ConFerm, *Yersinia enterocolitica*, Staphtox predictor, F value calculator
  - Shelf-life models, pork, beef and chicken cuts, minced pork, minced beef and bacon
Example and discussion of predictions

Listeria monocytogenes

<table>
<thead>
<tr>
<th></th>
<th>Generation times in hours when pH=6, salt-in-water=2 % and no additives</th>
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<tbody>
<tr>
<td></td>
<td>ComBase</td>
</tr>
<tr>
<td>At 5 °C</td>
<td></td>
</tr>
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<td>At 10 °C</td>
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<tr>
<td>At 5 °C</td>
<td>18</td>
</tr>
<tr>
<td>At 10 °C</td>
<td>6.7</td>
</tr>
<tr>
<td>At 20 °C</td>
<td>1.7</td>
</tr>
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Applications

What is it used for?
For assessment of microbial food safety and stability:
- Predicting the effect of product characteristics and storage
- Supporting HACCP systems
- Easing education and training activities
- Qualifying QMRA models
How are microbial predictive models used correctly?

The model
• Is the model validated?
  – Broth vs food
• Is it validated for the specific purpose?
  – Specific strain
  – Temperature range
  – Dynamic temperature profile

The input values
• Are the most important environmental factors included in the model?
  – Temperature, salt, $a_w$, pH, $CO_2$, others
• How are the values determined?
  – Measured vs calculated
  – Units
• Have measurements been repeated?
• How is variability of measurements included?
• How is initial count determined?
Experiment – can we predict temperature abuse from the microbiota in pork?

Pooling of carcass-swab and faeces samples

4 °C and 7 °C: chill-stored

16S rRNA gene sequencing

Predictive modelling

12 °C and 16 °C: temperature abuse

Tasja Buschhardt, 2017
Temperature driven changes in genus compositions

Tasja Buschhardt, 2017
Temperature driven changes in community compositions

PCoA as a conceptual “temperature index”, BUT variation needs to be taken into account.

Tasja Buschhardt, 2017