



ADVANCED FOOD MANUFACTURE

PROCESS AND GROWTH MODELLING

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Aims

- Introduce the concept of process and microbial growth modelling
- Explain the importance of modelling to food technologists- what can you do with models and why are they important? What are their limitations? What do the regulatory authorities say about using them?
- Review examples, from a range of process models, of model applications.

PROCESS AND MICROBIAL GROWTH MODELLING

- Conventional process optimisation is expensive and process modelling may be an alternative cost-efficient method
- Process modelling can be used to predict yield, quality, shelf life. It can potentially reduce costs and help explain problems. It can also be used to develop new products.
- Pathogen challenge testing to see if particular products might be susceptible to pathogen growth is time consuming and expensive. Use of microbial models can be an alternative rapid and cost-efficient method

Mechanics of process and microbiological models

- Models use equations whose solutions describe a process
- Two different types: Empirical and Fundamental

Empirical

- Based on observation and experimental data
- Extracts as much useful information contained in the measured data as possible
- Commonly used in the food industry

Fundamental

- Theory based
- Conversion of theories and concepts into mathematical and computer simulations.
- Data only used to calibrate / validate

ADVANTAGES OF MODELLING

- Enables the expression of knowledge in simple terms
- Reduces the cost of experimentation.
- Can extrapolate model to unexplored or unexplorable regions
- Allows alternatives to be considered which may be difficult or expensive to test
- Allows sensitivity of a process to variables, and design of optimal control strategies, to be studied.

MODELS CAN BE USED TO..

- measure the process efficiency of cheese making
- measure the quality of Cheddar cheese
- predict the shelf life of pickled beetroot and products preserved using acetic acid
- predict the stability of an emulsion
- predict the growth of spoilage and pathogenic micro-organisms
- Predict the cooking, heat transfer profile through non-uniform frozen foods

2. MODELS CAN BE USED TO..

- Optimise the quality of ice cream
- Predict the sweetness or hardness of ice cream
- Control bulk density during spray drying
- Model survival of pathogens during heat treatments
- Calculate the adequacy of sterilising-heat treatments
- Develop new cheeses
- Predict safe shelf life
- Hundreds of other uses!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!

EXAMPLES OF PROCESS MODELS

- Van Slyke equation for predicting the yield of Cheddar cheese
- Lawrence *et. al.* model for predicting the quality of Cheddar cheese
- Stokes Law to predict the conditions required for the creation of stable emulsions
- Preservation index, a model for predicting the microbial stability of pickled products

.....CONTINUED

- CIM ISCEE standard method for predicting the microbial stability of mayonnaise
- Lawrence *et. al.* model for differentiating between cheese varieties
- Shelf-life model for modified atmosphere packaging of fresh sliced mushrooms
- Predicting lactulose concentration in UHT milk

Examples of microbiological models

- ComBase - a Combined database for predictive microbiology <http://www.combase.cc/index.php/en/>
- Pathogen Modeling Program---
<http://www.ars.usda.gov/Services/docs.htm?docid=6803>
--Predicting and improving the microbiological safety and quality of foods
--Designing, producing and storing foods economically
--Assessing microbiological risk in foods.



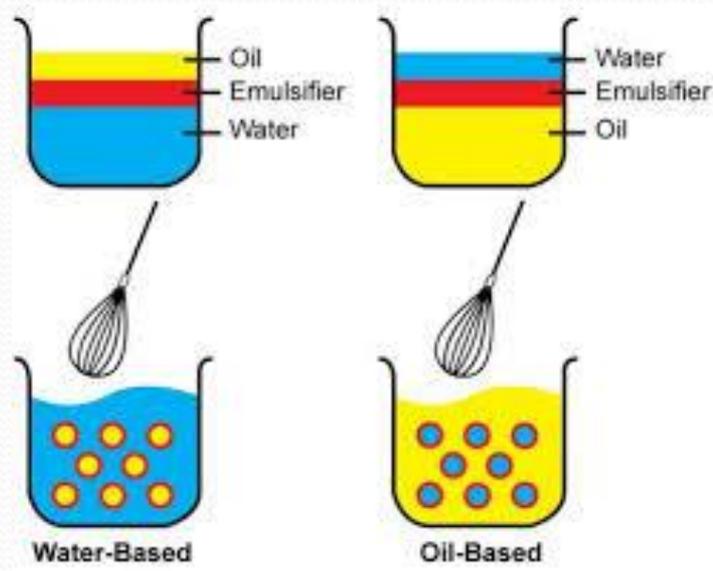
Explore ComBase

PROCESS MODELLING

Look at how two simple models can be applied

- Stokes Law
- Preservation Index

Types of emulsion



EMULSION TECHNOLOGY & STOKES LAW

What is an emulsion?

- System containing at least 2 immiscible liquids, a *dispersed* phase in a *continuous* phase e.g. oil in water
- Emulsion types
 - water in oil (w/o) – butter, margarine
 - oil in water (o/w) – milk, mayonnaise, ice cream
- Prepared by vigorous mixing so that very small *droplets* of the disperse phase form
- Emulsions are unstable systems prone to creaming because of the density difference between the phases.

STOKES LAW

The rate at which an isolated spherical particle creams in an ideal liquid is determined by the balance of forces which act upon it

Stokes Law

$$v = \frac{2r^2 (\delta_1 - \delta_2) g}{9\eta}$$

v = particle velocity (ms^{-1})

r = particle radius (m)

δ_1 = density of aqueous phase (kgm^{-3})

δ_2 = density of fat phase (kgm^{-3})

g = acceleration due to gravity (ms^{-2})

η = viscosity of continuous phase (Nsm^{-2})

Rule of thumb

An emulsion in which the creaming rate is less than about 1mm / day can be considered to be stable against creaming



Using Stokes Law predict factors required for maximum emulsion stability

Class discussion

STABLE EMULSIONS

- Droplet diameters are small ($< 1\mu\text{m}$) ideally greater than 98% $< 0.8\mu\text{m}$
- Densities of the two phases are close
- Viscosity of continuous phase is high

Processes leading to instability are creaming, flocculation, coalescence and phase inversion

Creaming

- Droplet density < continuous phase density
~ droplets rise

So???????????

- Reducing droplet size increases stability of the emulsion

Phase Inversion

- Can occur if volume of dispersed phase is high (concentrated system e.g. mayonnaise) and system is destabilised
- In more dilute emulsions following the separation of cohesive cream layer. O/w forms at top

Flocculation

- In dilute systems discrete clusters of droplets
- In concentrated systems may develop semi continuous floc structure (weak gel)
- Easily broken down by mixing

Coalescence

- Droplets merge to form larger globules and eventually free oil appears
- Reducing continuous phase viscosity causes continuous phase between droplets to thin and reach critical thickness

EMULSION FORMATION

- Energetic and dynamic process
- Fine emulsions produced by bringing liquid up to pressures of the order $7 \times 10^3 \text{ kPa}$ then discharging pressure suddenly by expansion through a small gap or nozzle - homogeniser
- On passing through the nozzle very large shear forces are exerted on the liquid
- Pressure drop across the homogeniser valve effects droplet size

Quality of Food Emulsion

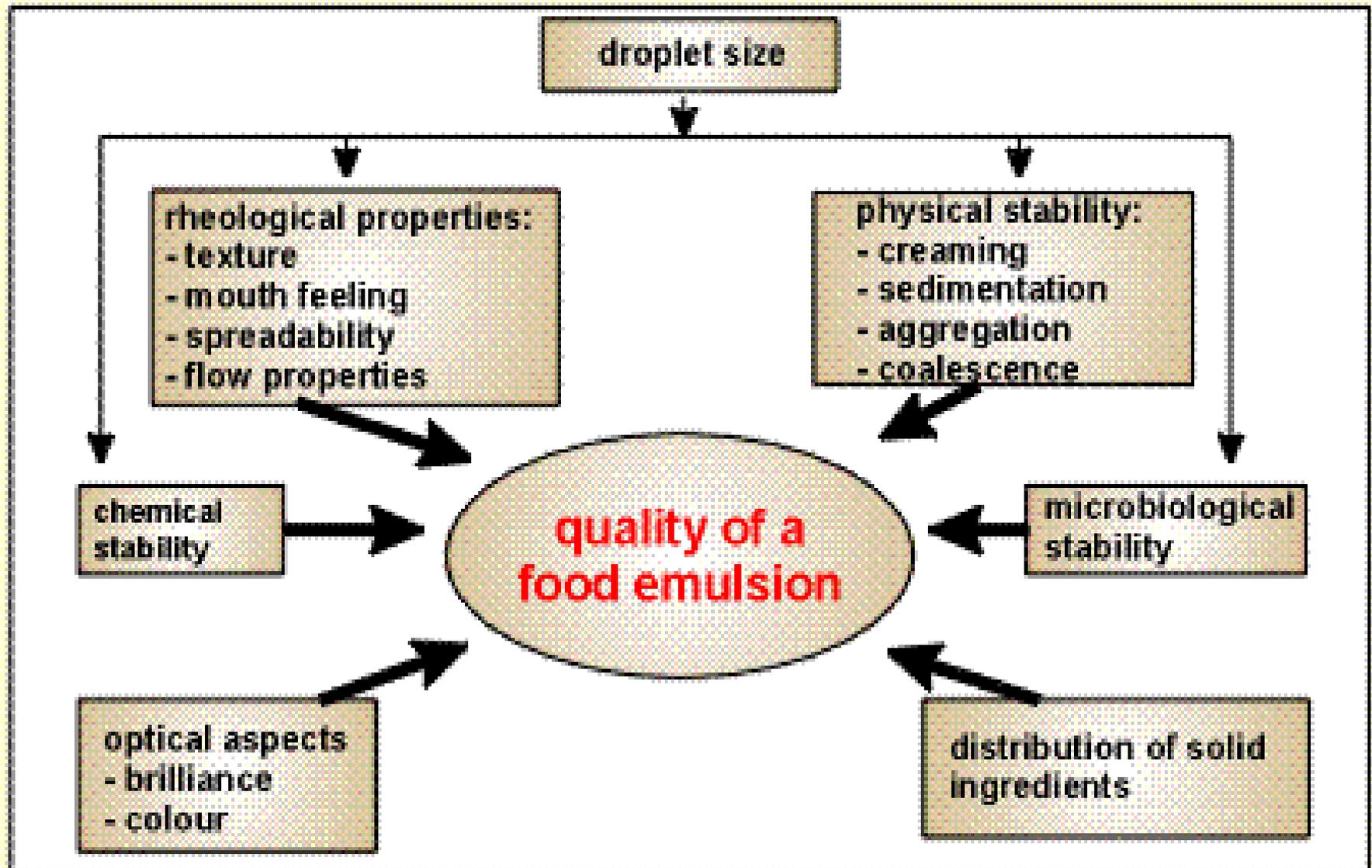


figure 3

EMULSIFIERS

- Substances which orientate themselves at the interface between oil and water and prevent oil droplets from coalescing to form larger droplets which rise more rapidly
 - lecithins, egg yolk, whey proteins, GMS
- Glycerol monosterate (GMS)
 - hydroxyl group – hydrophilic
 - sterate group – hydrophobic
 - Completely surrounds droplet preventing coalescence

HYDROPHILIC - LIPOPHILIC BALANCE (HLB)

- Each emulsifier is assigned a HLB value expressing the balance between number and strength of its polar as compared to its non-polar groups
- It is an indication of its emulsifying action and although not conclusive can help to narrow down choices

STABILISERS

- Substances with ability to absorb water and form gels - increasing the *viscosity* of the continuous phase
- gums, cellulose derivatives, gelatine

THEORETICAL STABILITY PREDICTION REQUIRE...

densities of dispersed & continuous phases

(density bottles, hydrometers, oscillating U tube meters)

droplet size distribution, diameters $< 1\mu\text{m}$ are generally stable. Ideally $> 98\%$ should be $< 0.8\mu\text{m}$ (microscopy, light scattering, electrical pulse counting)

rheological properties of continuous phase

(viscometers, dynamic shear rheometers)

ACCELERATED PREDICTION METHODS

- Kinetics of emulsion stability can be established by measuring the rate at which particle size increases with time
- Centrifuging an emulsion at a fixed speed for certain length of time
 - observe amount of creaming /oil separation
- Mechanical agitation, measure degree of droplet coalescence as
 - function of time at constant speed
 - function of speed for certain time

USING STOKES LAW EXPLAIN

- Why is double stage homogenisation better than single stage homogenisation?
- The basis of the 2 methods mentioned for accelerated shelf life testing of emulsions?

Preservation Index

Empirical measure of level of preservation existing in some pickled foods.

$$\text{P.I.} = \frac{\text{total acetic acidity}}{(100 - \text{total solids})} \times 100$$

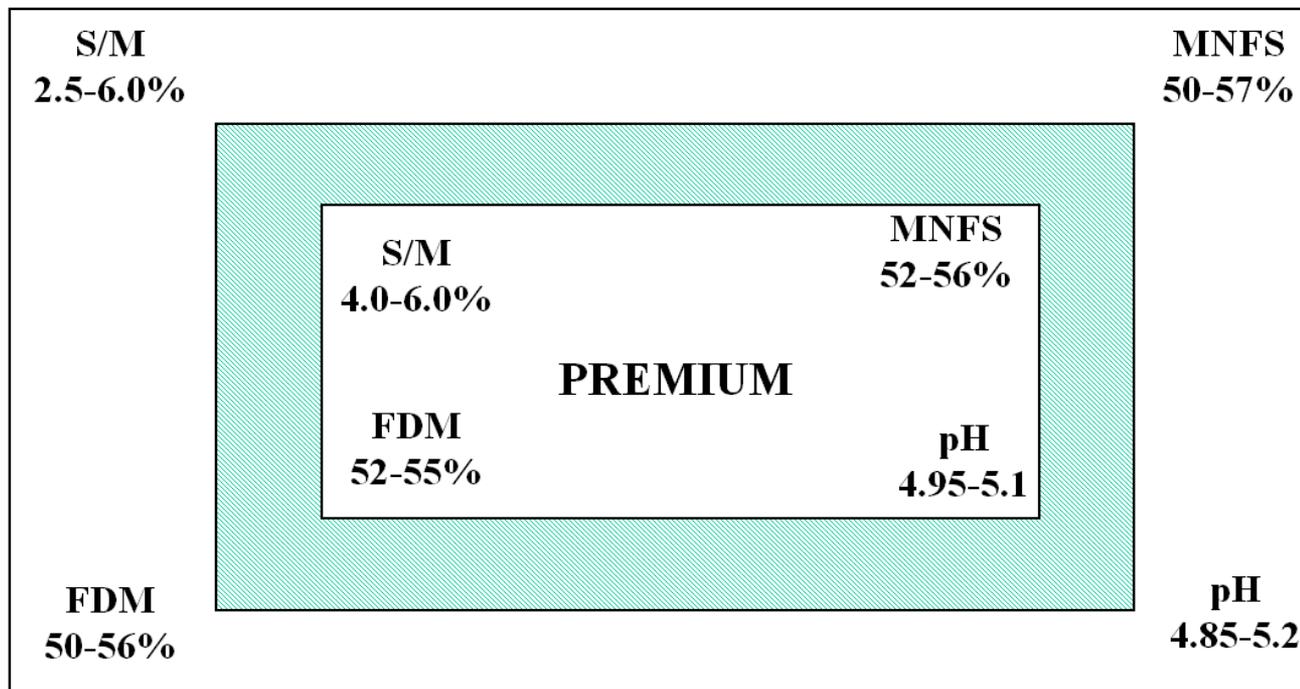
Value > 3.6% give products which are unlikely to allow growth of spoilage organisms.

Monilliella acetobutans

Using Preservation Index

- If value $< 3.6\%$ how would you increase the value?

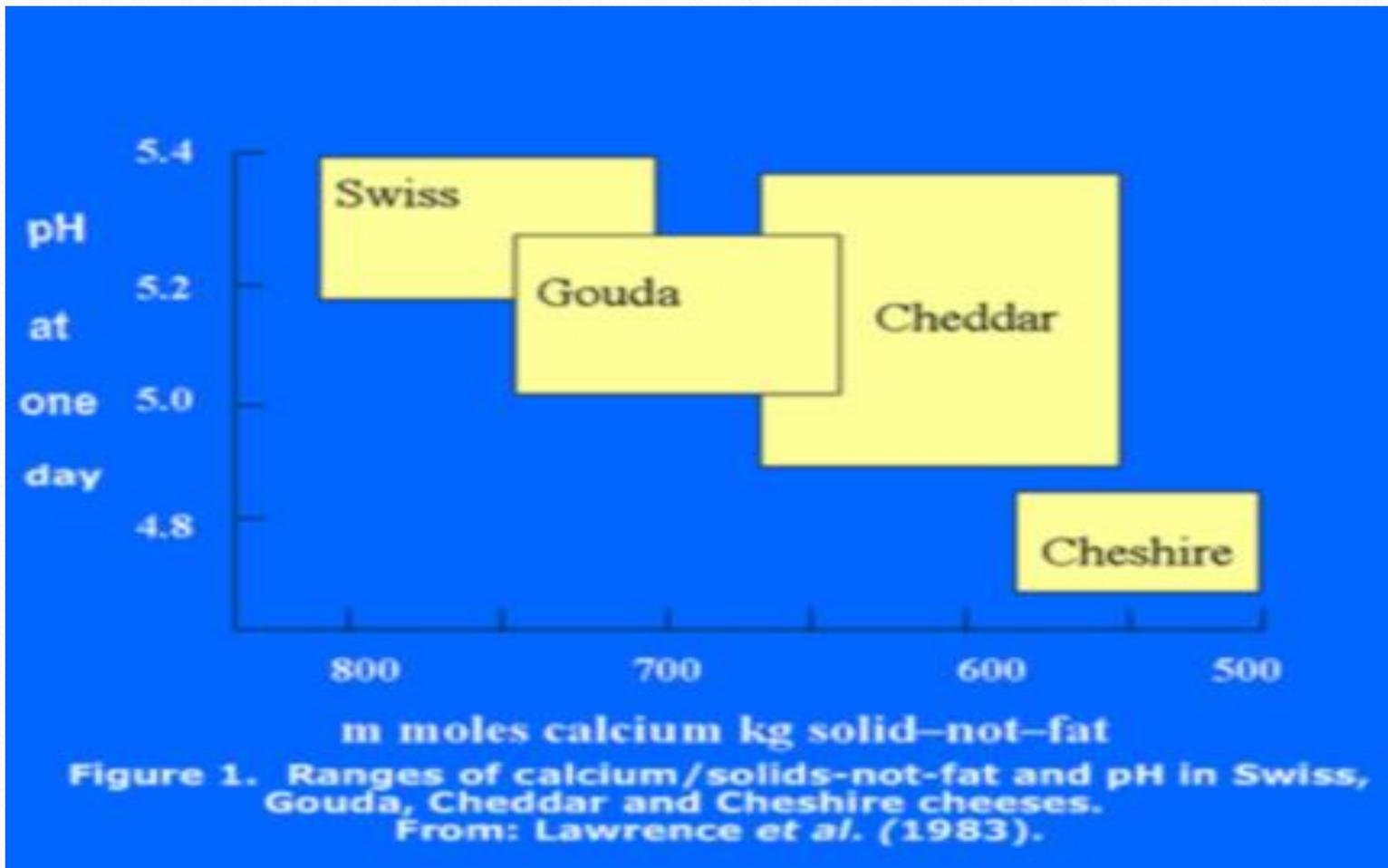
Predicting the grade value of Cheddar cheese



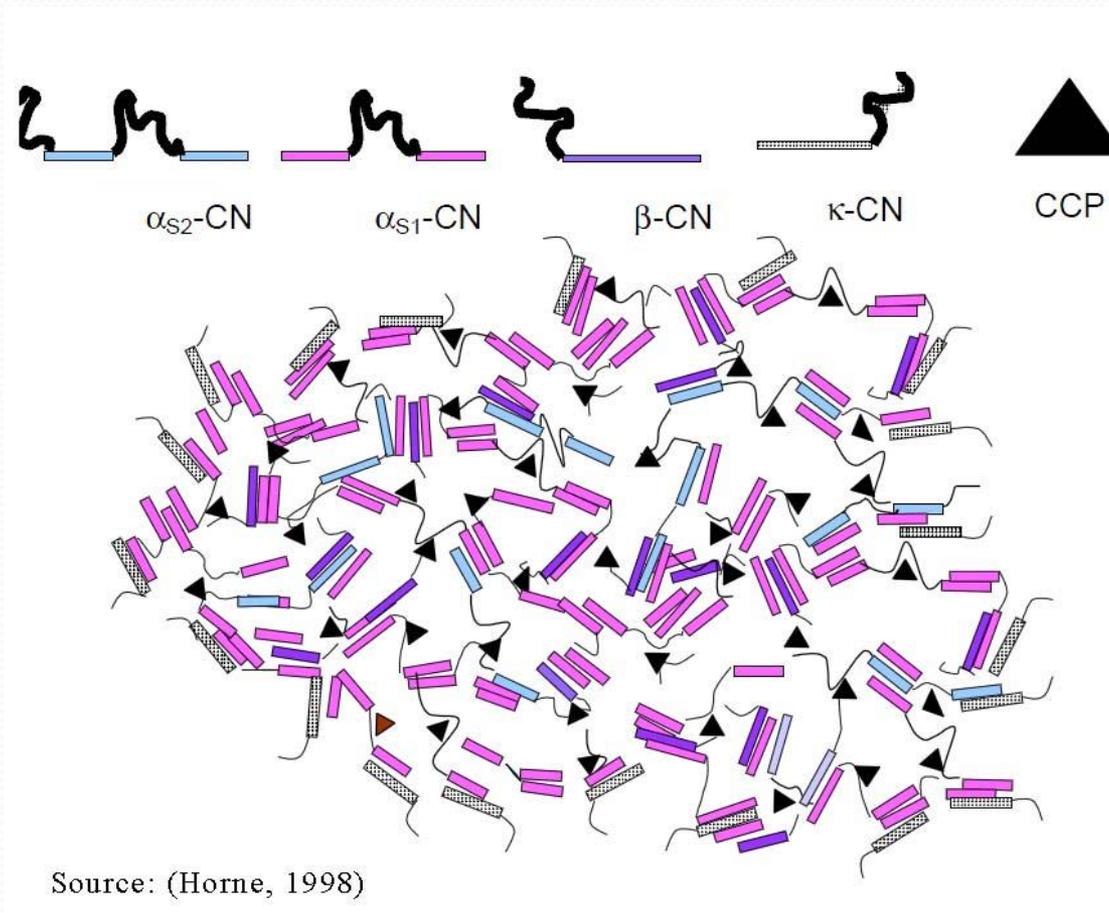
NOTES: Predictive model for Cheddar cheese developed by Lawrence et al. (1984)

 Graded Quality

Why are cheeses different?



Structure of casein micelle



Further reading

- Dairy Science and Food Technology website
 - <http://www.dairyscience.info/index.php/food-model.html>
 - <http://www.dairyscience.info/index.php/calculators-models.html>
 - Mullan, W.M.A. (2012). Thermal processing of acid fruit and vegetable products. Significant microorganisms, recommended processing time / temperatures, and public health significance of spoilage. Report available from: <http://www.dairyscience.info/index.php/thermal-processing.html>.