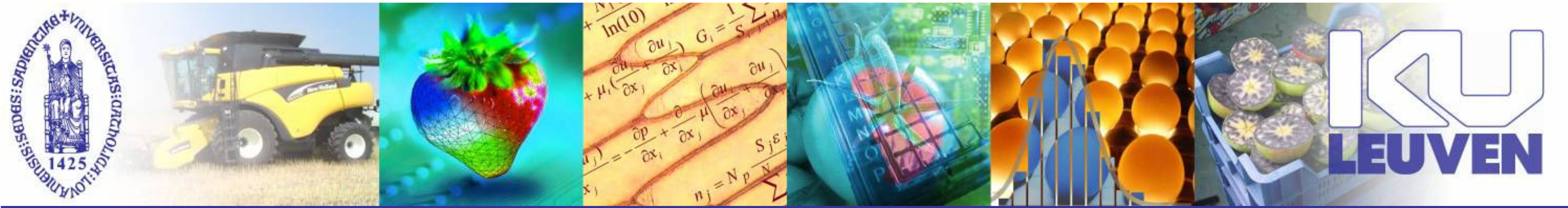

Food quality and safety modeling for assessing the impact of the cold chain

Annemie Geeraerd

Short course on Mathematical Modeling

1st IIR International Conference on Sustainability and the Cold Chain

Food quality

- Food chain management
  - guaranteeing food safety
  - satisfying consumer’ expectations
    - Taste & Flavor
    - Nutrition value
    - Color
    - Crispiness
    - …

Models for food quality indicators

- Quality indicators change as a function of conditions in the food (cold) chain
  - (Bio-)chemical reactions
  - Microbial reactions
  - Physical reactions

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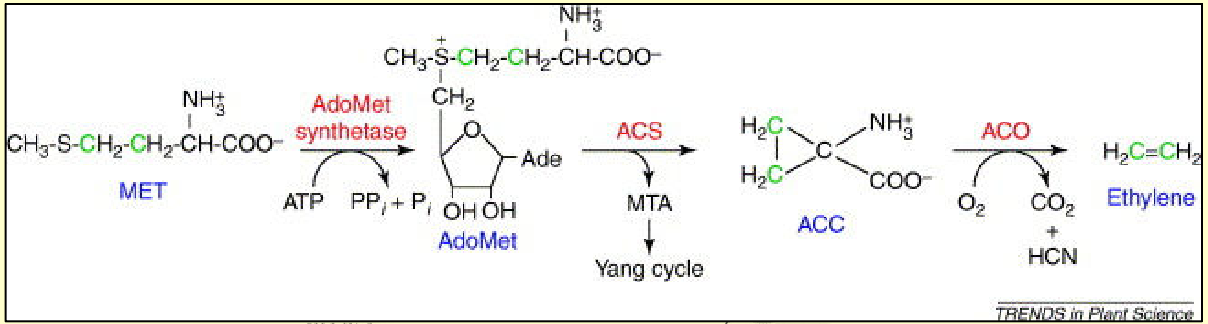
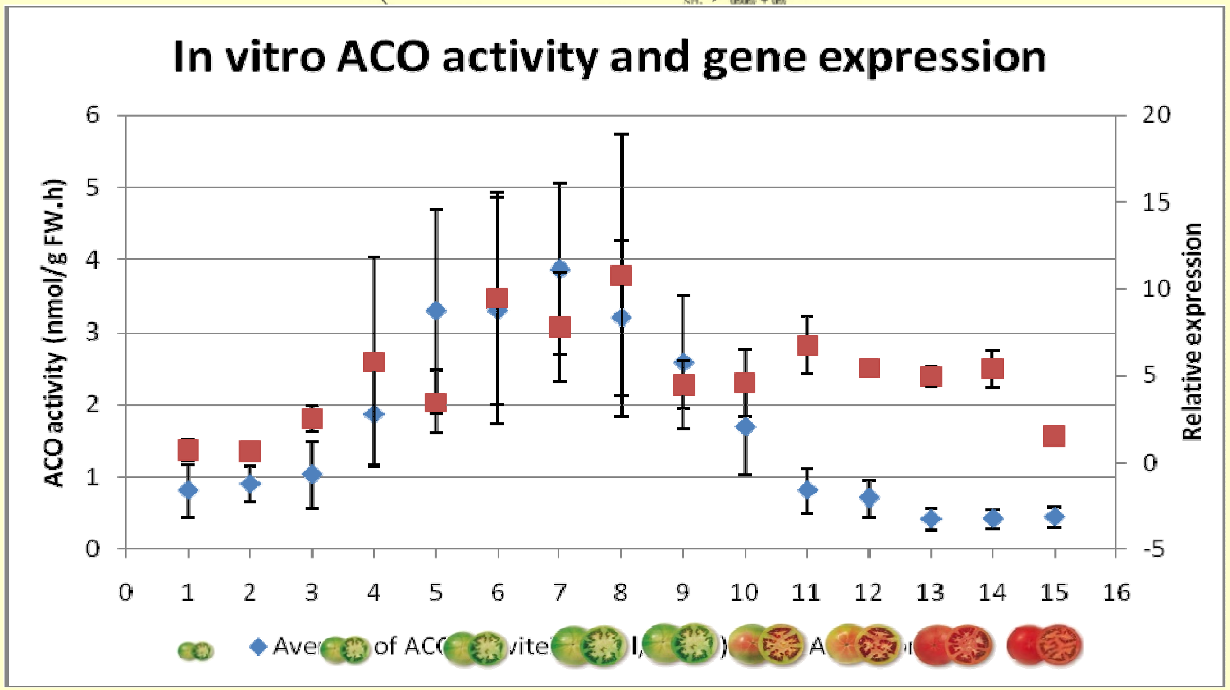
Modeling aims (1)

- Understanding (and ultimately prediction/control)





Modeling Aims (2)

- Prediction/control
  - Simplification of reality (~*semi-empirical*), but still grasping the main influences

- Types
- Kinetic models (~*movement*)
- Multivariate statistical tools (PCA, PLS)
- (Non-)linear regression
- Bayesian approaches
- …
- Deterministic/probabilistic
- Way of condensing information/knowledge on a certain topic

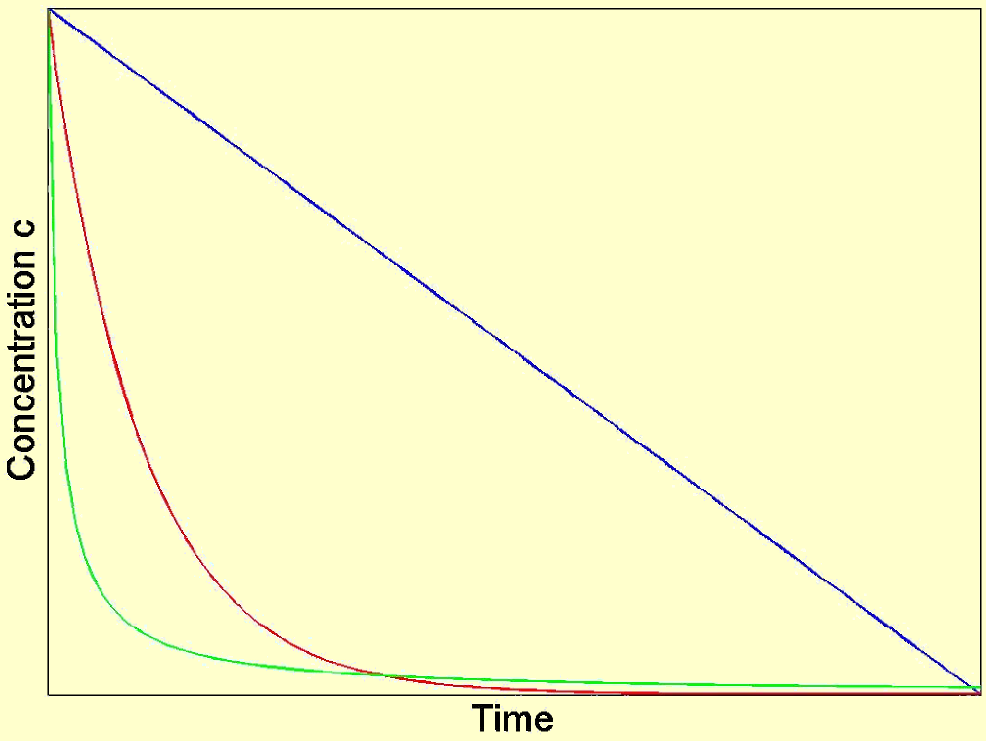
Kinetic modeling of chemical reactions

$$r = -\frac{dc}{dt} = kc^n$$

$$\frac{dc}{dt} = -k \text{ or } c = c(0) - kt$$

$$\frac{dc}{dt} = -kc \text{ or } c = c(0)\exp(-kt)$$

$$\frac{dc}{dt} = -kc^2 \text{ or } c = \frac{c(0)}{1 + c(0)kt}$$

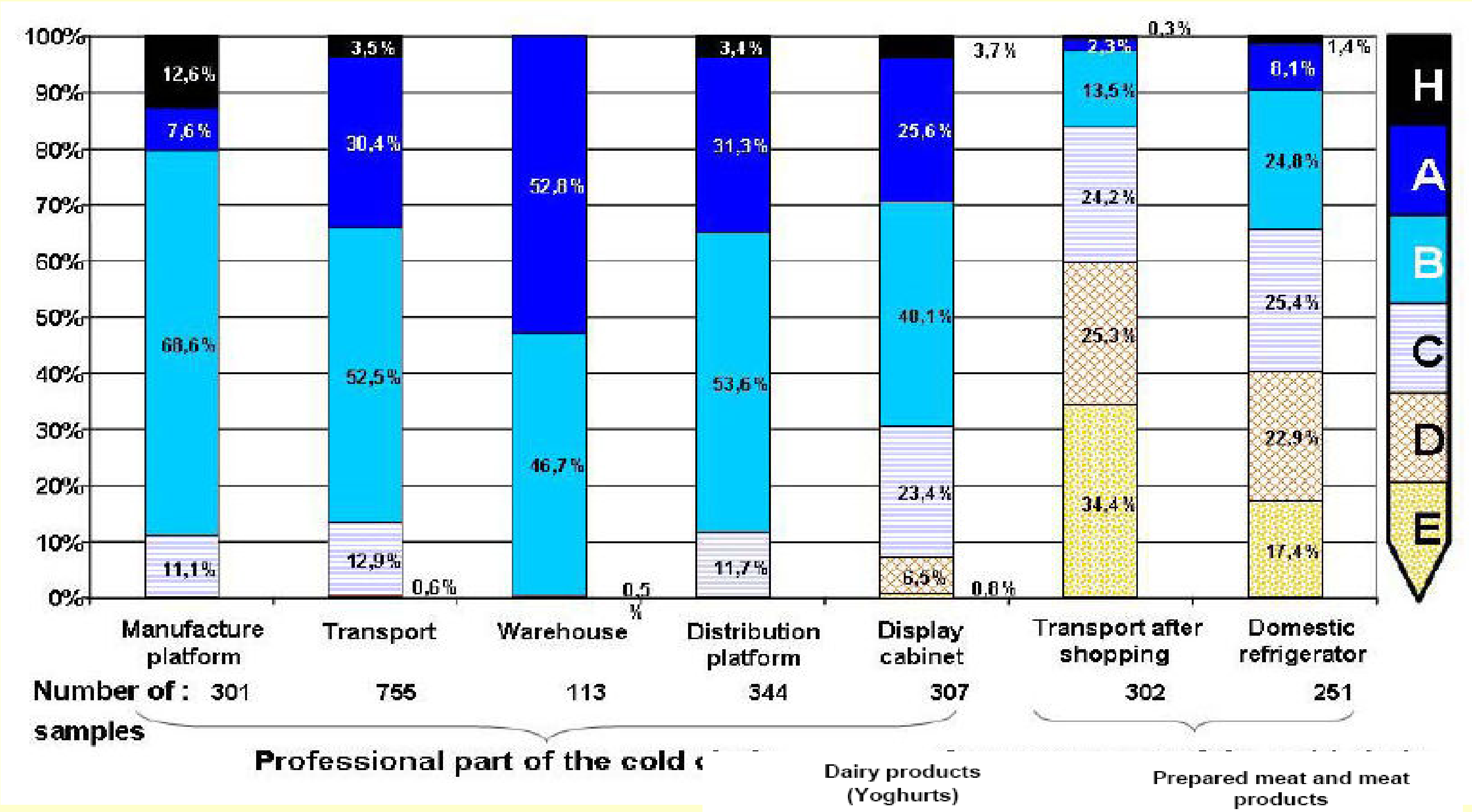


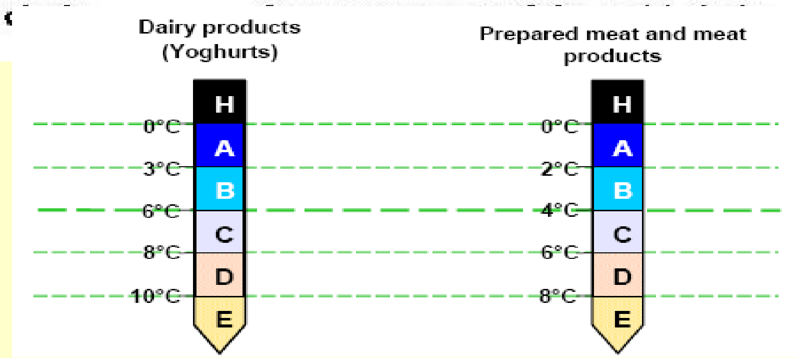
$$k = A\exp\left(-\frac{E_a}{RT}\right)$$

$$k = k_{ref}\exp\left[-\frac{E_a}{R}\left(\frac{1}{T} - \frac{1}{T_{ref}}\right)\right]$$

Simplifications, empirical when applied to real food products

Cold chain: professional/consumer part





Derens et al., 2007

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Example: predictive microbiology

- Imagine we buy smoked salmon
  - potentially contaminated with *Listeria monocytogenes*
  - generally has physicochemical characteristics supporting growth of psychrotrophic micro-organisms
  - EU 2005/2073: maximum limit of 100 cells/g at the end of shelf life
- What is the most risky consumer scenario?
  - Storing the salmon one week at 9°C at home?
  - Storing the salmon two weeks at 4°C at home?
  - After shopping, having a drink with a friend during summer for 3 hours (25°C) and subsequently storing the salmon at 4°C for one week?

What is needed for this simulation?

- A good guess of the potential outgrowth of (a representative strain of) *Listeria monocytogenes* in a salmon (with similar characteristics, like salt content, pH, …)
- A good guess of the temperature effect on the growth rate

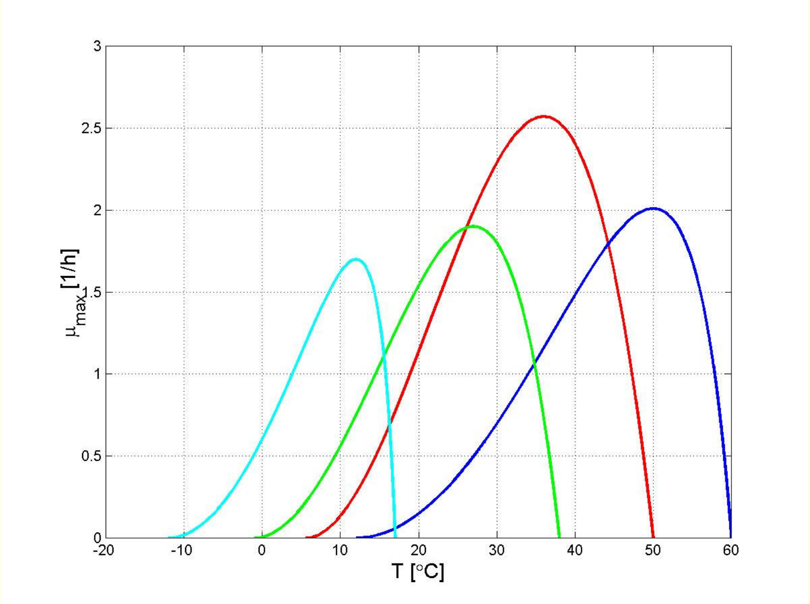
Listeria monocytogenes

Aeromonas hydrophila

Yersinia enterocolitica

Escherichia coli

Salmonella

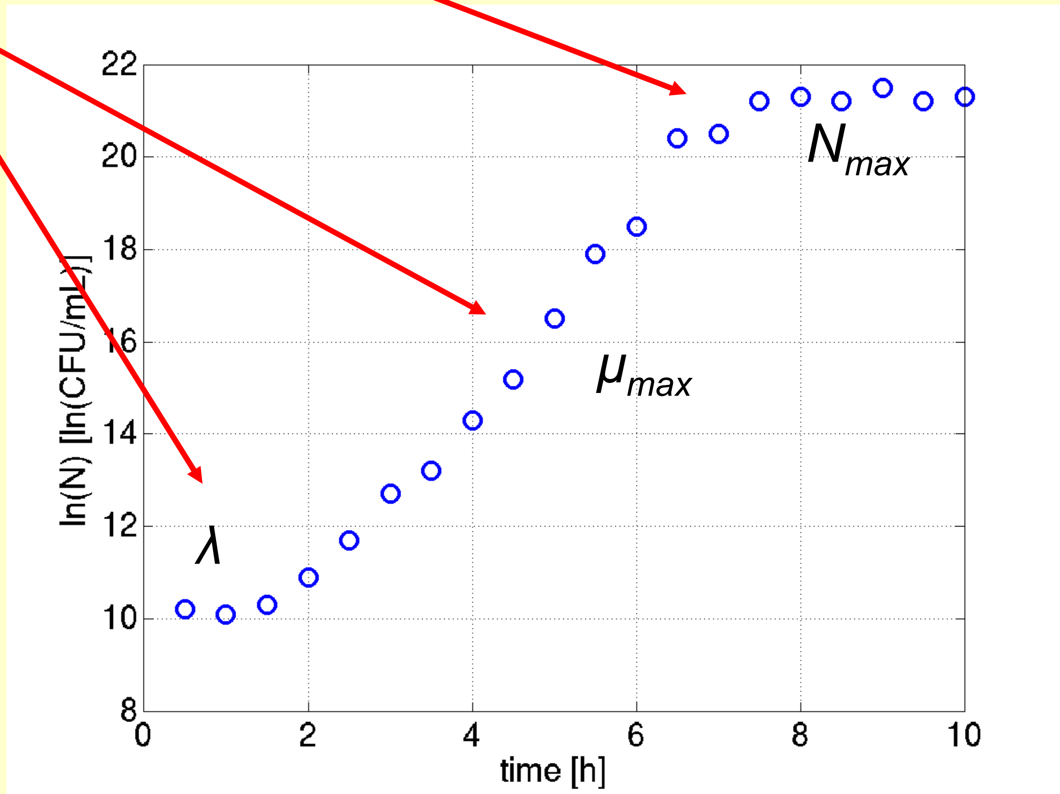


Kinetic model for growth

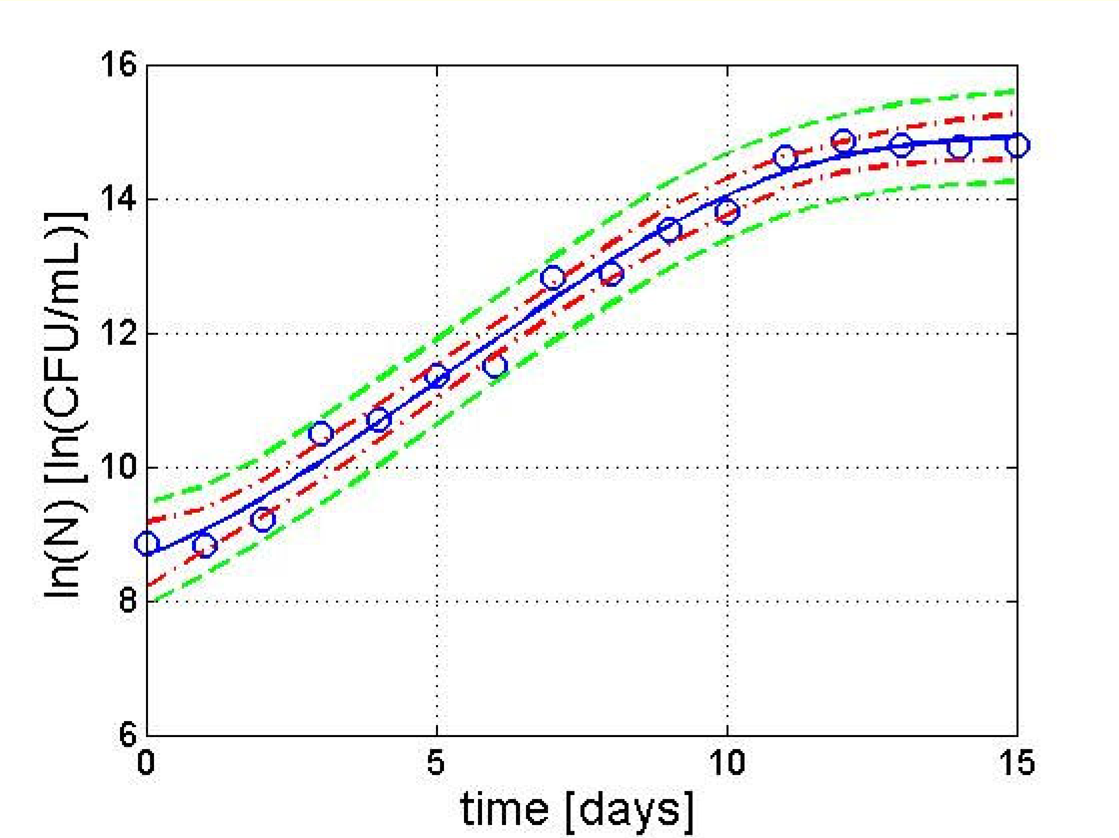
$$\frac{dN}{dt} = \mu_{\max} \frac{Q(t)}{1+Q(t)} \left(1 - \frac{N(t)}{N_{\max}}\right) N$$

$$\frac{dQ}{dt} = \mu_{\max} Q$$

Baranyi and Roberts, 1994



Growth of *L. monocytogenes*, 8°C



Cornu et al., 2006

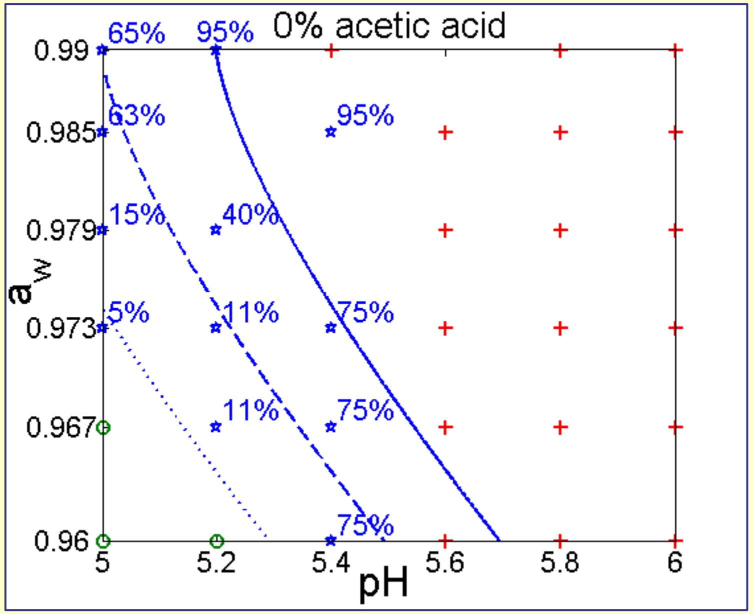
Free database of microbial responses
www.combase.cc

Growth rate in smoked salmon

$$\mu_{\max} = f(T, \mu_{opt})$$

$$\mu_{\max} = f(T, pH, a_w, \text{ MAP, lactate, nitrite, phenolic compounds, DAC})$$

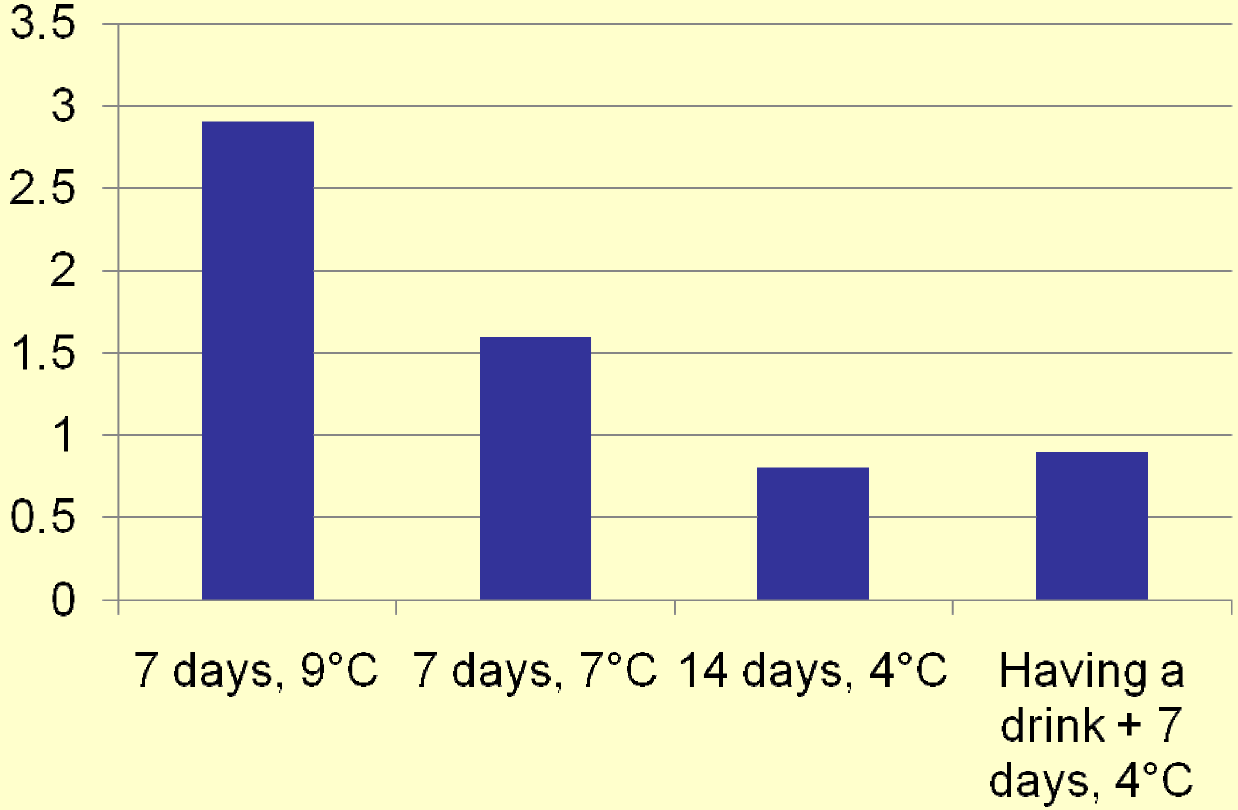
Mejlholm and Dalgaard, 2007



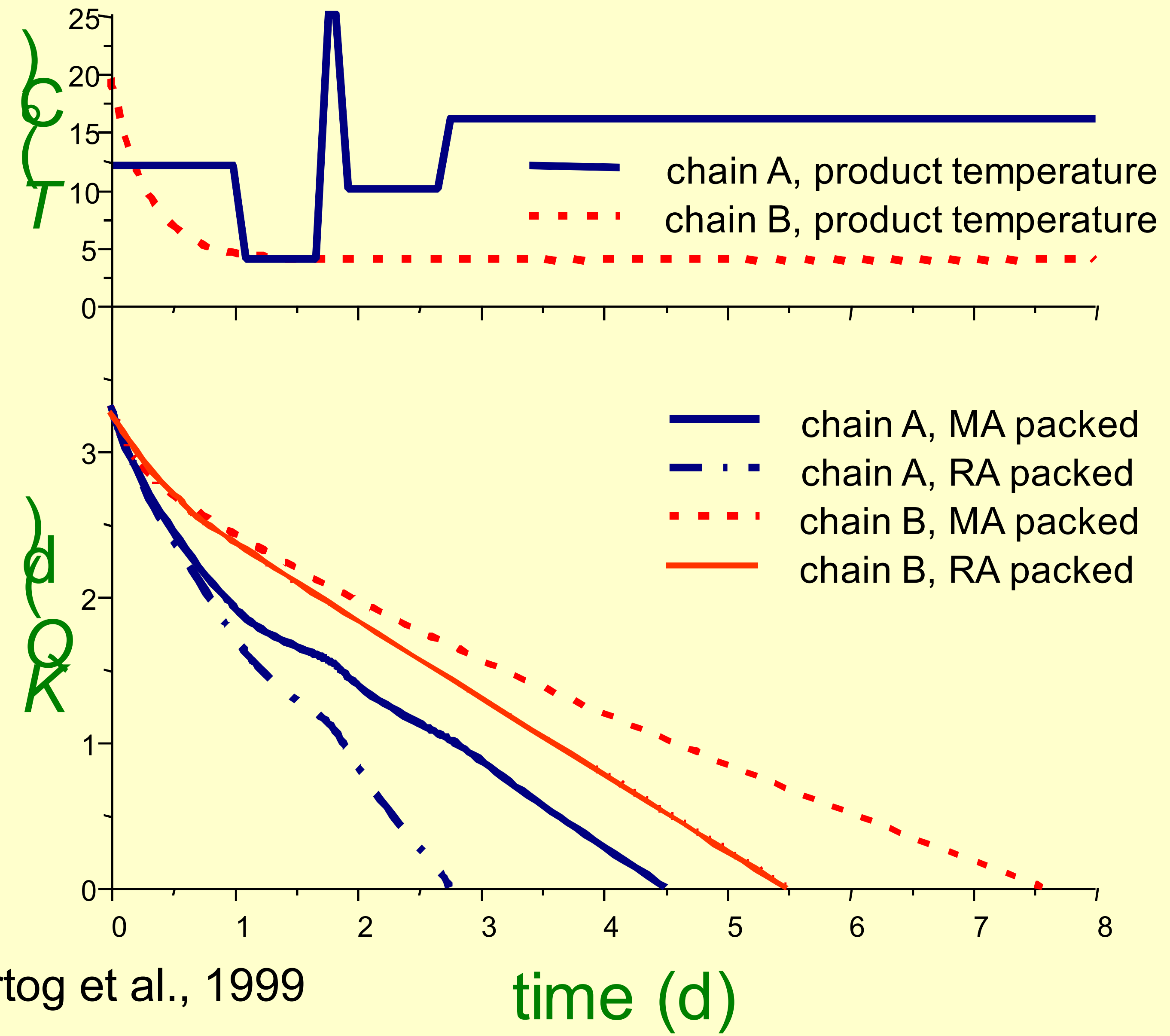
Gysemans et al., 2007

T
pH=6
a = 0.965
No MAP
0.7% water phase lactate
No nitrite
6 ppm phenolic compounds
No DAC

Growth increment [log cells/g]



Modeling Keeping Quality of strawberries



Hertog et al., 1999

Variability

- Variability represents a true heterogeneity of the population that is a consequence of the physical system and irreducible (but better characterized) by further measurements.
  - Initial status of food quality indicators
  - Differences in serving sizes between children/adults, male/female
  - Differences in temperature history
  - ...

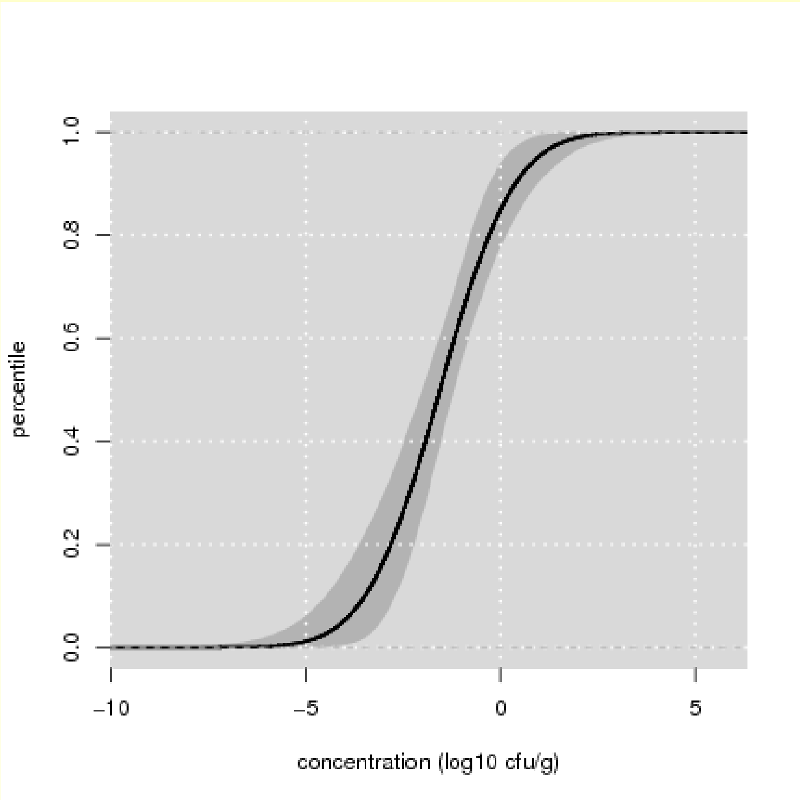
Uncertainty

- Uncertainty represents our lack of knowledge
  - Scenario uncertainty
    - Uncertainty due to necessary selection of processes to model (Descriptive errors aggregation errors, errors in professional judgement, incomplete analysis)
  - Model uncertainty
    - Uncertainty due to necessary simplification (Mis-specification of the model structure, model misuse, e.g., out of the validity range of grasping main influences)
  - Parameter uncertainty
    - Lack of perfect knowledge of a parameter value, which can be reduced by further measurements (Analytical uncertainty and sampling uncertainty)

Mokhtari & Frey, 2005

Example: Variability & uncertainty

- 103 censored measurements of *L. monocytogenes* in smoked fish



- Maximum Likelihood Estimation of a lognormal distribution
  - mean μ: -1.58 $\log_{10}$ cfu/g
  - SD σ: 1.54 $\log_{10}$ cfu/g
- bootstrap:
  - μ ~ Norm(-1.58, 0.20)
  - σ ~ Norm(1.51, 0.28)

Busschaert et al., 2010

Risk Assessment

- **Hazard Identification (⇦ epidemiology, microbiology)**

  what biological, chemical and physical agents are we dealing with and with which foods is it associated?
- **Hazard Characterization or Dose-response Characterization (⇦ epidemiology, animal/human volunteer studies)**

  what illness(es) can be caused, associated with which dose and for which population?
- **Exposure Assessment (⇦ microbiology, food technology, food consumption)**

  how likely it is that an individual or a population will be exposed to a microbial hazard and what numbers of organisms are likely to be ingested?
- **Risk Characterization**

  the integration resulting in probabilities and uncertainties/variabilities

Exposure assessment – Key questions

- Frequency and level of contamination in the raw materials
- Effects of processing/decontamination
- Re-contamination
- Primary packaging
- Effects of storage and distribution
- Consumer use (single or multiple)
- Effects of storage, usage and preparation
- Food intake

Two-dimensional Monte Carlo simulations
Bayesian approaches

Table IV. Risk Mitigation Strategies Ranked According to the Predicted Number of Listeriosis Cases Due to Consumption of Cold-Smoked Salmon in France

Risk Mitigation Strategy	Value in the Baseline Model	Rank Based on the 99th Percentile of Exposure at Consumption(13)	Rank Based on the Probability of Exposure >10^8 cfu/Serving(13)	Predicted Listeriosis Cases Compared to a Base 100 for the Baseline Model
Baseline model		1	1	100
Initial contamination: <10 cfu/g	No limit			100 [94; 100]
Effective shelf-life: 25 days	Up to 32 days			93 [56; 100]
Initial contamination: <1 cfu/g	No limit	2	2	92 [73; 99]
Mean retail temperature: N (3.6°C, 2.2°C)	N (4.6°C, 2.2°C)			80 [53; 93]
Shelf-life: 21 days	Up to 32 days			73 [27; 93]
Mean retail temperature: 4°C	N (4.6°C, 2.2°C)	5	3	67 [31; 92]
Mean retail temperature: N (2.6°C, 2.2°C)	N (4.6°C, 2.2°C)			66 [35; 87]
Consumed within 10 days after purchase	Up to 32 days			58 [18; 84]
Initial contamination: <1 cfu/50 g	No limit			55 [24; 80]
Reduced CSS consumption: 50% in increased susceptibility subpopulations				55 [54; 56]
Prevalence: 0.5 baseline model	1	7	4	50 [50; 50][a]
Mean refrigerator temperature: N (5.0°C, 3.0°C)	N (7.0°C, 3.0°C)			49 [18; 76]
Consumed within 7 days after purchase	Up to 32 days	4	5	37 [9; 67]
Mean refrigerator temperature: N (4.0°C, 3.0°C)	N (7.0°C, 3.0°C)			34 [10; 64]
Prevalence: 0.25 baseline model	1			25 [25; 25][a]
Shelf-life: 15 days	Up to 32 days	3	6	23 [4; 56]
Mean refrigerator temperature: 4°C	N (7.0°C, 3.0°C)	6	7	23 [5; 53]

[a]Note that these results are trivial according to the model, and can be directly extrapolated to other decreases in prevalence.

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Pouillot et al., 2009

Conclusion

- Good mathematical models for food quality indicators are the only feasible way for condensing knowledge into a tangible format suitable for assessing the impact of the food (cold) chain …
  - when carefully selected, tailored and validated
  - when interpreted considering
    - variability
    - scenario, model and parameter uncertainty