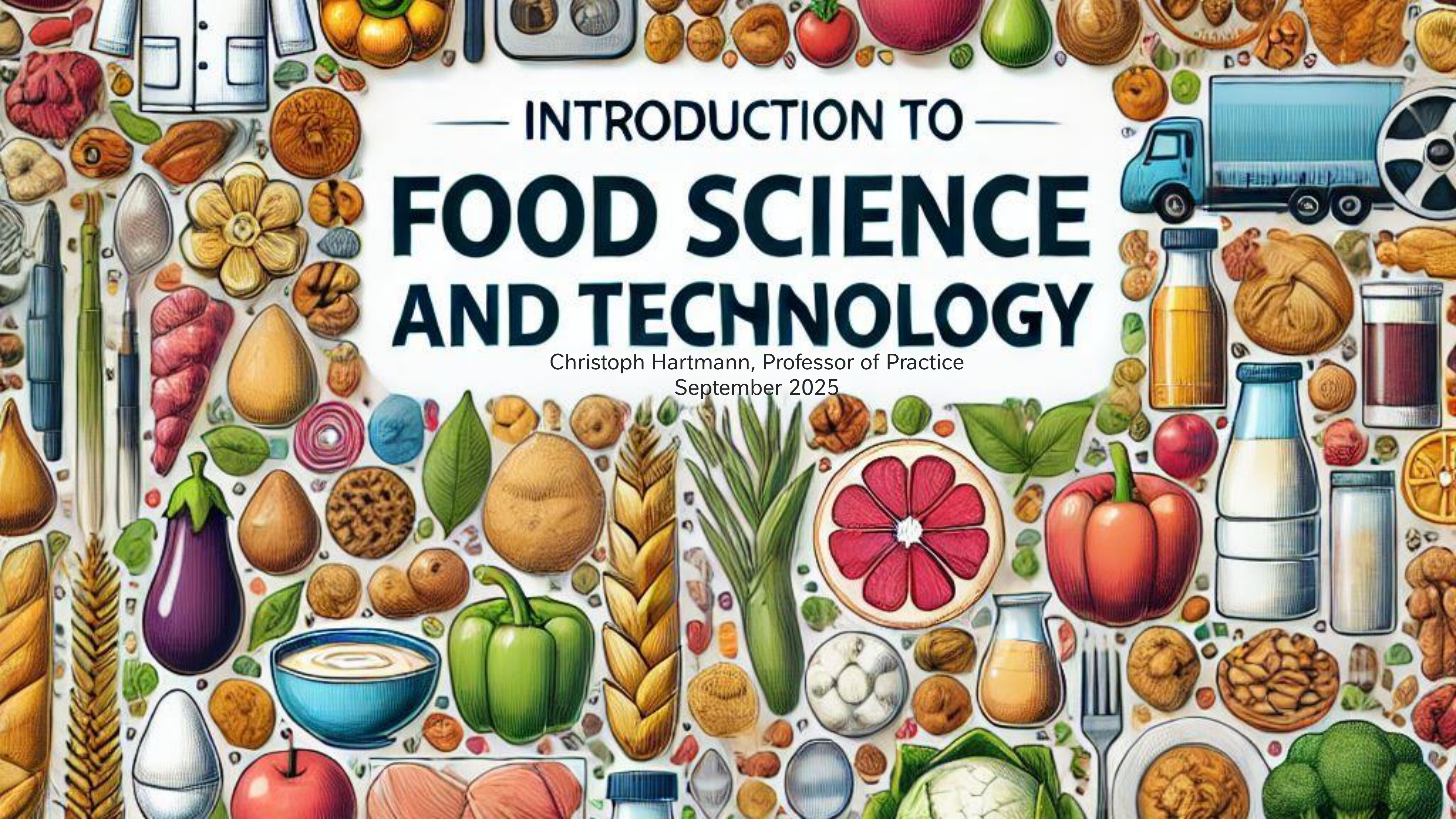


Christoph Hartmann, Professor of Practice
September 2025

Biography

- Born 1967, German and Swiss Nationality
- Dipl.-Ing. Mechanical Engineering,
- PhD in Computational Fluid Dynamics
- Habilitation in Biomechanics
- Professor in Materials Science, German Univ. Cairo
- Since 2006 in Nestlé R&D
  - Biophysics of Sensory Perception
  - Food Materials Science
- Since Nov 2019 Honorary Professor at TU Berlin
- Since March 2025 Professor of Practice at EPFL
- Hobbies: Family, Triathlon, Piano

TECHNISCHE UNIVERSITÄT DARMSTADT

Technische Universität München

GUC German University in Cairo
الجامعة الألمانية بالقاهرة

Nestlé Research and Development

Technische Universität Berlin

EPFL

Introduction to Food Science and Technology – General Aspects

- 2 hours lecture per week per semester
- 1 homework (ca. 10 hours)
  - Literature review and executive summary on a topic of current research, < 5000 words
  - Examples: sustainable packaging materials, cost of nutrition, ultra-processed food: myths and truth

- 1 Excursion to Nestlé Research
- Oral examination of 30-40 minutes duration
- 4 credit points

A First Reflection on Food and its Value

The food does not just appear on the table. A whole system is involved in overcoming and coordinating space and time so that the food can be consumed "just in (meal) time." And the cleaning and waste must also be organized.

Dr. Ulrich Oltersdorf

Ernährungsdenkwerkstatt

http://ernaehrungsdenkwerkstatt.de/home.html

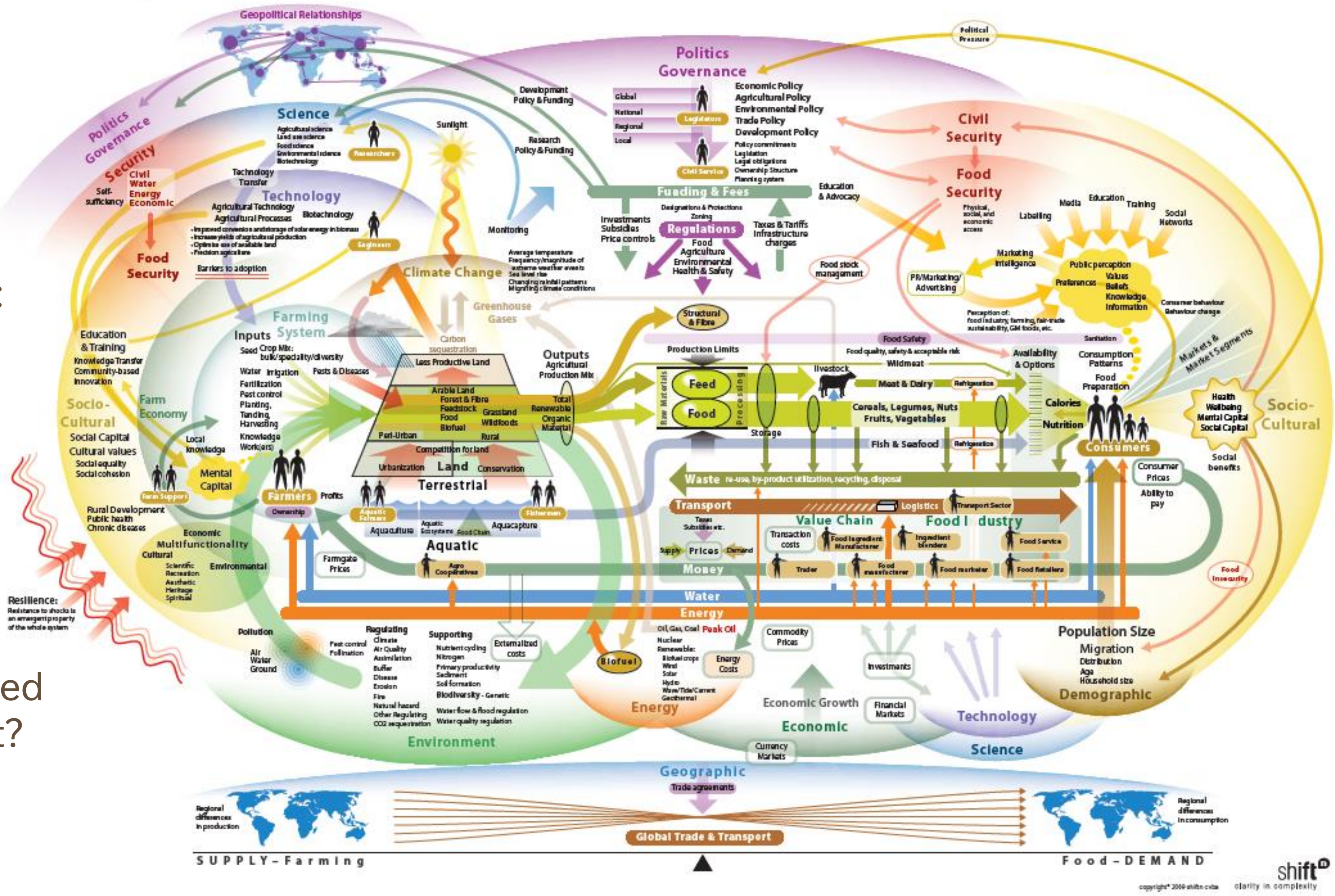
Challenges of the food system – Primary production

Food System

- provides our daily nutrition
- bridges between time & location:
  - of food supply and
  - of food demand

Imagine your breakfast today

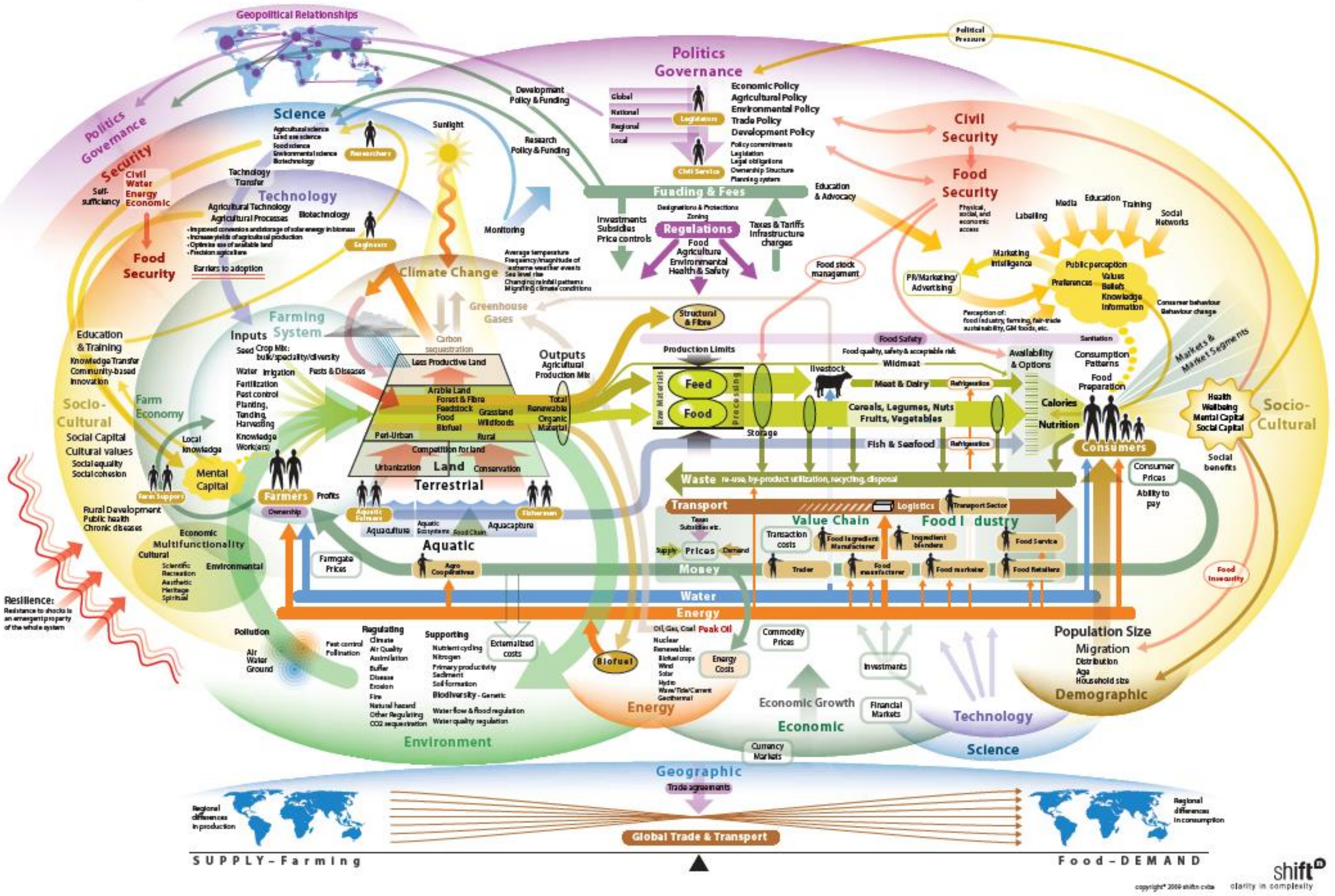
- Where & when were its components produced?
- How was the process synchronized to get your breakfast ready to eat?
- How important was this synchronization for you?



2016 Garnett, Benton, Nicholson, Finch. Overview of food system challenges (Foodsource: chapters). Food Climate Research Network, U. of Oxford

Challenges of the food system – Demographic megatrends

1. Population growth, urbanization, ageing
2. Economic growth, investment, trade & food prices
3. Competition for natural resources
4. Climate change
5. Agricultural productivity & innovation
6. Transboundary pests & diseases
7. Conflicts, crises & natural disasters
8. Poverty, inequality & food insecurity
9. Nutrition & health
10. Structural change & employment
11. Migration & agriculture
12. Changing food systems
13. Food losses & waste
14. Governance for food & nutrition security
15. Development finance



2017 FAO, Future of Food and Agriculture
2016 Garnett, Benton, Nicholson, Finch. Overview of food system challenges (Foodsource: chapters). Food Climate Research Network, U. of Oxford

Traditional Values of Food

We appreciate of food because it is of value to us. Value can be classified into categories:

Hedonic value	How much do I like this food?
Health risk (Food Safety)	How safe is it for consumption?
Convenience	How easy is it to prepare & consume the food ?
Availability in time & space	How easy is it to get this food ?
Cultural value	How much is this food related to (my) culture?

Research and Development

Value of Food

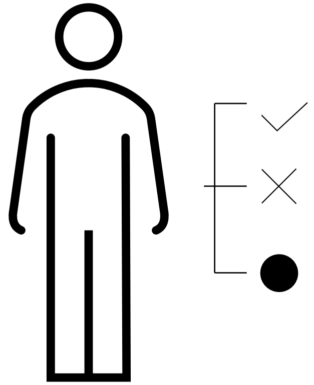
We appreciate of food because it is of value to us. Value can be classified into categories:

Hedonic value	How much do I like this food?
Nutritional value	How good is quality & quantity macro- & micronutrients?
Health value	How much does this food improve my health (beyond nutrition)?
Health risk (Food Safety, Allergies)	How safe is it for consumption?
Convenience	How easy is it to prepare & consume the product?
Availability in time & space	How easy is it to get this food?
Social value	How good is the impact of my consumption on society, on my relationship with others?
Cultural value	How much is this food related to (my) culture?
Ecological impact	How does this food help protect the environment?

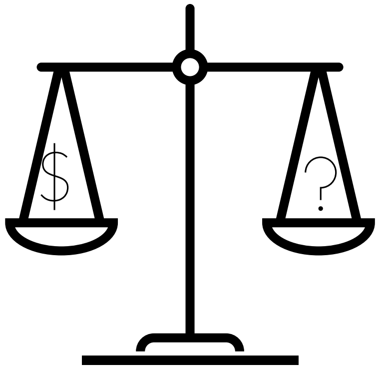
Value of food

- Hedonic value
- Nutritional value
- Health value
- Health risk (food safety)
- Convenience
- Availability in time & space
- Social value
- Cultural value
- Ecological impact

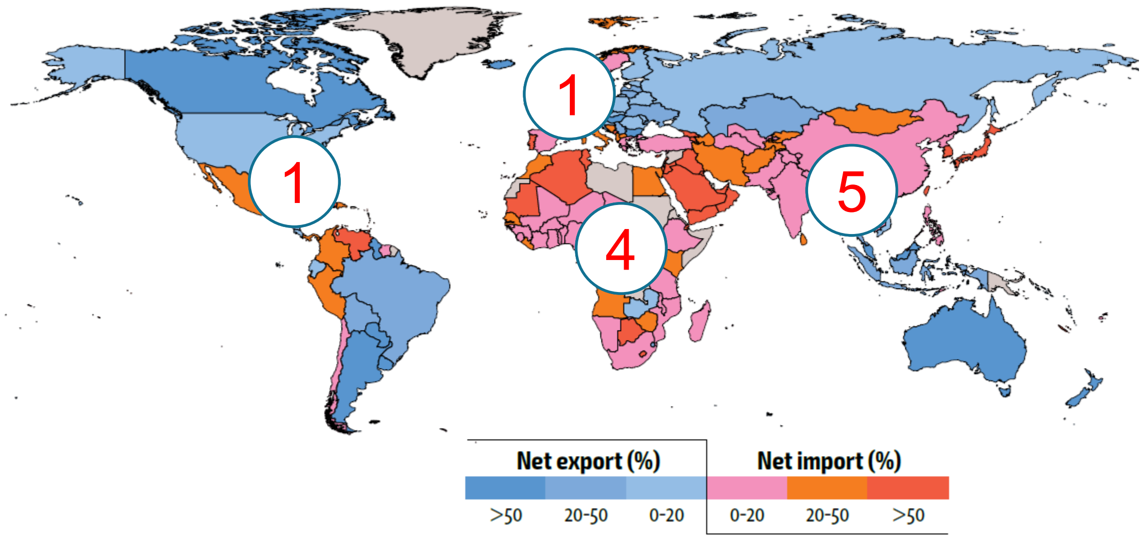
Drive our decision making when we choose food



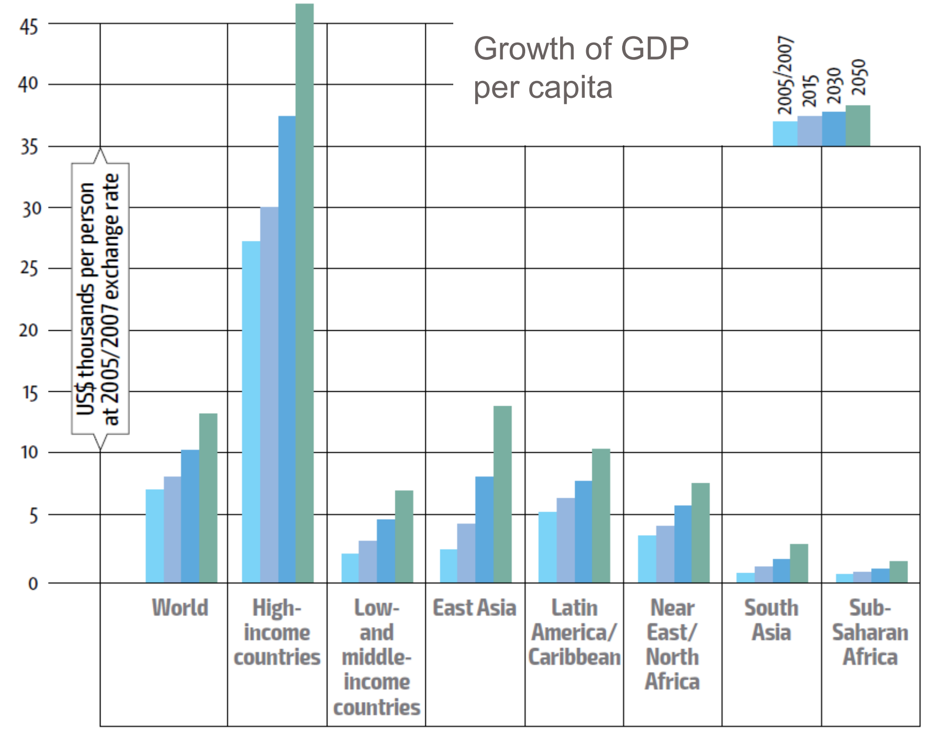
Are compared to and exchanged against a monetary equivalent: the selling price



Undernutrition in Areas of Population Growth



Source: FAO Global Perspectives Studies, using 2011 food balance sheets from FAO, 2016a.

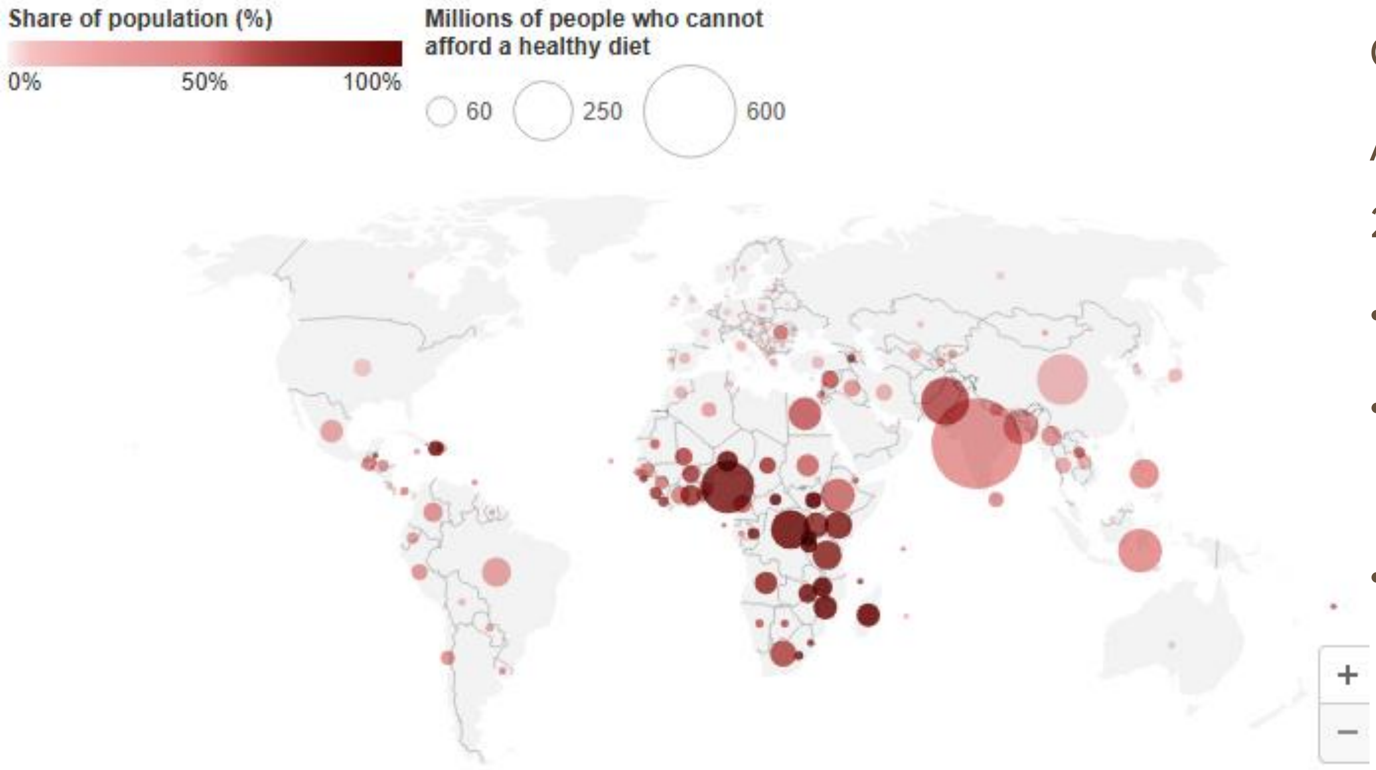


Note: Regional groups do not include high-income countries.
Source: Data for 2015 are based on FAO Global Perspectives Studies (unpublished data); data for 2005–2007, 2030 and 2050 are based on Alexandratos and Bruinsma, 2012.

- Highly populated areas depend on food import
- Food productivity increase challenging
  - Population growth rate
  - Climate change, soil depletion, water scarcity, environmental pollution
- Small increase of purchase power in areas of high population growth
- Undernourishment remains critical notably for micronutrients, protein

Cost of calory sufficient diets and healthy diets

Population who cannot afford a healthy diet, 2024



[Food Prices for Nutrition DataHub: global statistics on the Cost and Affordability of Healthy Diets]

Cost of healty diet increases to 4.5 PPP dollars

About 2.6 bio people in 2024 (- 48.8 mio since 2023)

- Lack protein, micro-nutrients, fibers
- Mainly source calories from cereals, roots and tubers
- **Income vs. cost**: Global income growth helped offset rising food costs, improving affordability in many regions

Research and Development

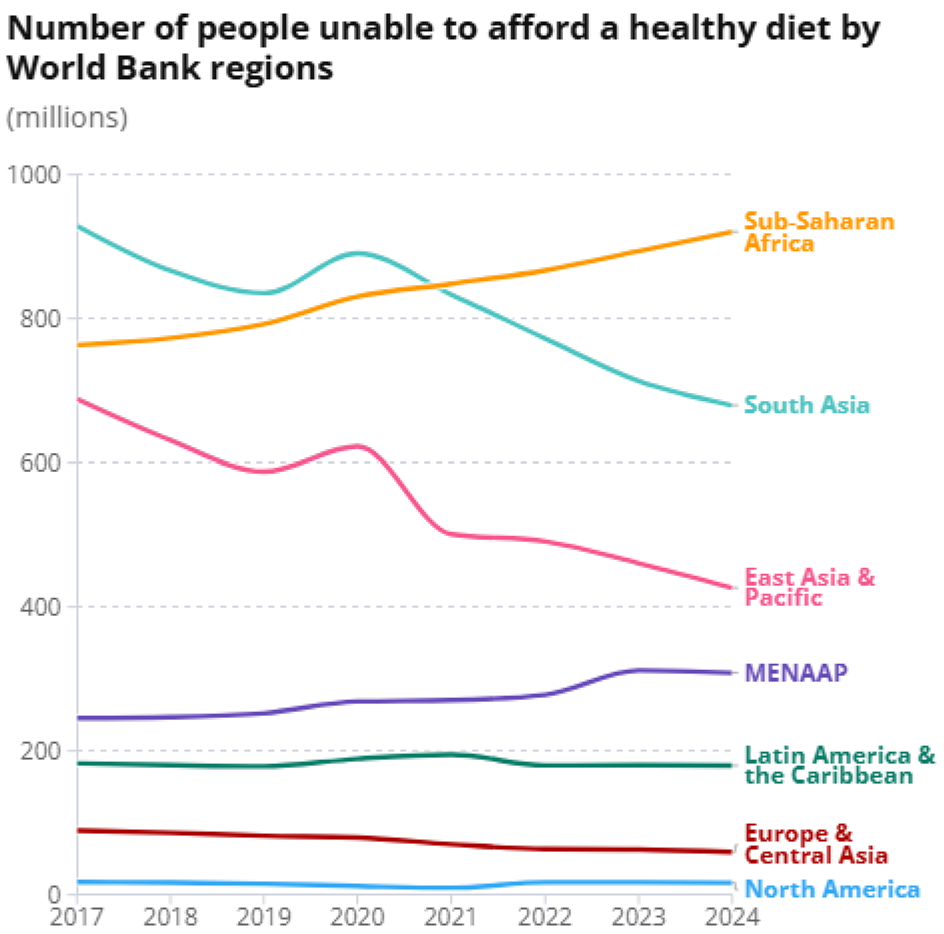
Cost of calory sufficient diets and healthy diets

However, global averages mask regional disparities

- •Sub-Saharan Africa and MENAAP* worsening despite global improvement
- •Food inflation in these regions has eased only marginally, leaving diet costs near record highs

Food Group	Global Avg Cost ($/day)
Animal-sourced foods	$1.00
Vegetables	$0.76
Fruits	$0.67

*MENAAP: Middle East & North Africa, Afghanistan, Pakistan



Haishan Fu et al. 2025, retrieved from: Can everyone afford to eat healthy? New data show progress, but not everywhere

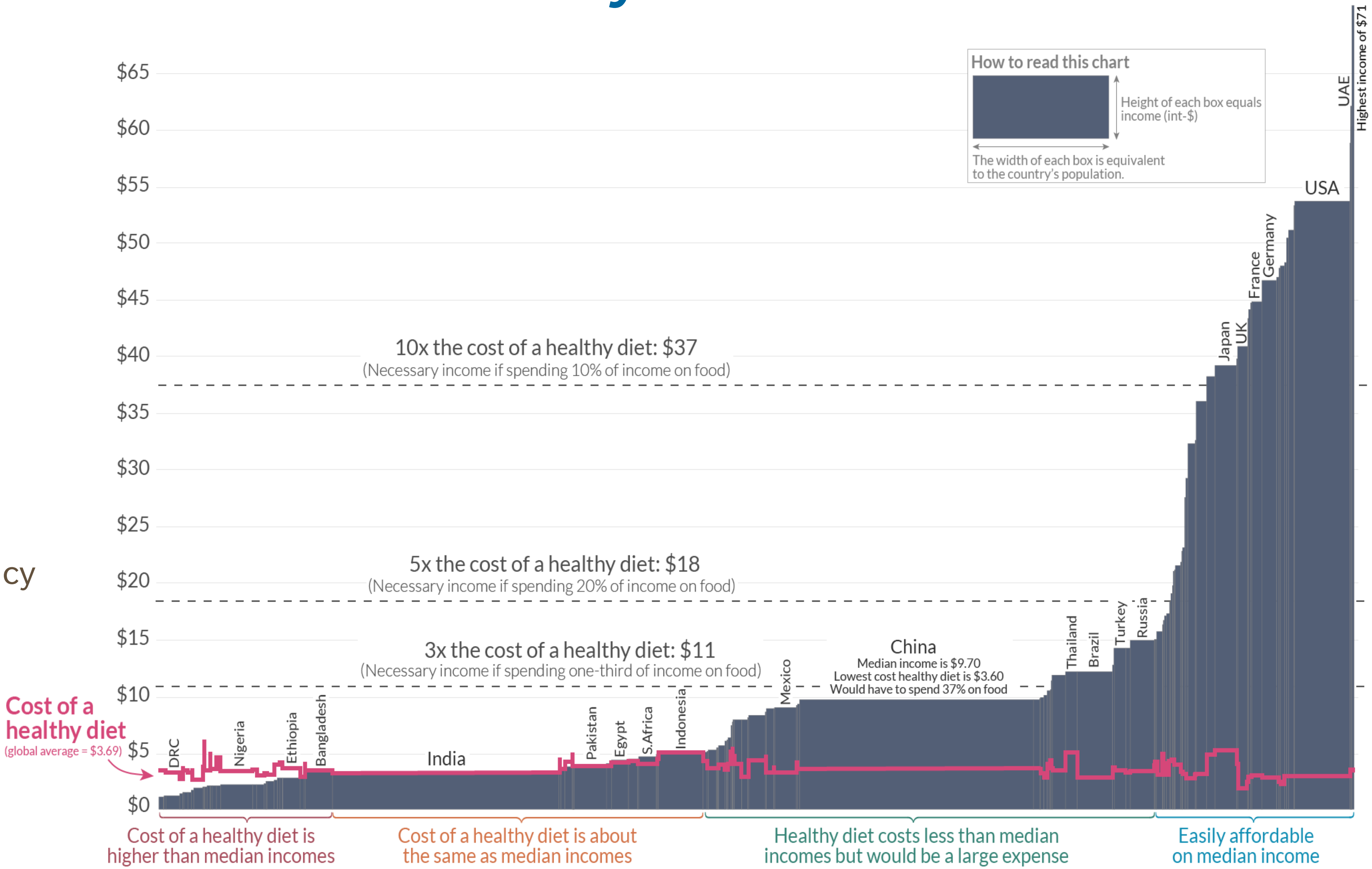
Research and Development

Cost of calory sufficient diets and healthy diets

A diet is affordable if less than 52% of daily income required

Cost of

- A calorie sufficient diet: 0.83 intl.-$ / Day
- A healthy diet: 3.69 intl.-$ / Day
- International dollar: PPP* adjusted, hypothetical currency



*PPP = purchasing power parities
2020 data

Herforth, A., Bai, Y., Venkat, A., Mahrt, K., Ebel, A. & Masters, W.A. 2020.
Hannah ritchie 2021, retrieved from: 'https://ourworldindata.Org/diet-affordability'
Berta Rohenkohl et al 2025, retrieved from: [What are international dollars? - Our World in Data]

Research and Development

Macronutrients

Energy = required for all functions, movements and metabolism in the body

- Energy requirement = resting energy consumption + energy consumption for physical activity
- Differs from person to person and from day to day depending on various factors such as gender, age, height and weight, stress, and hormones

The main sources of energy are **carbohydrates, fat, protein** and alcohol:

Carbohydrates are important for:
- Energy production
- Satiety
- Blood sugar balance

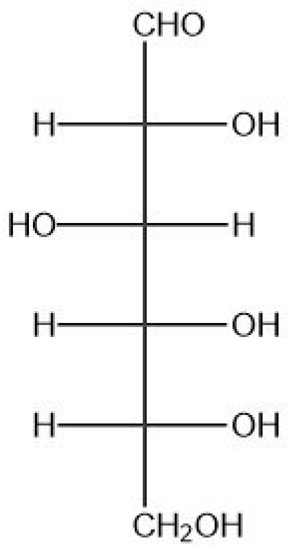
Protein:
- Supplies the body with amino acids and nitrogen for the formation of cells, tissue, enzymes and hormones
- Provides energy

Dietary fat:
- Provides energy and essential fatty acids
- Is a carrier of fat-soluble vitamins and flavor
- Offers protection against cold and organ damage

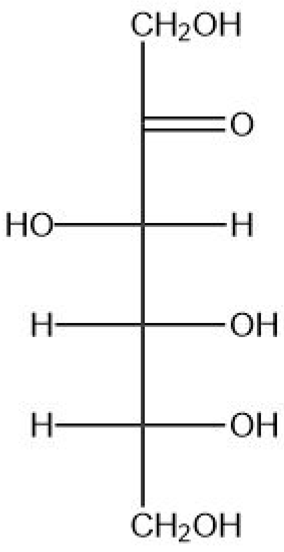
Macronutrients – molecular structure

Carbohydrates

- General structure: $C_n(H_2O)_n$

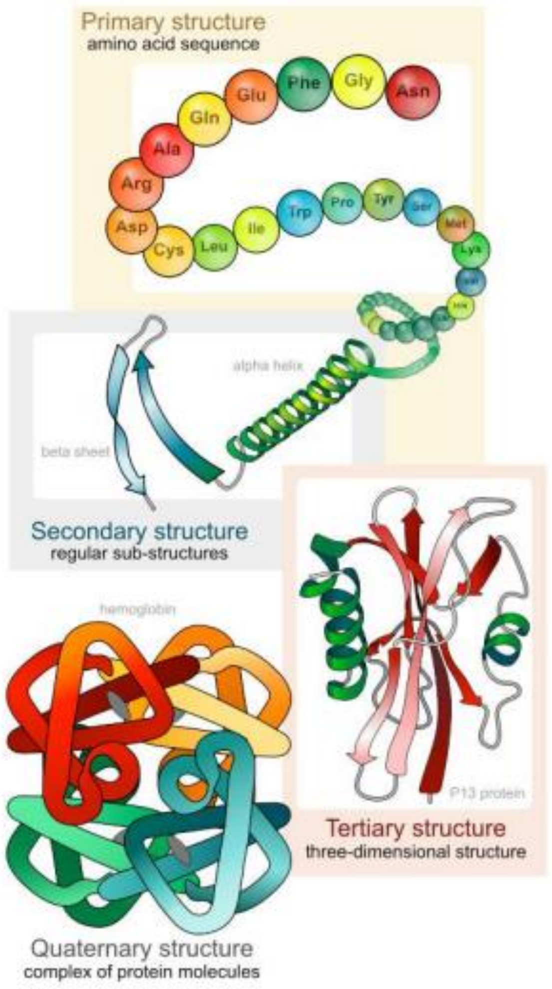


Glucose

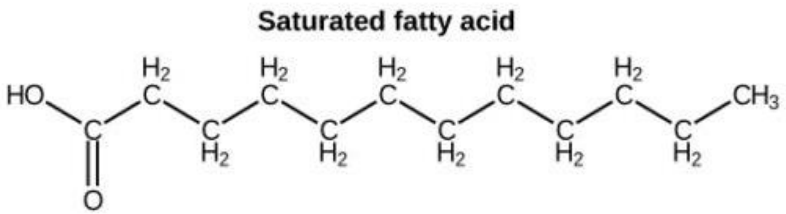


Fructose

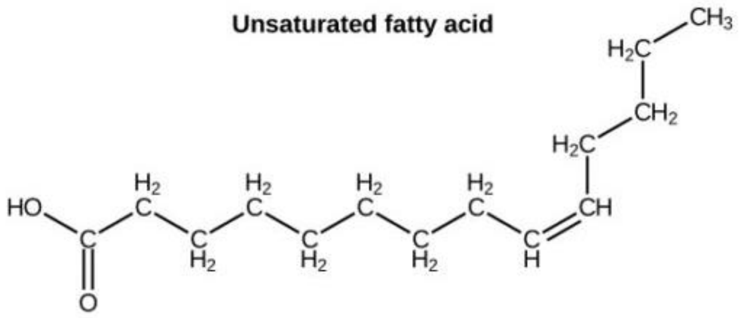
Protein



Lipids

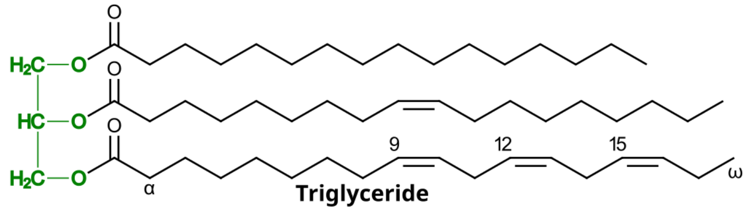


Each carbon atom is fully "saturated" with hydrogen atoms, forming only single bonds, which gives SFAs a straight, rigid structure, allowing them to pack tightly together.



One **(mono-unsaturated)** or more **(poly-unsaturated)** carbon-carbon double bond in the chain prevents full saturation with hydrogen atoms, introducing a bend in the structure, making it more flexible, kinked shape

Glycerol + 3 fatty acid chains = triglyceride

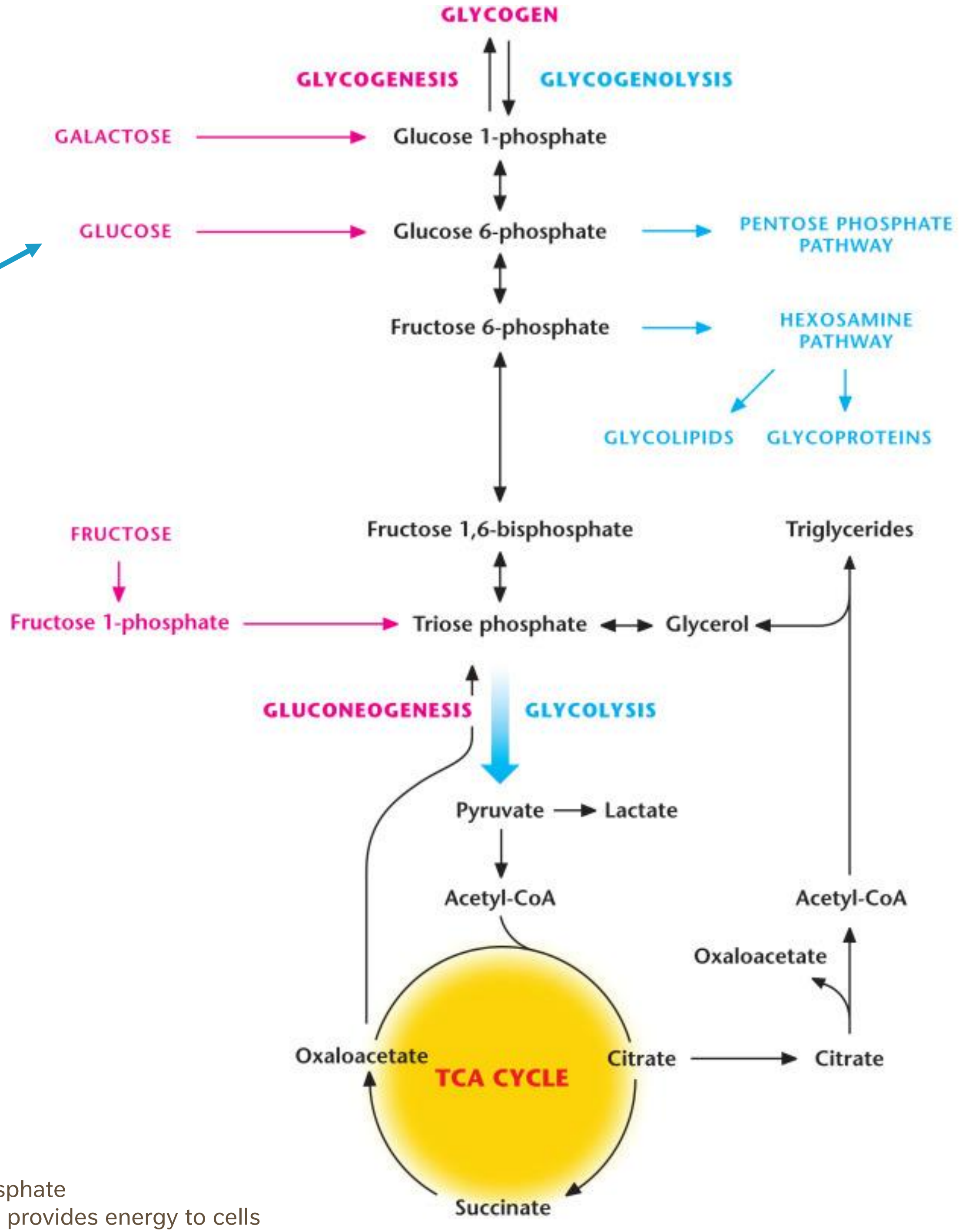


Carbohydrate metabolism

Degradation of di- and polysaccharides (e. g. sucrose, lactose, starch) **into glucose which then enters glycolysis**

Glycolysis is a ten-step enzymatic pathway that converts glucose into **pyruvate**, producing **ATP** and **NADH**

- Simple sugars, such as glucose, fructose, and galactose, can enter glycolysis
- Fructose is primarily metabolized by the liver
- The maintenance of glucose levels at around 5.5 mmol/L in the blood is critical
- At the cellular level, liver and kidney cells can generate glucose by
  a) converting stored glycogen in the liver into glucose (glycogenolysis), or
  b) synthesizing new glucose molecules (gluconeogenesis)

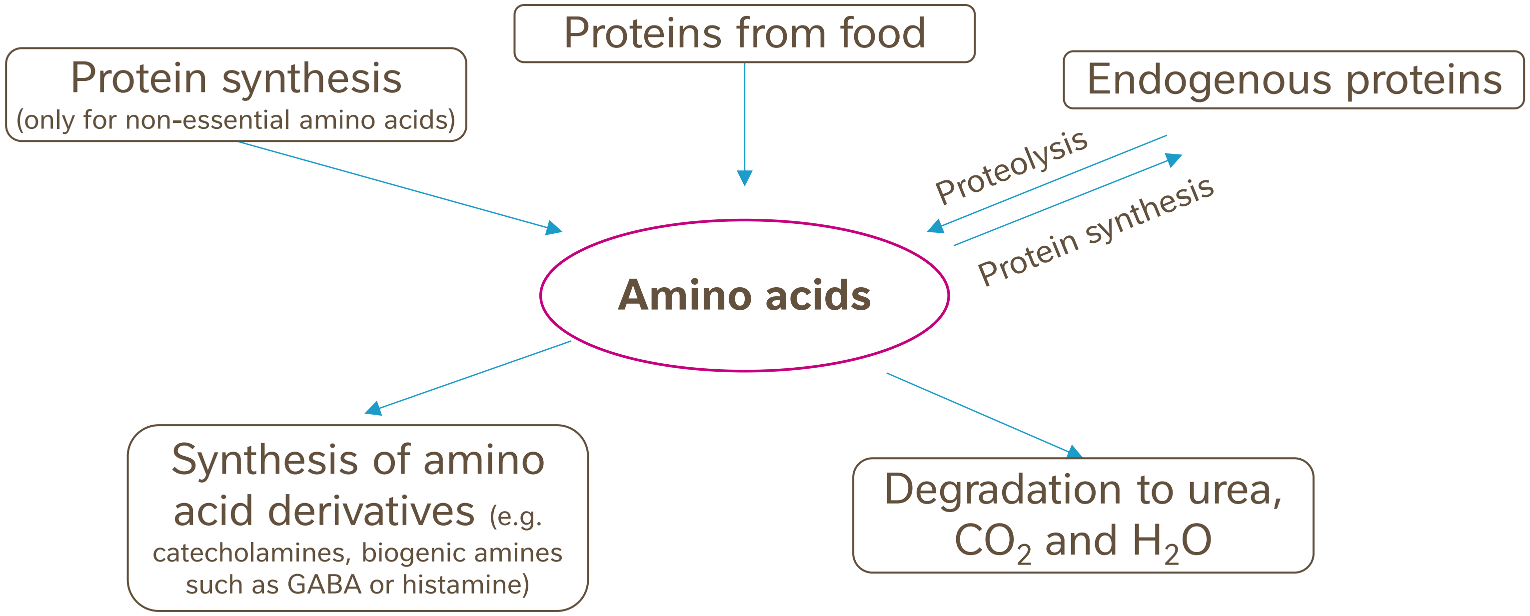


ATP = adenosine triphosphate
> Organic molecule that provides energy to cells

Protein metabolism

Breakdown of proteins into amino acids for energy production and synthesis of new molecules

- Proteolysis = degradation of protein into amino acids via proteases (group of enzymes)
- Degradation of amino acids: transamination → deamination → decarboxylation



Amino acids

- Important sources of energy
- Can be converted into pyruvate, acetyl-CoA or metabolites of the citric acid cycle
- Precursors of gluconeogenesis and biomolecules such as biogenic amines

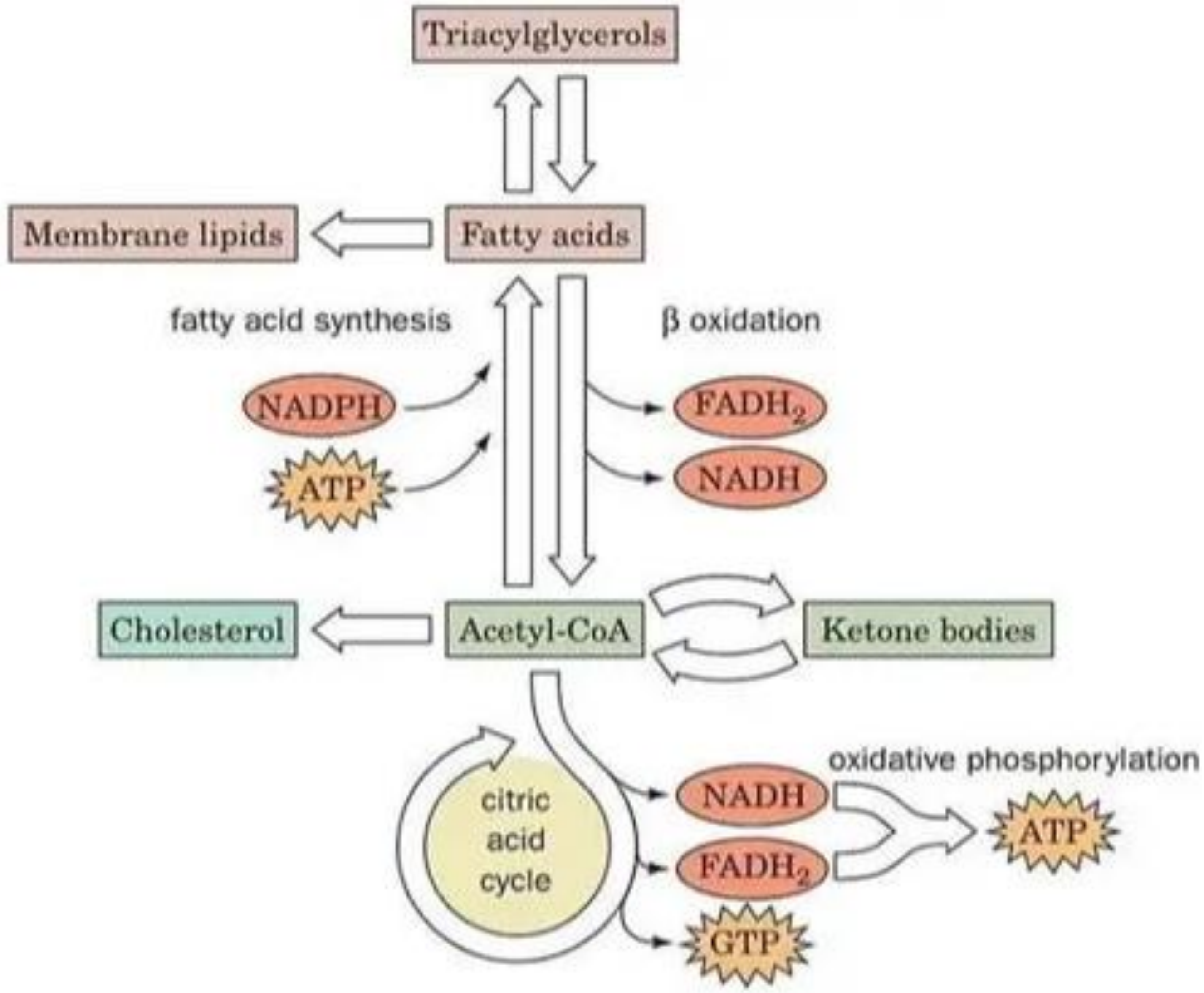
Essential amino acids

- Cannot be synthesized by the body
- Must be obtained through diet

Lipid metabolism

- Lipids in form of triacylglycerols are broken down into **free fatty acids (FFAs)** during digestion

- **FFAs** enter the mitochondria of cells, where they undergo **β-oxidation**, producing **acteyl-CoA (**acetyl coenzyme A)
- Acetyl-CoA is then used either:
  - in ketogenesis to produce **ketone bodies,** or
  - in the citric acid cycle (TCA) to generate **energy (ATP)** → see carbohydrate metabolism



Micronutrients

The micronutrients include

- Fat-soluble vitamins
- Water-soluble vitamins
- Trace elements

Adequate nutrition:

- Ensures vital metabolic, physical and mental functions
- Prevents nutrient-specific deficiency diseases
- Avoids over- or undersupply of nutrients

Referenzwerte | DGE

A Guide to Micronutrients: Recommendations & Sources [NASM] - NASM

The role of water

Water plays a critical role in the construction and behavior of many foods

– Over the temperature range found in foods, water can exist in a solid, liquid or gas state

– Acts as a medium where other molecules can dissolve and interact → BUT also provides a place for microbial growth which leads to food spoilage

– Present in all cells and body fluids

– Serves as a transport and solvent for nutrients

– Helps to regulate body temperature

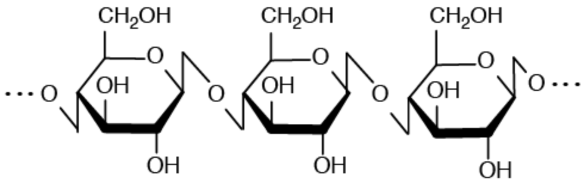
– Percentage of water in food

- Meat: 50%
- Eggs: 75%
- Watermelon: 92%
- Lettuce: 95%

Fibres

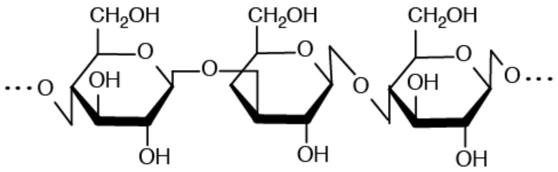
= Type of carbohydrate that cannot be broken down into sugar molecules, and instead pass through the body undigested

Cellulose: *β-1,4 glycosidic bonds*



β-Glucan:

mixed β-1,3 and β-1,4 glycosidic bonds



- Fibers provide various health benefits:
  - Regulate the body's use of sugars, helping to keep hunger and blood sugar in check
  - Anti-inflammatory effects in the gut microbiome
  - Lowering risk of developing various conditions, including heart disease, diabetes, diverticular disease, and constipation
- Children and adults need at least 25 to 35 grams of fiber per day for good health

<u>Soluble fiber</u>

- Dissolves in water
- Slows digestion
- In whole fruits, root vegetables, nuts, seeds, oats, legumes

<u>Insoluble fiber</u>

- Does not dissolve in water
- Does not get digested
- In green vegetables, fruits, potatoes, whole grains, nuts

What makes our food tasty ?

Components of Food

- Proteins, fats, carbohydrates (energy providers)
- Dietary fibre (e.g. cellulose), minerals, water
- Vitamins, trace elements, secondary plant compounds
- Aromatic substances, flavouring agents, additives




Aroma and taste active substances are

- contained in many ingredients
- added as additives during the preparation
- also produced during preparation
  - Cooking, baking, roasting (for around 800,000 years)
  - Fermentation (for around 10,000 years):
    beer, bread, yoghurt, cheese, sauerkraut, soy sauce, Maggi seasoning



The Five Senses

When something truly tastes good, it's not just about the flavour!

The interplay of the five senses:

- Vision of light (colour)
- Touching shape and texture
- Hearing pressure waves (air, water, bone)
- Tasting flavour-active molecules
- Smelling aroma-active molecules

Smell and taste are chemical senses.

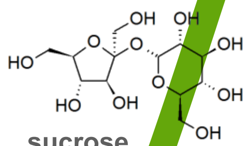
Social factors

- Alone or in company
- At leisure or in a hurry
- At home or in a restaurant
- Familiar or new

Hunger state

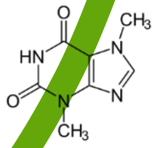
The sense of taste

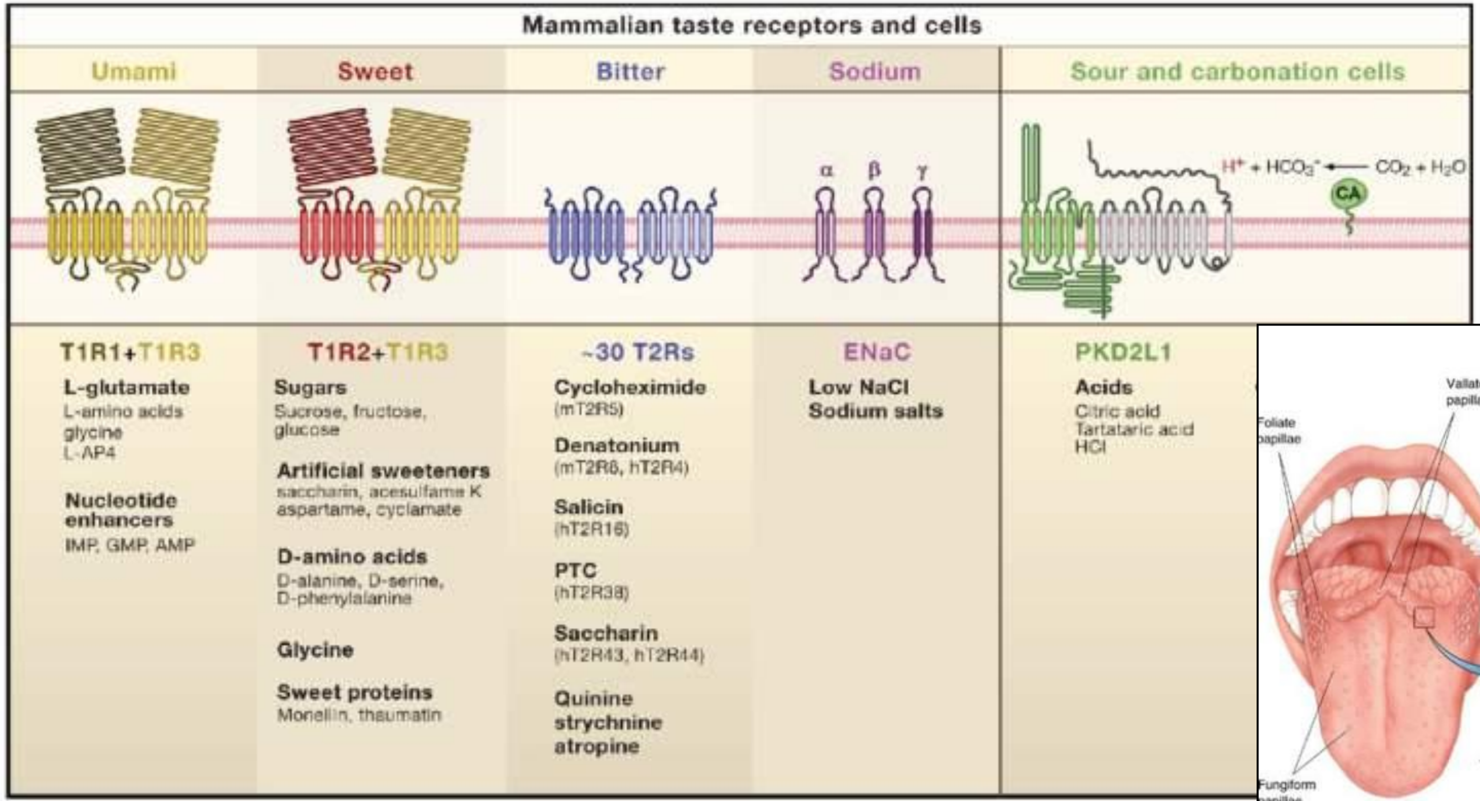
- **Taste** is perceived in **five qualities**: bitter, sweet, salty, sour, umami
- Taste active molecules are dissolved from the **food matrix** into **saliva** and transported to ca. 30 types of **taste receptors on the tongue**

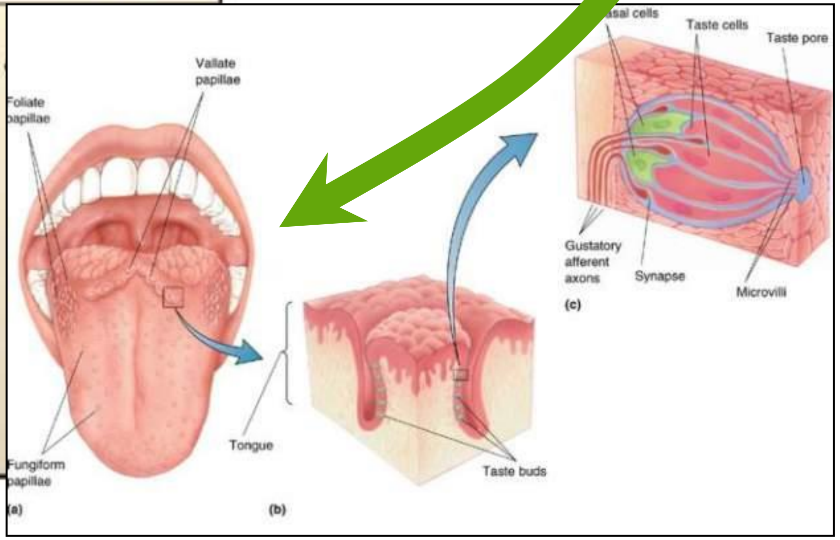


sucrose

theobromine

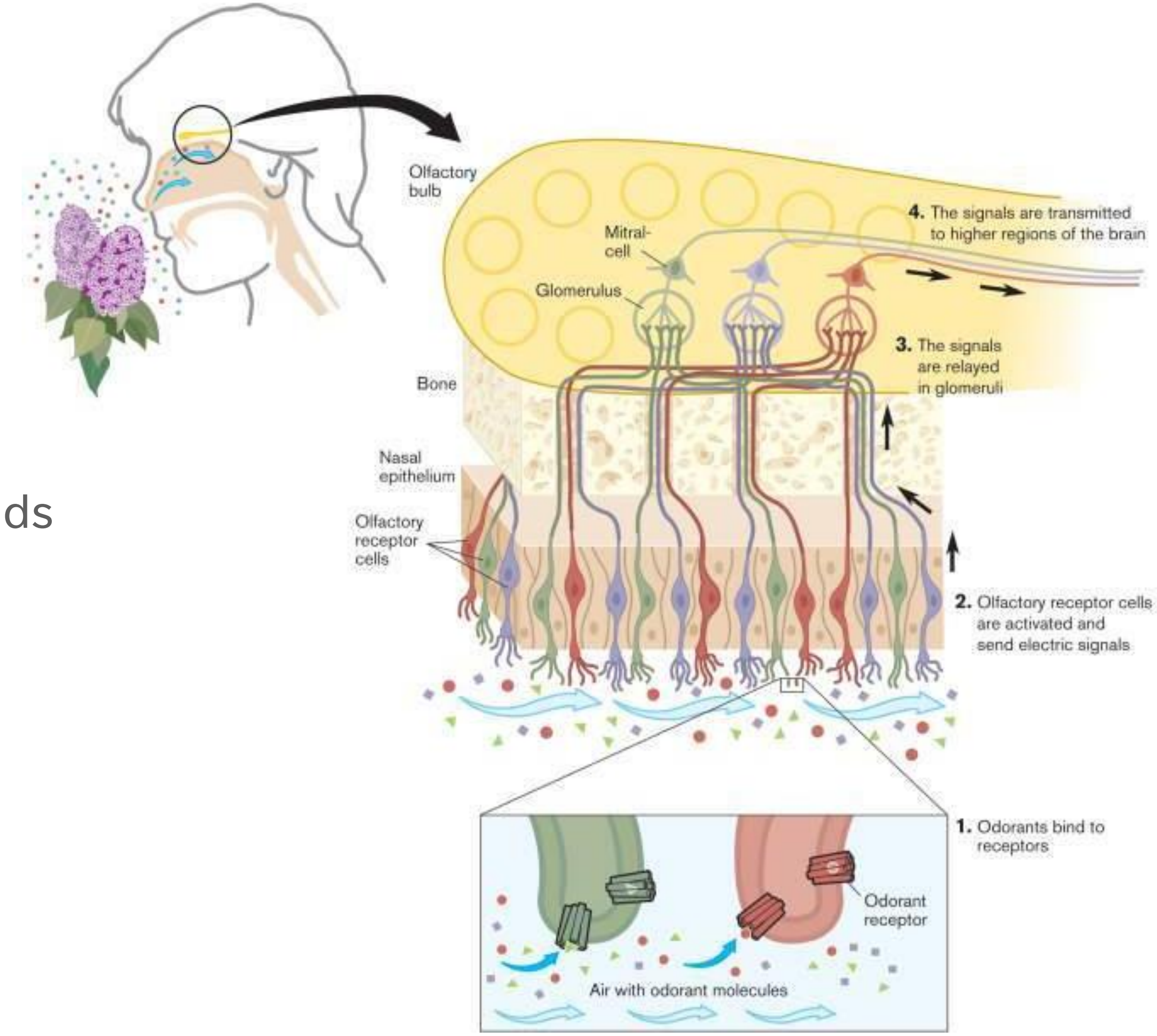






Sense of olfaction: smell and aroma

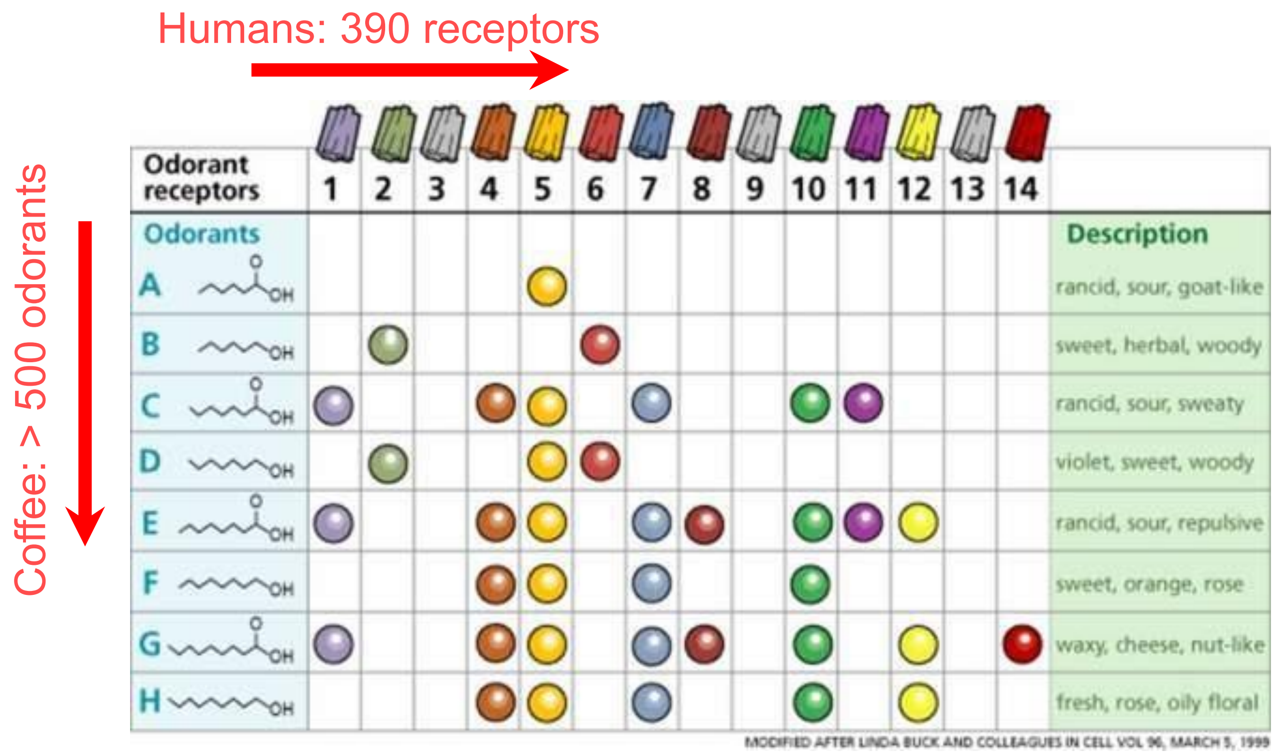
- Aroma compounds (odorants)
  - volatile molecules (30-300 Da)
  - stimulus for olfaction (odor, aroma, smell)
- We can distinguish ~10’000 types of odorants
- In mixture of +10 odorants, individual compounds can hardly be dissociated
- For humans 390 olfactory receptors are known



- In dark chocolate more than 500 types of aroma compounds are present

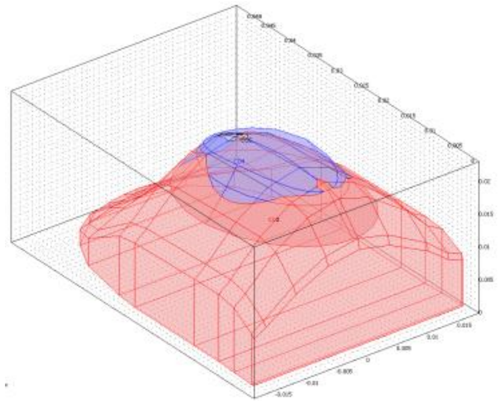
Sense of olfaction: smell and aroma

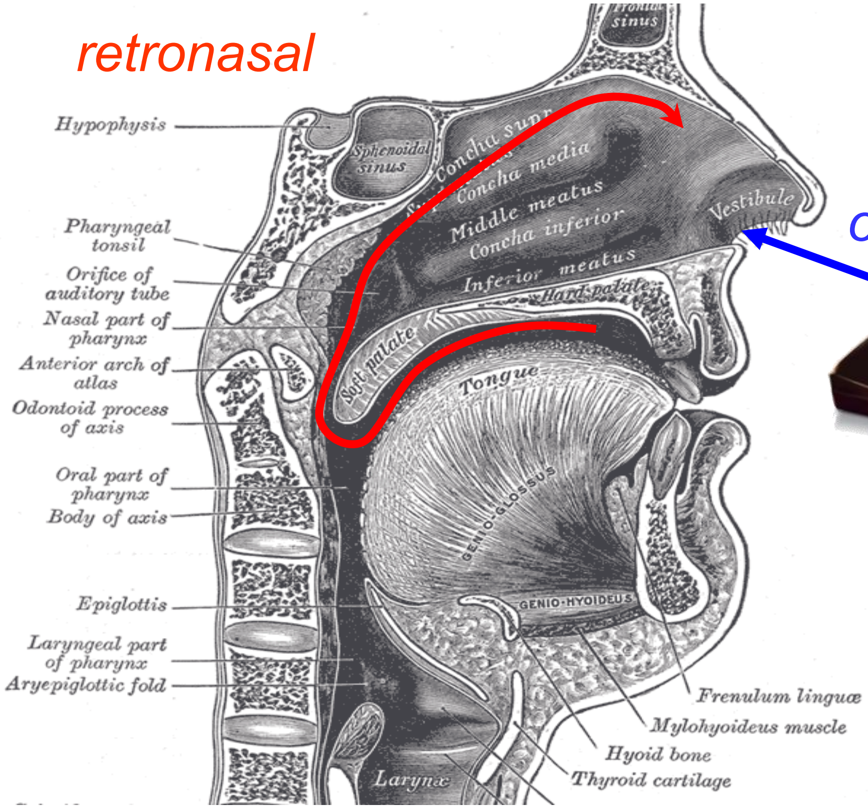
- One odorant binds to multiple receptors
- One receptor can host multiple odorants
- Odorants can activate and/or inhibit receptors
- An « olfactory code » is transmitted to the brain



The two ways of aroma perception

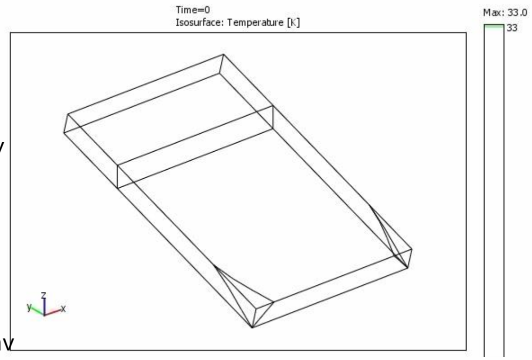
- Aroma compounds delivered to the olfactory receptors through ortonasal and retronasal channels
- Retronasal pathway dominant for **aroma perception** during product **consumption** !!

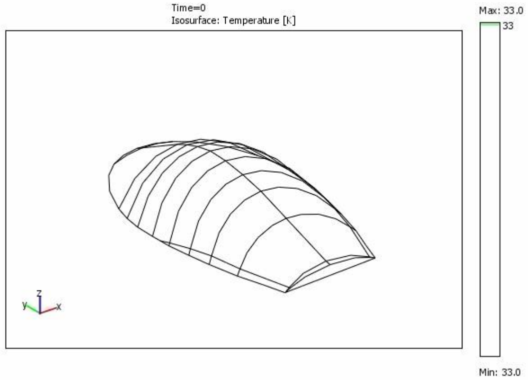




form4bist33c.wmv

formidealbt33c.wmv



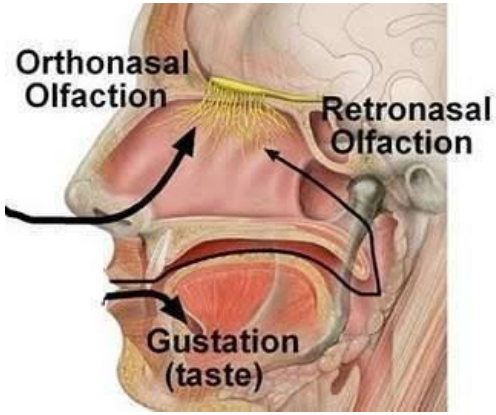


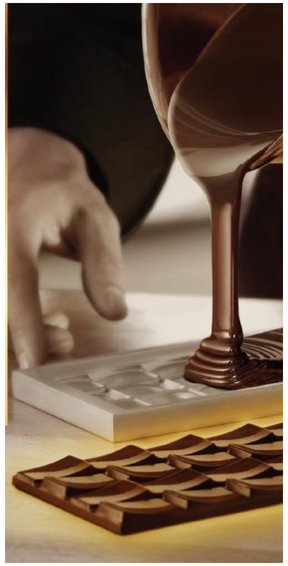
- Does melting in the mouth modulate arom release of a product?

Odor, aroma, taste and flavor – what is it about?

- Food aroma and taste are perceived through the senses of smell and taste
- Aroma and taste are stimulated by molecules
  - smell & taste are chemical senses (unlike vision, touch, audition)
  - molecules bind to receptors on tongue and in nose
  - ca. 30 taste receptors *vs.* hundreds of taste cpds.
  - ca. 400 olfactory receptors *vs.* thousands of aroma cpds.

- The combination of aroma and taste is often called flavour
- Aroma and taste active molecules are
  - added to the matrix (e. g. sugar, flavourings)
  - contained in ingredients (e. g. vanilla, fruit)
  - generated during food processing (e. g. cocoa roasting, conching)





How to make your dishes tasty

- Know what your guests like
- Use ingredients of best quality
- Use the appropriate preparation (transformation) method

Flavor is formed during the preparation

The flavor is great, because I like it

Flavor is in the ingredient

How to make your dishes aromatic?

Flavoring substances (natural/ artificial)


Chemical Reactions



Biological & Enzymatic Reactions


→ **Tasty Food**

Flavoring substances

Natural

= "A flavouring substance is considered to be '**natural**' when it is obtained from material of vegetable, animal or microbiological origin, by natural processes, and has been "**identified in nature**." - EFFA_Guidance_brochure_ANTILOPE_Layout 1

Distillation

- Especially steam distillation is used to extract volatile flavor compounds from plants (e.g. essential oils from mint or lavender
- The raw material is treated with steam, the flavor compounds evaporate and are then condensed

Filtration

- Separation of solid and liquid components after extraction
- Often used as an intermediate step to remove unwanted particles

Extraction

- Flavor compounds are dissolved from the raw material using a solvent (e.g. ethanol, water, CO_2)
- Examples: vanilla extract from vanilla pods, citrus oil from peels

According to EU Regulation 1334/2008, these processes are considered natural as long as they do not intentionally alter the chemical structure of the flavouring components

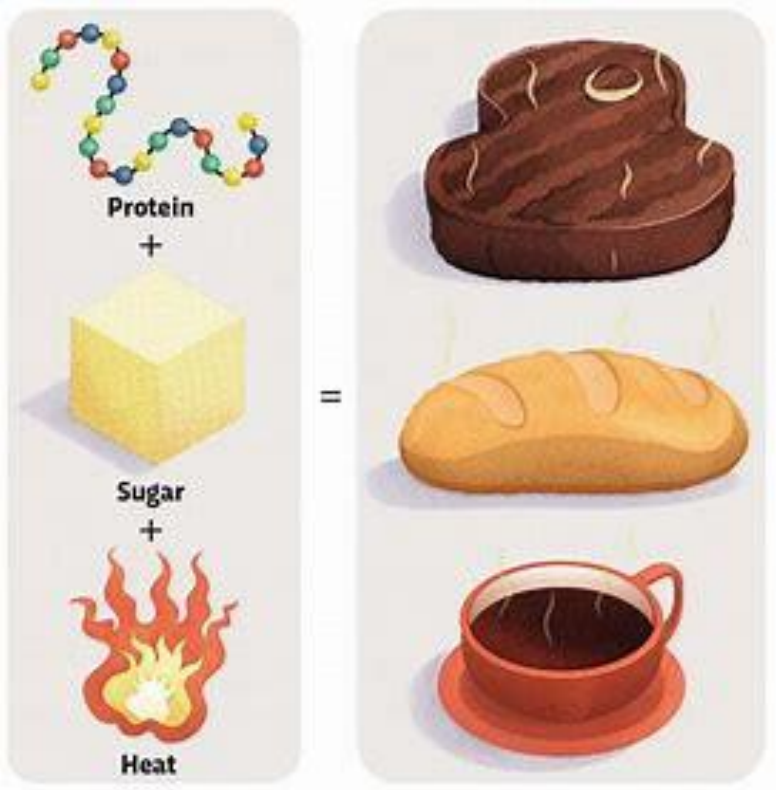
Artificial

= **Artificial flavourings** are created by **chemically synthesizing** flavor molecules in a laboratory. Unlike natural flavorings, they are not derived from plant, animal, or microbiological sources, but are instead built from basic chemical substances

- Created entirely in the lab, often from inedible sources like **petroleum**.
- Chemists identify the **key molecules** responsible for a flavor and then synthesize them using chemical reactions
- Many artificial flavors are made by **combining acids and alcohols to form esters**, which produce fruity or sweet aromas (e.g., butyl butyrate for pineapple, methyl cinnamate for strawberry)
- Over 2,000 chemicals are used to create more than 500 unique artificial flavors.
- Example: **Vanillin** is often produced synthetically – originally even from lignin (a component of wood) or from guaiacol, which can be derived from petroleum

Chemical reactions - Maillard reaction

Maillard reaction = non-enzymatic reaction of an amino group and a reducing group that leads to the formation of compounds which ultimately polymerize to form brown pigments [1]



– Series of reactions between **protein** and a **reducing sugar**, such as glucose or fructose, sped along by **heat**

– The reactions give a wide range of cooked foods their **appealing flavors and color** (non-enzymatic browning)

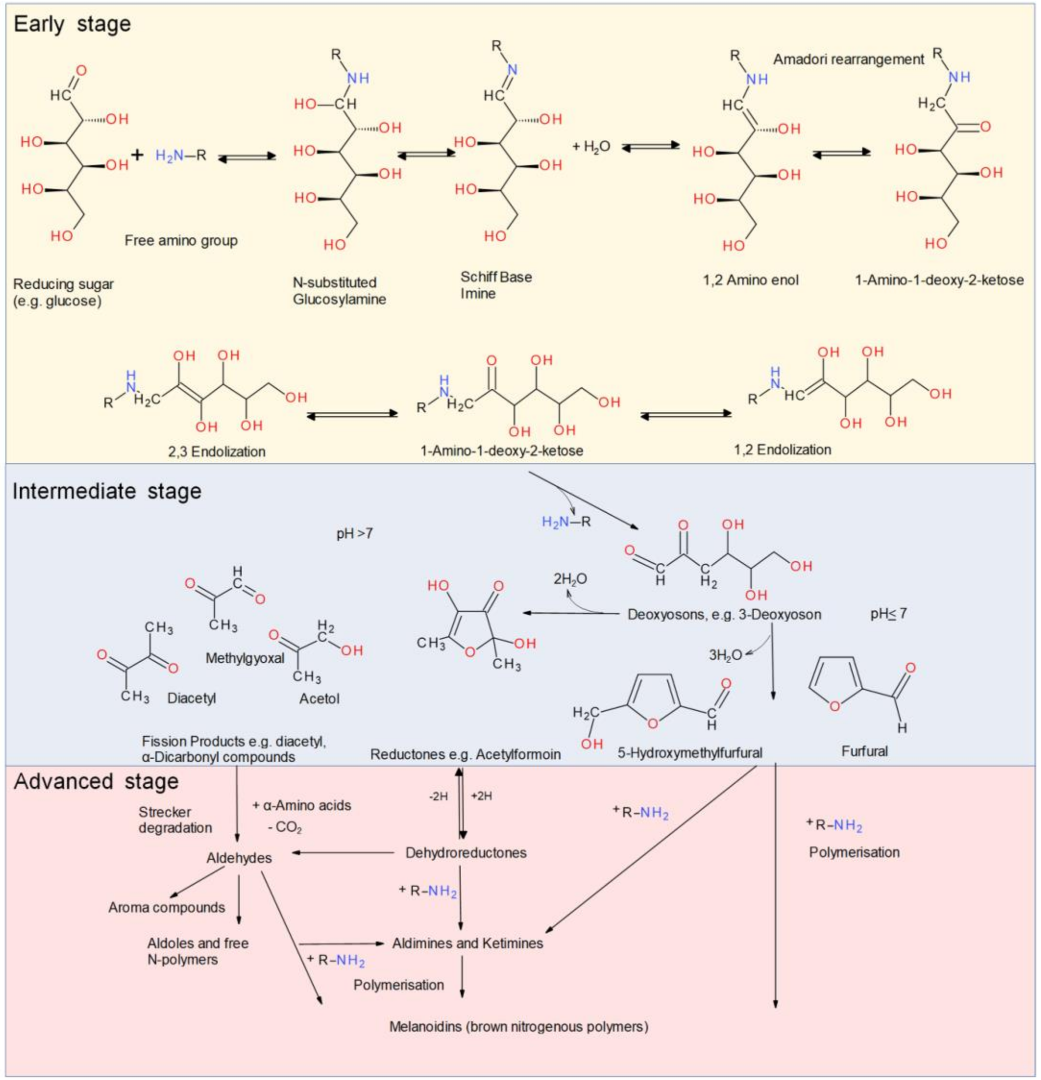
– Ideal temperature range: **120 to 170°C**

> If the temperature is too high, bitter flavors can develop

– Downside: creation of **acrylamide** (carcinogen) as a by-product

[1] J.C. Acton, P. L. Dawson (2004): 25 – Impact of proteins on food colour. *Proteins in Food Processing*, p. 631-668.
What is the Maillard reaction? - BBC Science Focus Magazine

Chemical reactions - Maillard reaction



Ines Kutzli et al. (2022): Glycation of Plant Proteins Via Maillard Reaction: Reaction Chemistry, Technofunctional Properties, and Potential Food Application

Early stage: Sugar–Protein Interaction

- **reducing sugar** reacts with an **amino group** from a protein
- forms an unstable intermediate that rearranges into a more stable compound
- **starting point** for browning and flavor formation

Intermediate stage: Breakdown & New Compounds

- initial products **break down** into smaller, reactive molecules
- molecules interact further, forming **aroma compounds** and **light browning**
- Reaction pathways depend on **pH, temperature and moisture**

Advanced stage: Polymerization & Browning

- Complex reactions lead to the formation of **melanoidins** (brown pigments)
- These polymers give food its **color and flavor**
- At high temperatures, **acrylamide** (carcinogenic by-product) can form
  - o BUT only possible when the amino acid asparagine and glucose react

Chemical reactions that produce taste in food

Caramelization

Thermal Decomposition of Sugars

Sugars heat above 160°C decomposes

Flavor Development

Volatile compounds formed create sweet, nutty, and complex flavors in caramelized foods.

Color Formation

Polymerization of sugars results in brown-colored compounds giving caramelized foods their distinctive appearance.

Culinary Applications

Caramelization enhances flavor and color in caramel, roasted coffee, and baked goods.

- Like the Maillard reaction, caramelization is a type of non-enzymatic browning.
- Unlike the Maillard reaction, caramelization is pyrolytic, as opposed to being a reaction with amino acids.
- Caramelization is a complex, poorly understood process that produces hundreds of chemical products, and includes the following types of reactions:
  - equilibration of anomeric and ring forms
  - sucrose inversion to fructose and glucose
  - condensation reactions
  - intramolecular bonding
  - isomerization of aldoses to ketoses
  - dehydration reactions
  - fragmentation reactions
  - unsaturated polymer formation

Chemical reactions that produce taste in food

Oxidation of fat (rancidity)

Causes of Fat Oxidation

Fat oxidation occurs due to exposure to oxygen, light, and heat, mainly affecting unsaturated fatty acids.

Chemical Changes During Oxidation

Initial oxidation forms hydroperoxides that break down into aldehydes and ketones causing rancid flavors.

Impact of Rancidity

Rancidity degrades food quality by producing off-flavors and reducing nutritional value and shelf life.

Prevention Strategies

Antioxidants, proper packaging, and storage conditions help prevent rancidity and preserve food quality.

Aroma from fermentation – Lactic Acid Bacteria (LAB)

What is fermentation?

A metabolic process where microorganisms like **yeast** or **bacteria** convert **sugars** into other compounds, producing aromas and flavor, among other things.

Main aroma compounds produced

Aroma compound	Examples in food
Alcohols	beer, wine
Esters	yogurt, wine, floral notes incheese
Acids	lactic acid in yogurt, acetic acid invinegar
Ketones & Aldehydes	buttery, creamyor nutty aromas

Example: Sourdough bread

Main fermentation drivers:

Homofermentative LAB
- Convert glucose mainly into **lactic acid** (no gas)
- Result: Strong pH drop, mild aroma

Heterofermentative LAB
- Convert glucose into **lactic acid, acetic acid, ethanol** and **CO_2**
- Result: Tangy aroma, gas for leavening, complex flavors

Yeast
- Converts sugars in **ethanol** and **CO_2**
- Result: CO_2 causes dough to rise, Ethanol and other by-products contribute to the aroma

Different species of LAB use different metabolic pathways to break down sugars, which is why we distinguish between homofermentative and heterofermentative LAB

Food Processing - Why?

FOOD SAFETY, PRESERVATION & FOOD SECURITY

- Inactivate pathogens and prevent formation of toxins.
- Extend shelf-life while maintaining nutritional quality.
- Non-perishable foods contribute to food security.

SENSORY

- Improve appearance, taste, flavor and texture.

NUTRITION & HEALTH

- Improve digestibility, and reduce anti-nutritional factors.
- Eliminates natural toxins.
- Fortify and enrich with vitamins, minerals, proteins and fibers.
- Tailor to specific nutritional needs, e.g. allergen free or vegan.

SUSTAINABILITY

- Reduce waste through side stream valorization.
- Efficient energy and water usage.
- Eco-friendly packaging reduces carbon emissions.
- Long shelf-life helps to diminish food waste.

FOOD DIVERSITY, CONVENIENCE & AFFORDABILITY

- Increase access to seasonal foods or agricultural commodities.
- Time saving in food preparation and clean up.
- Large-scale processing lowers cost, making food reasonably priced.

Preservation and Microbiological Safety

Heating and cooling

Freezing
Fully stops microbial growth.

Cooling
Slows down microbial growth.

Heating
Inactivates pathogens and other microbes.

Removing water

Drying
Removes water to prevent growth of microbes.

Sugar / Salt
Draws water out of microorganisms to prevent growth of microbes.

Acidifying

Acid addition
Acidic pH prevents growth of microorganisms.

Fermentation
Bacteria convert sugars to acid.

1

Ensuring microbiological safety by:

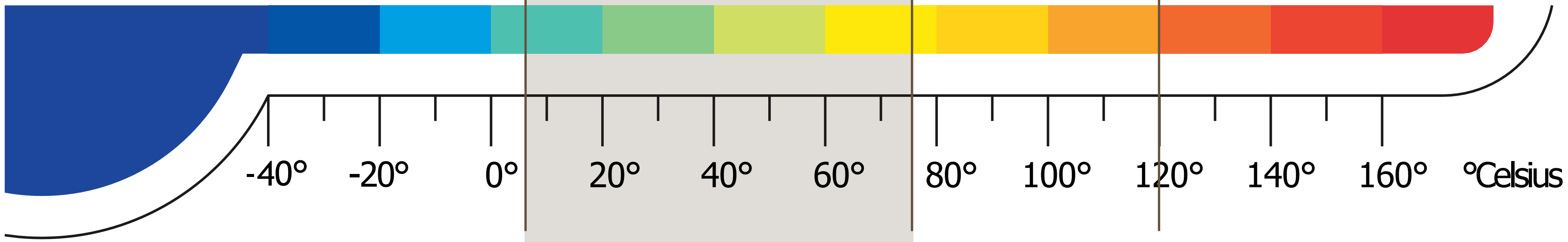
1.1 heating & cooling

Food safety
- Refrigerator temperatures below 4°C slow growth of spoilage microorganisms.
- Freezing (below 0°C), some bacteria survive but no growth occurs.

The danger zone
- Rapid growth of bacteria, some producing toxins.
- Products are only stable if all bacteria and spores are inactivated and kept under sterile conditions or growth is prevented by dehydration.

Food safety
Most harmful microbes are destroyed at temperatures above 75°C.

Food safety
Bacterial spores e.g. *Clostridium botulinum* require cooking above 120°C to be inactivated.



Freezing
Rapid freezing to prevent growth of microorganisms and maintain quality.

Cooling
Rapid cooling to below 4°C to avoid risk of microbial growth in the danger zone.

Pasteurization
Mild heat treatment e.g. of milk and fruit juices at 80°C and quickly cooled back to below 4°C.

UHT Treatment / Canning
- Ultra high temperature treatment (UHT) sterilizes liquid foods at 135°C inactivating also bacterial endospores.
- Canning in a closed container sterilizes food under high temperature and pressure.

1

Inactivation of harmful bacteria

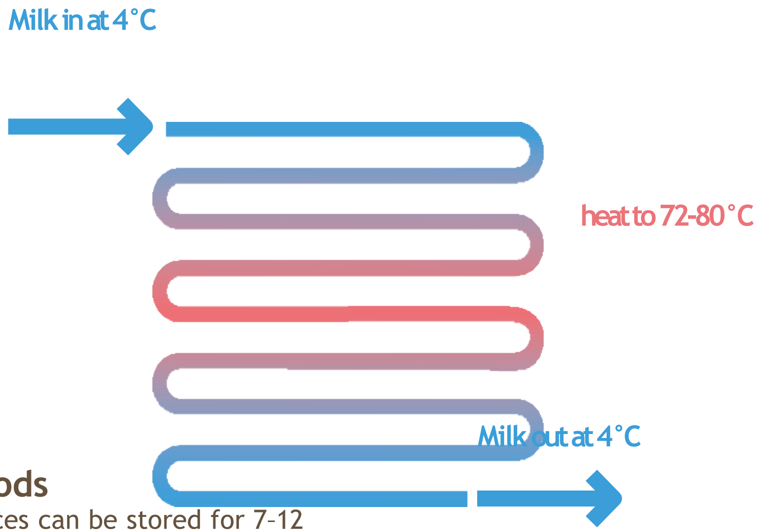
1.1.1 through mild heating

What it is

The technology by which liquids are heated (typically 72-80°C for 15-30 seconds) followed by rapid cooling to inactivate pathogenic microbes and enzymes is called pasteurization.

How it works - Example pasteurized milk

Milk flows in heated pipes for a short time, followed by cooling pipes, before being filled into bottles or other packages.



The benefits and typical foods

Pasteurized milk and fruit juices can be stored for 7-12 days in a refrigerator. Their nutritional quality and sensory characteristics are very well maintained.

When pasteurization is combined with acidification e.g. in flavored beverages the shelf-life can be increased from weeks to several months and products can be stored at room temperatures but need refrigeration once opened.

About the history

In 1886, Franz von Soxhlet, a German agricultural chemist, was the first person to propose pasteurization to be applied to milk for inactivation of harmful bacteria such as *Salmonella*, and other disease-causing pathogens. The term "pasteurization" is derived from Louis Pasteur's pioneering work on the destruction of microbes through heat treatment.

Achieving long shelf-life of liquids

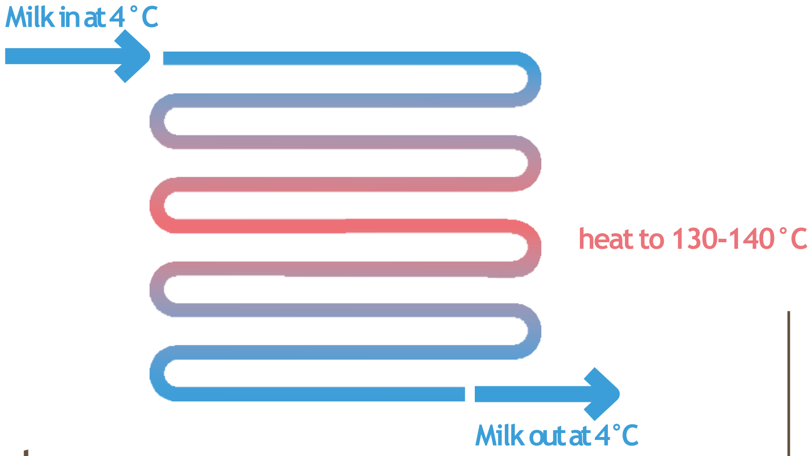
1.1.2 by heat treatment

What it is

The technology that sterilizes liquid foods at high temperature (130-140°C) for a short time (2-5 seconds) is called Ultra High Temperature (UHT) treatment. It inactivates pathogenic and spoilage microorganisms including spores. UHT treatment combined with filling in a sterile environment is called aseptic packaging.

How it works - Example UHT milk

After shortly heating the milk to high temperature and rapid cooling, it is filled into containers under sterile conditions.



The benefits and typical foods

UHT products can be stored for 6 to 9 months at room temperature. Once the container is opened, the milk should be refrigerated and has the same shelf-life as pasteurized milk. The long shelf-life contributes to food security. Typical products are milk and fruit juices.

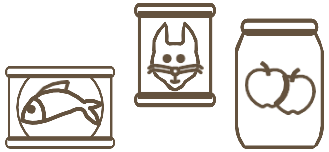
About the history

In 1912, the UHT technology was patented. However, it was only in the 1960’s when UHT made its breakthrough when *Tetra Pak* combined carton assembling and aseptic packaging technologies.

1

Achieving long shelf-life of liquids

1.1.3 Preserving solid foods



What it is

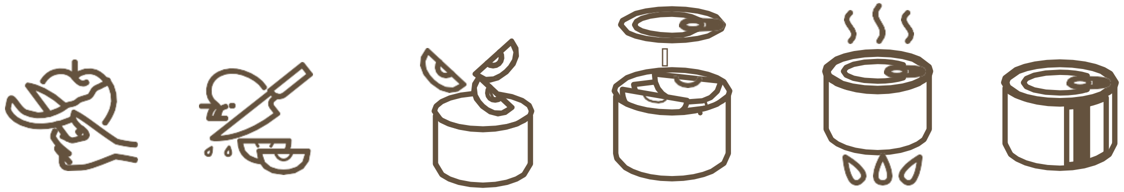
When food is sealed in a container, such as a tin, canister, glass jar or metalized plastic pouch, and then cooked at 120°C for 10 - 20 minutes, is called canning, retorting or sterilization.

The benefits and typical foods

Canned foods have a very long shelf-life up to 2 years. It's a convenient offering for out of season harvests and agricultural commodities that are produced elsewhere and contributes to food security. Typical canned foods are tuna, fruits and vegetables.

How it works - Example canning of fruits

The heating step at elevated temperature and pressure destroys pathogenic and spoilage microorganisms including spores and inactivates enzymes to preserve the safety and quality of the food.



1. Peeling.
2. Coring and slicing.
3. Filling of fruit slices and juice.
4. Hermetically sealing the can.
5. Heating to 120°C under pressure .
6. Cooling and labelling.

About the history

The use of high temperature and pressure to produce safe food products dates to the 1790s in France. Nicolas Appert discovered a method to preserve food by heating it in air-tight glass jars and bottles. The technology, further adapted to cans, was applied to *Maggi* ravioli as early as 1957 and in the 1960s to flexible pouches.

Removing water for long shelf

1.2 stability & lighter foods

What it is

Drying or "dehydrating" food is a preservation method that removes water from food so that microbes such as bacteria, yeasts and molds cannot grow. The technology to dry products depends on the type of food. Solid food such as fruits, legumes etc. are dried by using sun, air, oven and freeze-drying, while liquids are usually dried by drum- and spray-drying.

Benefits

Drying results in long shelf-life products and makes foods lightweight and convenient to transport, store and use. It contributes to food security as it allows access to out of season harvests and agricultural commodities that are produced elsewhere such as milk.

Main technologies used for drying

- Sun heated air
- Air & oven drying
- Drum-drying
- Spray-drying
- Freeze-drying

About the history

Food drying is one of the oldest methods of preserving food. The earliest known practice is 12000 BC by inhabitants of the Middle Eastern and Asian regions.

1

Creating powders from liquid

1.2.1 for long shelf-life & ease of use

What it is

Converting a liquid such as milk into a fine powder by spraying it into hot air to evaporate most of the water is called spray-drying.

The benefits and typical foods

Food powders are easy to pack, distribute and handle due to their low bulk weight and provide excellent microbiological stability.

Milk is a good source of high-quality proteins and essential nutrients. Providing it as a powder allows to widen safe access to remote areas that do not have access to fresh milk.

Spray-drying is widely applied for dairy products, such as milk or coffee creamer powders, as well as soluble coffee, tea or fruit juice powders.

How it works - example dairy powders

1. Concentrate milk by evaporating it at low temperature in a vacuum.
2. Create a spray of fine liquid droplets from concentrate.
3. Dry the droplets in hot air.
4. Collect and package the powder.

About the history

Spray-drying was invented by Samuel Percy in 1872. Nestlé pioneered this technology already in the 1920s to produce infant foods based on milk powder and in 1938 to produce *Nescafé*. Since World War II, spray-drying was widely used to produce milk and coffee powders.

Water removal below zero degree is

1.2.2 a gentle way to dry delicate foods

What it is

Putting a frozen food into a vacuum and slowly warming it up to allow the ice in the food to change directly to a vapor is called freeze-drying. The vaporized water is recovered and used in the manufacturing of products.

How it works - example freeze-dried instant coffee

1. Roasting the beans.
2. Grinding the beans.
3. Extracting the coffee.
4. Concentrating the extract.
5. Freezing to -40°C.
6. Drying in vacuum chamber below 0°C.
7. Grinding the dried cakes & packaging in jars.

The benefits and typical foods

Freeze-drying helps to maintain a flavor and aroma profile that is very close to the profile of the fresh raw material. It also preserves the color and shape and retains nutritional value better than other drying methods. Freeze-drying is used for premium instant coffee as well as dry fruits and vegetables.

About the history

Freeze-drying was invented by Jacques-Arsene d'Arsonval at the College de France in Paris in 1906. In 1965 Nestlé sold the first freeze-dried pure soluble coffee under the *Nescafé* brand.

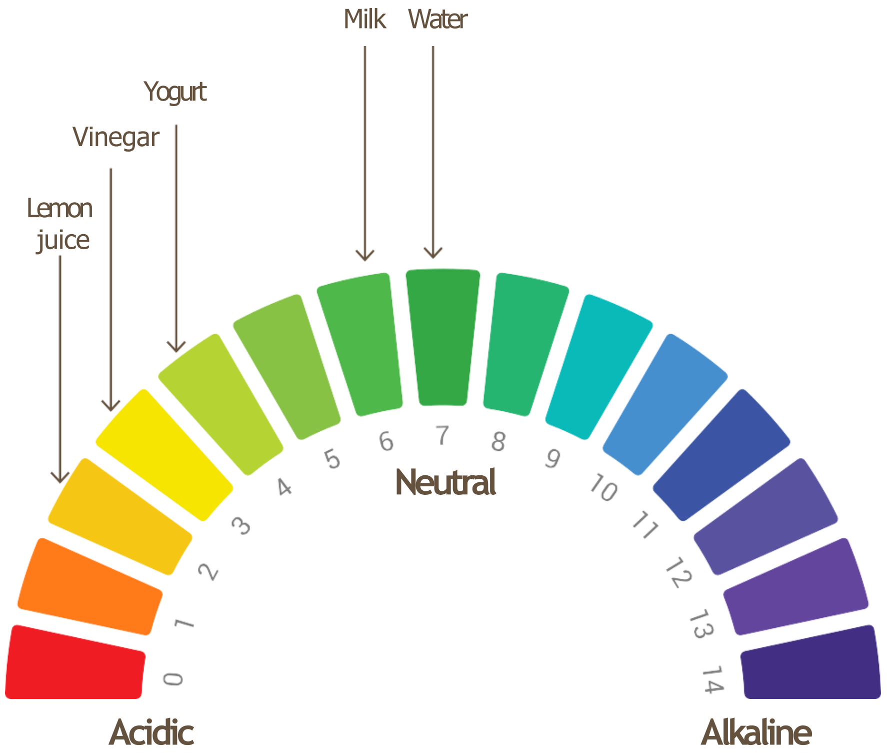
Acidification is a traditional

1.3 preservation method

What it is

Acidification of foods is a means of controlling the growth of undesirable microorganisms, including pathogens. Acidity is a function of the concentration of hydrogen ions and is measured as pH. Environments with pH values **below** 7 are acidic, with a high concentration of hydrogen ions. Those with pH values **above** 7 are considered basic or alkaline. A pH of 7 is considered neutral. Most pathogenic bacteria grow optimally at a pH between 5 and 8. This is the reason why a pH below 5 prevents the growth of these pathogenic microbes.

Most foods have a pH below 8. Typical food acids are citric acid present in lemon juice, acetic acid in vinegar and lactic acid in fermented dairy products.



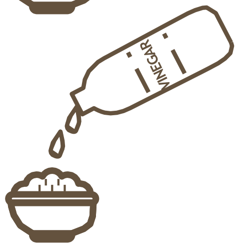
Adding acids prevents the growth

1.3.1 of harmful microbes

How it works

Acidification can be achieved by adding acids such as citric acid present in lemon juice.

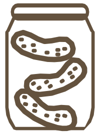
Any food grade acid such as vinegar (acetic acid), citric, lactic, malic or phosphoric acid can be added to food to establish a final pH below 5, required to prevent growth of harmful microorganisms.



Acidification is often applied in combination with heat treatment such as pasteurization.

The benefits and typical foods

Acidification extends the shelf-life of a product due to the preservative effect of the acid. The acidification also helps to create a desired sour taste. Acidified foods include sauces, dressings, carbonated drinks, pickles and salsas.



About the history

Putting vegetables in vinegar to preserve them out-of-seasons consumption first originated in ancient Mesopotamia around 2400 BC. Acidification was probably discovered when food was placed in wine to preserve it. Wine is converted to vinegar by acetic acid bacteria. The low pH and the taste of the food in the wine once it soured was found to be rather appealing.

Fermentation produces acids in

1.3.2 a natural way

What it is

The growth of beneficial microorganisms such as bacteria in milk or yeasts in a dough is called fermentation. These microorganisms break down food components like sugars into other products for example lactic acid in yogurt and acetic acid in vinegar.

How it works- example yogurt

1. Fat level adjustment of milk.
2. Pasteurization, heating to 80°C.
3. Homogenization to reduce fat droplet size.
4. Cooling down to 40°C.
5. Adding lactic acid bacteria.
6. Fermentation at 42°C.
7. Cooling the yogurt, 7°C.
8. Adding fruits & flavors (optional).

About the history

Historians have traced signs of fermentation in food and beverage preparation dating back as far as 7000 years BC. Today, fermented foods and beverages are common to many households around the world, such as yogurt, pickles, cheese, salami and beer. Less well-known ones are becoming popular like kefir, kimchi or kombucha.

The benefits and typical foods

Fermented foods usually have an improved microbial stability and safety, and some like Sauerkraut and pickles can be stored even at ambient temperatures for extended periods of time. Lactic acid in yogurt curdles the milk protein to give yogurt its characteristic texture and sour taste. Furthermore, certain microbes produce small amounts of some B Vitamins increasing the nutritional value of the fermented food.

Taste and Texture

Heat

Gelling
Heating up and cooling specific ingredients such as starch, proteins etc. can lead to gel formation.

Baking
Helps solidify batters and doughs leading to flavor, color and crust formation e.g. in pizza and bread.

Frying
Is done at high temperature in oil and generates crispiness, flavors and golden colors.

Roasting
Use of dry heat in an oven or over a flame creates colors and aromas.

Mechanical - Stress and Strain

Shaping and forming
Is used to produce low moisture products such as pasta, cookies, breakfast cereals, pet food and high moisture meat analogues.

Homogenizing
Breaking down larger chunks/particles/fat droplets into smaller ones leads to creamy products.

Acidification

Adding acids / Fermenting
Acids added or produced by fermentation promote gel formation of proteins such as in yogurt.

Cooking generates flavors

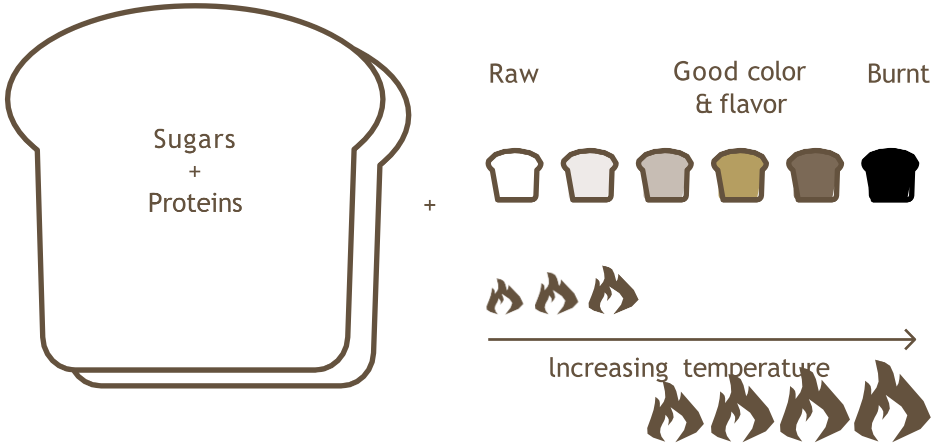
2.1 colors & textures

What it is

Flavors are naturally created when roasting, grilling, baking, frying or toasting. It is the so called Maillard reaction that is responsible for the browning of food and the release of pleasant flavors.

How it works - example toast

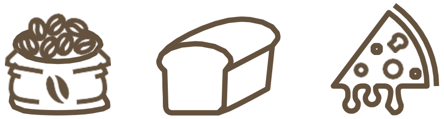
Maillard reaction is a series of chemical reactions that occur when proteins and sugars in a food are heated together. Water content and temperature of the food influence the speed of the reaction and the type of aromas released. As the heating speed is different in various cooking methods such as baking, grilling, roasting and toasting the same food will produce different flavors and colors.



Benefits and typical foods

Maillard reaction-induced flavors are often meaty, brothy, roasty, toasty, nutty or gravy-like in taste and smell.

Heating conditions at industrial scale are very well controlled, so that the formation of unwanted compounds such as acrylamide can be dramatically reduced as compared to home cooking.



About the history

In 1912 Louis-Camille Maillard described that upon heating sugars and protein in water, a golden-brown color developed. It was only in the late 1940s that many scientists began to go back to his studies, using the expression Maillard reaction for the first time.

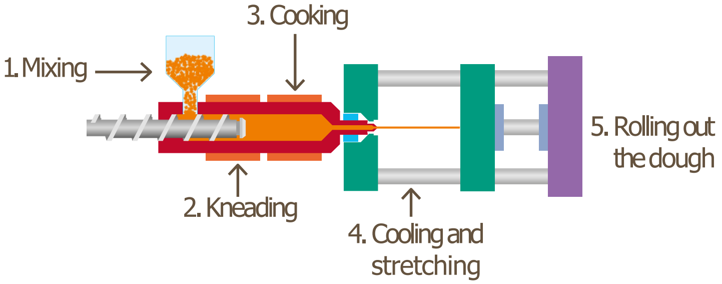
2

Cooking and shaping a dough to craft

2.2 a variety of textures & forms

What it is

A combination of mechanical and thermal technologies in a single machine including mixing ingredients, forming a dough, cooking under pressure and pushing the cooked dough through an orifice to create different shapes or a dough sheet is called extrusion.

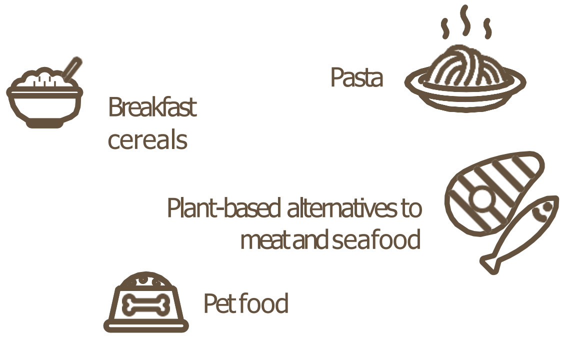


How it works

1. Mixing flours (wheat, soy or pea) and sometimes flavors.
2. Adding water & kneading to form a dough.
3. Cooking the dough under pressure (optional).
4. Cooling and stretching the dough to form fibers (for meat alternatives).
5. Pushing the dough through an orifice to roll out sheets.
6. Cutting the sheets in the desired shape.

Benefits and Typical Foods

This versatile technology is mainly used to create textures of plant-based foods. It also inactivates harmful microbes and reduces anti-nutritional factors.



About the history

Food extrusion was developed in the 1930s and is used for many different products including dry pasta or breakfast cereals. In the 1950s, it was applied for pet food manufacturing. Recently extrusion has expanded as an alternative method to produce ice-cream or create plant-based alternatives to meat or seafoods.

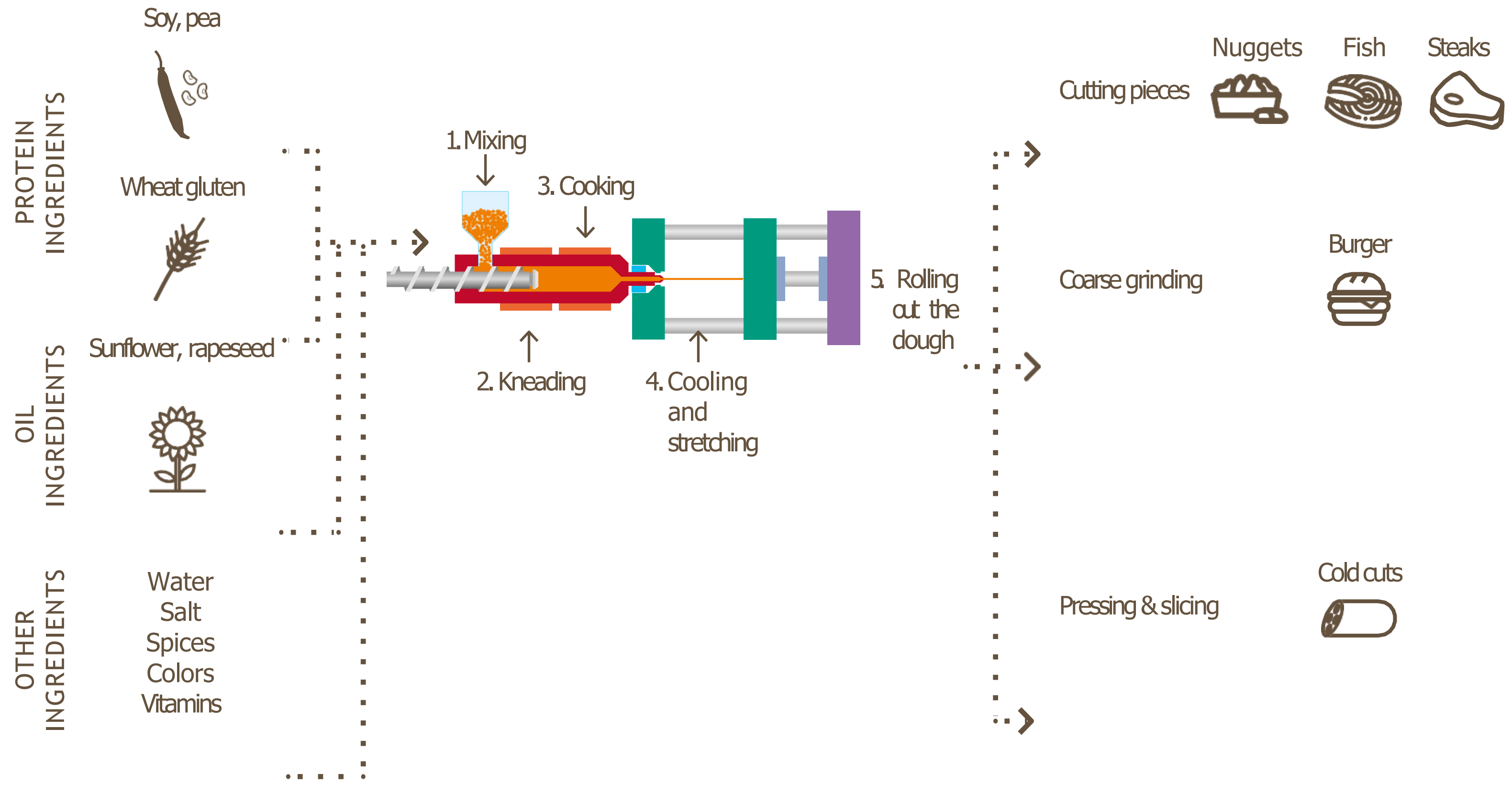
Shaping plant protein doughs

2.3 for meat & seafood alternatives

Use of different protein rich ingredients and adjustment of production parameters allow to create different textures with the same equipment.

How it works

Protein rich ingredients are blended with other ingredients such as water, oil and spices to knead a dough and exposed to heat and pressure to form the fibrous structure of e.g. meat and fish.



Generating small fat droplets to enhance

2.4 creaminess & product stability

What it is

Mixing two immiscible liquids such as oil and water and creating very fine oil droplets e.g. in an emulsion is called homogenization. This is achieved by pumping e.g. milk through small openings under high pressure.

Benefits and typical foods

Homogenization prevents the separation of oils in liquid dairy and culinary products such as milk, culinary sauces and salad dressings etc. and contributes to the creaminess of these products.

How it works - example the making of mayonnaise

1. Whisk an egg yolk; helps to stabilize the oil droplets.
2. Add vinegar or lemon juice.
3. Add drops of oil.
4. Whisk vigorously to break the oil into small droplets until thick and creamy.

About the history

Auguste Gaulin invented the first homogenizer. It was a simple machine, comprised of a piston pump that forced milk through a narrow tube while applying pressure. Yet the machine, patented in 1899, didn't gain traction with the general public until about 1919. At that time, people noticed the difference in quality between homogenized and non-homogenized milk.

Adapted from: https://www.thespruceeats.com/how-to-make-mayonnaise-996044

Enhancing nutrition

Tailoring to specific needs

- Enzymatic treatments and separation technologies such as extraction and filtration are used to isolate molecules from raw materials that provoke food intolerance (e.g. lactose).

- Foods produced for vegans and vegetarians are often enhanced with vitamin B12 which isn't found in plants, and soya drinks may be enriched with calcium for those who don't consume dairy products.

Enrichment, restoring & fortification

- Certain foods are enriched with proteins and fibers

- Food processing, conducted either in an industrial or domestic environment, can also lower the nutritional value of foods, particularly for heat sensitive water-soluble vitamins C, B1, B2, B6, and folic acid. To replenish losses, vitamins can be added after thermal processing, as a dry mix or by coating the product.

- Fortification refers to the addition of micronutrients to foods. It helps to address micronutrient deficiencies. A good example is iodine fortification of salt, as iodine deficiency is a common cause of goiter.

Improving digestibility

- Digestibility of plant nutrients can be impaired by anti-nutritional factors. For example, phytates and polyphenols reduce the uptake of minerals and trypsin inhibitors impair the digestibility of proteins. Thermal processing and the use of enzymes can effectively reduce some of these anti-nutritional factors.

- The bioavailability of the red tomato pigment lycopene, a powerful antioxidant, is increased in cooked tomatoes.

3

Enriching plant proteins to

3.1 obtain a desired nutritional value

What it is

Plant proteins are obtained from pulses and legumes such as soy and pea or cereals such as wheat (gluten). Soybeans can be eaten whole or made into a variety of products, including tofu, tempeh, soy milk and other dairy and meat alternatives.

How it works

Beyond proteins, seeds contain other components such as oil, starch and fibers. Proteins are enriched by separating the oil, fibers and starch as illustrated below.

1
Separation & cleaning of the soy seeds.

2
Crushing & milling.

3
Extracting the oil (for oil containing seeds only).

4
Separation of fibers & starch.

5
Further separation of fibers & starch.

Protein 36%
Oil 19%
Carbohydrates 28%
Moisture 13%
Minerals 4%
→

Full fat soy flour
36% protein.
→

Defatted soy flour
40-60% protein.
→

Soy protein concentrate
60-80% protein.
→

Soy protein isolate
More than 90% protein.

Benefits and typical foods

Providing plant-based alternatives to meat, dairy or sea food makes it easier for consumers to reduce their animal sourced product consumption.

Adding micronutrients

6.2 to close nutritional gaps

What it is

Adding micronutrients such as minerals and vitamins to foods is called fortification. It is a means of improving the nutritional status of a population or potentially a sub-population.

How it works

Micronutrients are added via dry mixing, coating or direct addition to liquids of regularly consumed food such as staples or condiments. Care must be taken, that the added micronutrients do not change the sensory aspects of the food. For instance, iron can react with food components, resulting in a change of color, or leading to an unpleasant off-taste.

Iodine and iron | Iron, folic acid | Vitamin A / D | Iron, vitamin A.

Benefits and typical foods

Food fortification is a safe and cost-effective strategy for improving diets. The main advantage of fortification and enrichment, compared to other methods that can increase the micronutrient content of the diet such as supplements, is that they don’t require people to change their eating habits. Scientifically proven benefits of micronutrients are:

1. **Iron** to prevent iron deficiency anemia and maintain cognitive and physical development.
2. **Iodine** for optimal brain development and a healthy metabolism.
3. **Vitamin A** for growth and development, good eye health, and a strong immune system.
4. **Zinc** for growth and development, and a strong immune system.

About the history

Food fortification began in 1920s with the addition of iodine to table salt to prevent goiter and was introduced also in Nestlé’s infant cereal Farine Lactée. With the discovery of the relationship between folic acid and neural tube defects, food fortification has gained traction in many countries worldwide.

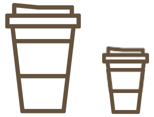
Optimizing raw material use

7 energy efficiency for sustainability

Waste reduction

Every year about 30% of the food production is lost along the value chain, mainly due to spoilage and food wasting. Strategies to valorize whole ingredients as well as optimized packaging solutions help to reduce waste.

Transforming side streams to valuable ingredients e.g. proteins and fibers in spent grains from malt production.

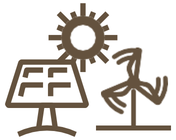


Packaging plays an important role in protecting and preserving food throughout the supply chain and portion sizing helps avoiding that one buys too much.

Use of recyclable or compostable packaging.

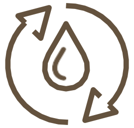
Energy and water use efficiency

Environmental impact of food production is reduced by using renewable energy sources as well as recuperating process energy and reuse of process water.



Use renewable solar or wind energy in manufacturing.

Using spent coffee grains as biofuel and heat recovery systems for food production and heating of buildings.



Reutilization of water removed form food during manufacturing in our zero water factories.

4

Other benefits: food diversity, convenience & affordability

Convenience

Pre-prepared ingredients or foods help to shorten the time of meal preparation and cleaning.

Some foods can be eaten immediately out of the packaging.

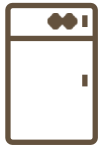
Bouillon cubes

Instant coffee

Others need some simple preparation such as adding some water, heating or thawing.

Food diversity

An increased food choice permitting a more diverse diet, is more likely to provide all the nutrients required for good health.



Freezing or drying of fruits and vegetables increase access to out of season harvest.

Plant-based alternatives to reduce consumption of animal-based proteins.

Drying milk increases access to high nutritious food produced elsewhere.

Affordability

Applying technologies at scale lowers cost while maintaining consistent quality.

Further readings

1. Weaver, C.M., et al., Processed foods: contributions to nutrition. Am J Clin Nutr, 2014. 99(6): p. 1525-42.
   - https://doi.org/10.3945/ajcn.114.089284

2. WBCSD, Processed food and its role in nutritious and sustainable diets. 2021. WBCSD. https://www.wbcsd.org/contentwbc/download/13469/196607/1

3. Safefood 360, I., Thermal Processing of Food. 2014.
   - http://www.tiselab.com/pdf/Thermal-Processing- of-Food.pdf

4. Rickman, J.C., D.M. Barrett, and C.M. Bruhn, Nutritional comparison of fresh, frozen and canned fruits and vegetables. Part 1. Vitamins C and B and phenolic compounds. Journal of the Science of Food and Agriculture, 2007. 87(6): p. 930-944. https://doi.org/10.1002/jsfa.2825

5. Misra, N.N., et al., Landmarks in the historical development of twenty first century food processing technologies. Food Res Int, 2017. 97: p. 318-339.
   - https://doi.org/10.1016/j.foodres.2017.05.001

6. McClements, D.J. and L. Grossmann, A brief review of the science behind the design of healthy and sustainable plant-based foods. NPJ Sci Food, 2021. 5(1): p. 17. https://www.nature.com/articles/s41538-021- 00099-y.pdf?origin=ppub

7. Gu, B.J., R.J. Kowalski, and G.M. Ganjyal, Food extrusion processing: An overview. 2017. Washington State University. http://pubs.cahnrs.wsu.edu/publications/wp-content/uploads/sites/2/publications/FS264E.pdf

8. International Food Information Council Foundation. 2010. What is a Processed Food? You Might be Suprised! https://foodinsight.org/wp-content/uploads/2019/08/IFIC_Handout_processed_foods. pdf

9. Amit, S.K., et al., A review on mechanisms and commercial aspects of food preservation and processing. Agriculture & Food Security, 2017. 6(1). https://doi.org/10.1186/s40066-017-0130-8

10. Food Processing IFT. https://doi.org/10.1002/jsfa.2825

esearch and
evelopment

Food Processing Classification

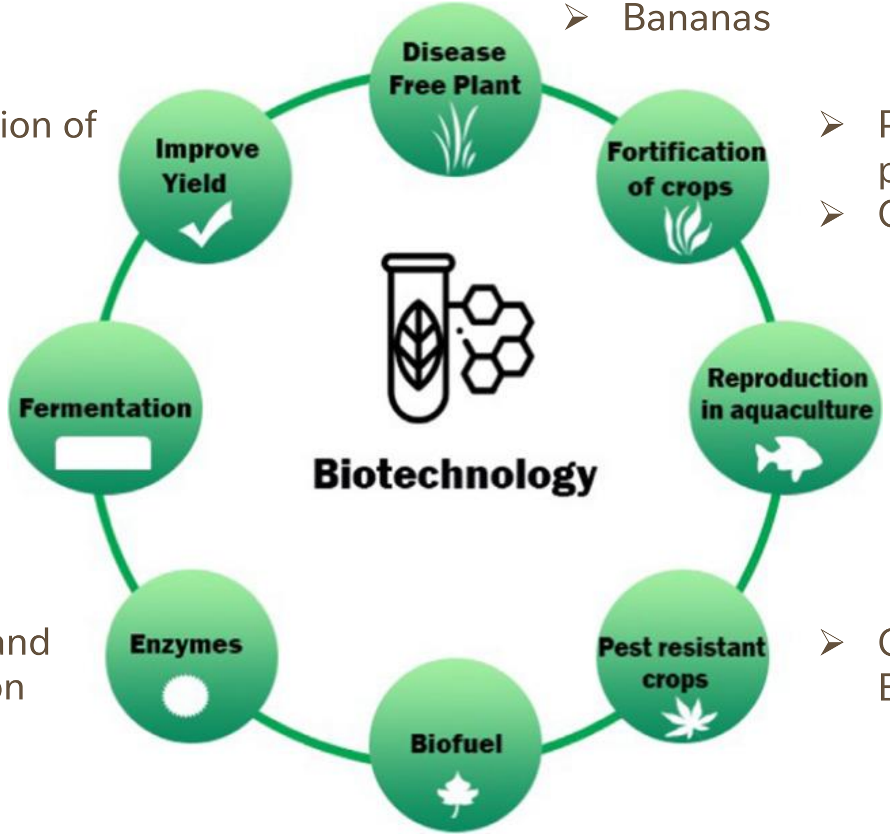
- Biological Processing
- Mechanical Processing
- Thermal Processing
- Chemical Processing

Biotechnology in Food and Agriculture

Biotechnology includes a **range of developed technologies** that create or modify a **product for applied purposes utilizing living organisms and/or substances** from these

Examples include:

- Increased milk production of cows due to higher Somatotropin levels
- Yogurt, cheese, kefir
- Kimchi, sauerkraut, Tempeh
- Use of carbohydrases and proteases for production of curd and cheese



- Bananas
- Potatoes with higher protein content
- Golden rice (ß-carotene)

- Salmon, trout
- Shrimps, oysters, crabs
- Cotton resistant to Bacillus thuringiensis

Fermentation

Fermentation is a metabolic process

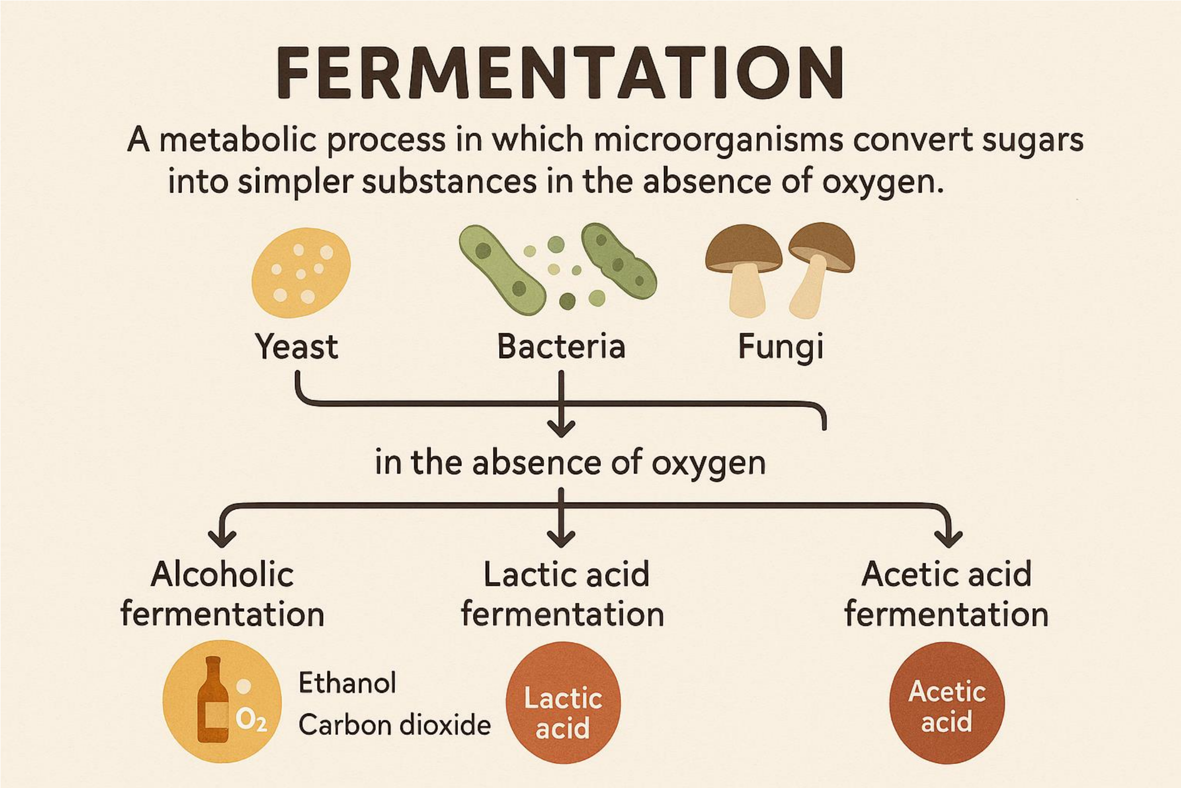
Microorganisms like bacteria, yeast, or fungi convert organic compounds—typically sugars—into simpler substances, such as acids, gases, or alcohol, in the absence of oxygen.

Types of fermentation

- Alcoholic fermentation: Yeast converts sugars into ethanol and carbon dioxide. This is used in brewing beer, making wine, and baking bread.
- Lactic acid fermentation: Bacteria convert sugars into lactic acid. This is used in making yogurt, sauerkraut, and kimchi.
- Acetic acid fermentation: Converts ethanol into acetic acid, used in vinegar production.

Fermentation

- Is used in food production, biotechnology, and in energy generation
- Is one of the oldest food processing methods used by humanity (7000 years B.C.)
- Improves safety through acidification
- Changes taste and texture of substrate
- Changes nutritional composition and Influences the gut microbiome

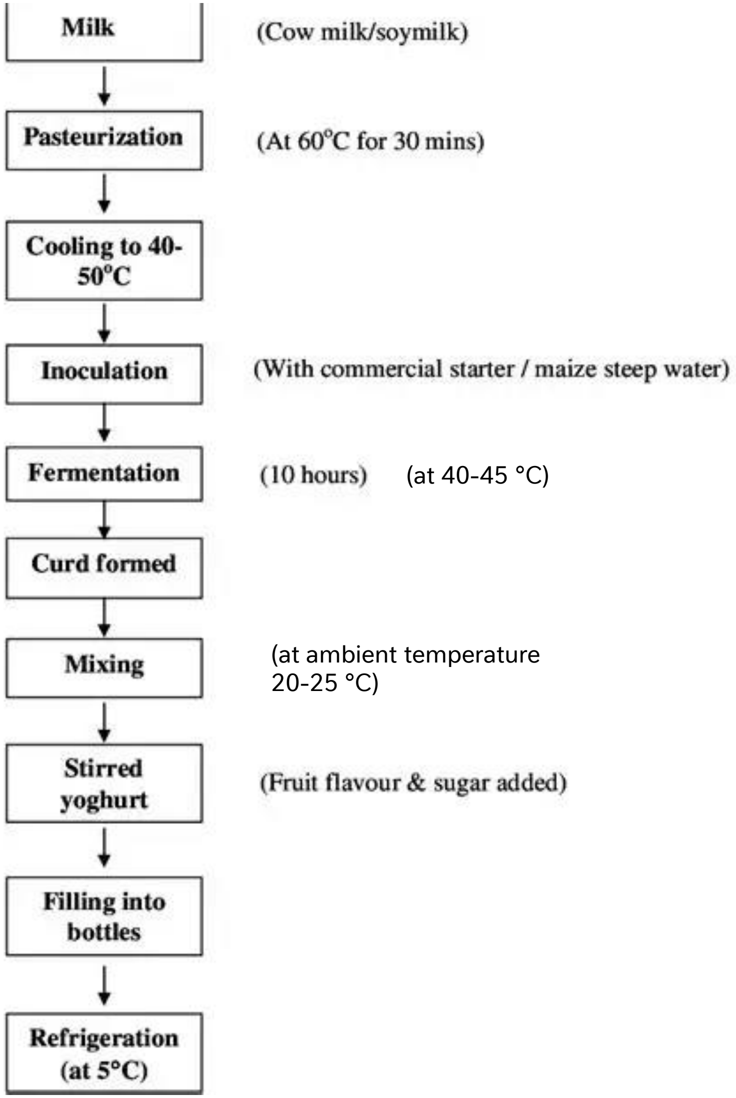


Gänzle, M. G.; Seifert, J.; Weiss, J.; Zijlstra, R. T. Food Fermentation: An Essential Unit Operation towards Secure, Sustainable, Safe, and Sustaining Food Systems. *Front Sci* **2025**, *3*. https://doi.org/10.3389/fsci.2025.1693920.

Liquid-state fermentation

- **Liquid-state fermentation (LSF)** is a bioprocess where microorganisms grow in a liquid medium with high moisture content, typically in controlled bioreactors
- It is commonly applied for the production of metabolites, enzymes, and other bioproducts, with process parameters such as pH, temperature and aeration regulated to optimize microbial activity

Yoghurt Production



Solid-state fermentation

- **Solid-state fermentation (SSF)** is a bioprocess where microorganisms grow on solid materials with little or no free water
- It replicates conditions similar to compost and is applied to convert biomass or waste into products such as enzymes, bioactive compounds and food ingredients
- Requires controlled parameters like temperature, pH and humidity

Tempeh Production

WHOLE SOYBEANS

↓

Cleaned

↓

Boiled for 30 min to facilitate hull removal

↓

Dehulled

↓

Soaked overnight (at ambient temperature 20-25 °C)

↓

Boiled for 60 min in soak water

↓

Drained and cooled

↓

Inoculated with *Rhizopus oligosporus* (at 30-35 °C)

↓

Wrapped or packed

↓

Incubated for up to 48 hr (at 30-35 °C)

↓

FRESH TEMPEH

Koji Fermentation

- **Koji** is a traditional Japanese fermentation starter made by cultivating fungi (primarily *Aspergillus oryzae)* on grains like **rice, wheat** or **soybeans**
- It plays a central role in producing miso, soy sauce, sake and other fermented foods, contributing enzymes that aid digestion and enhance flavor, aroma, and color

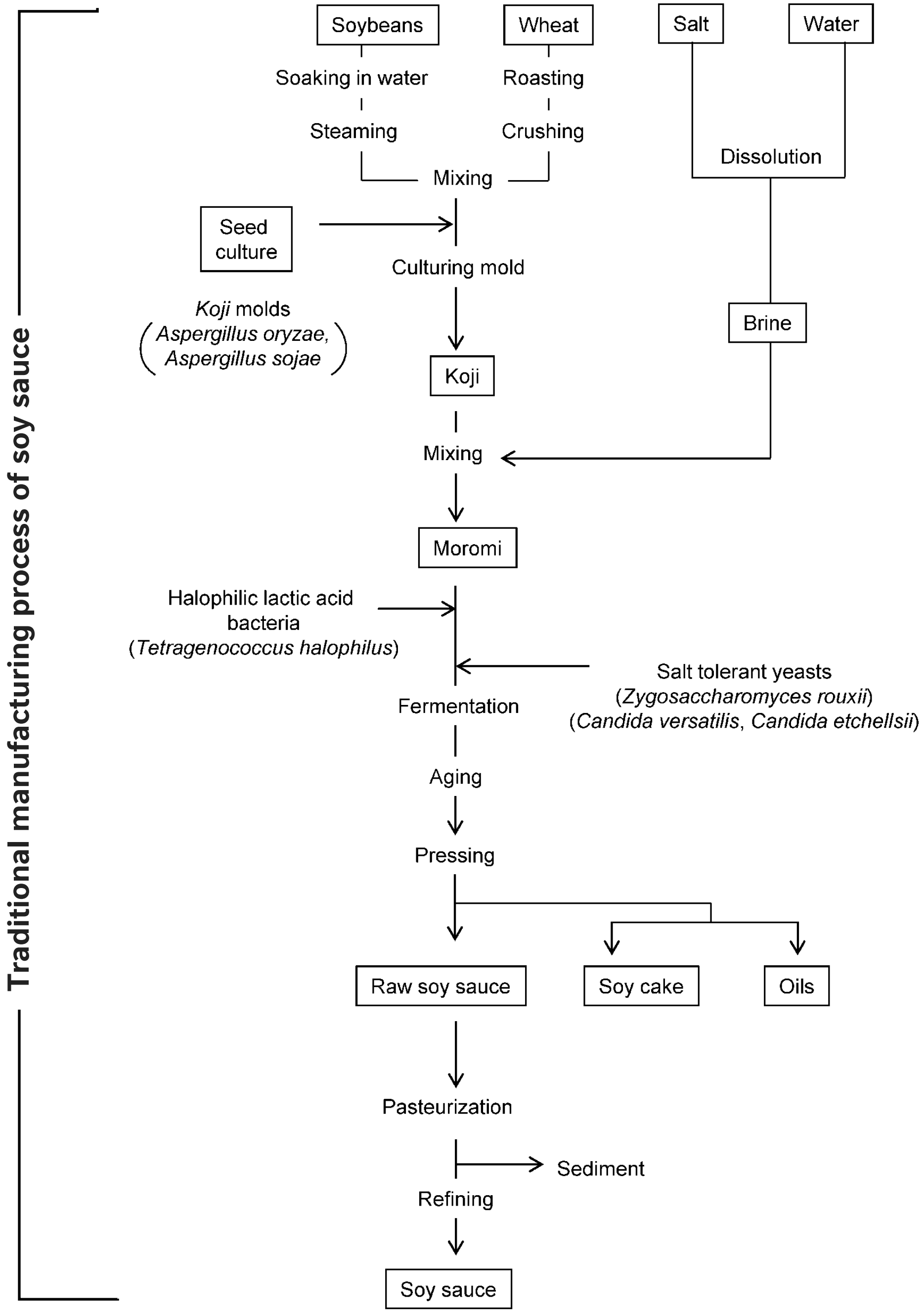
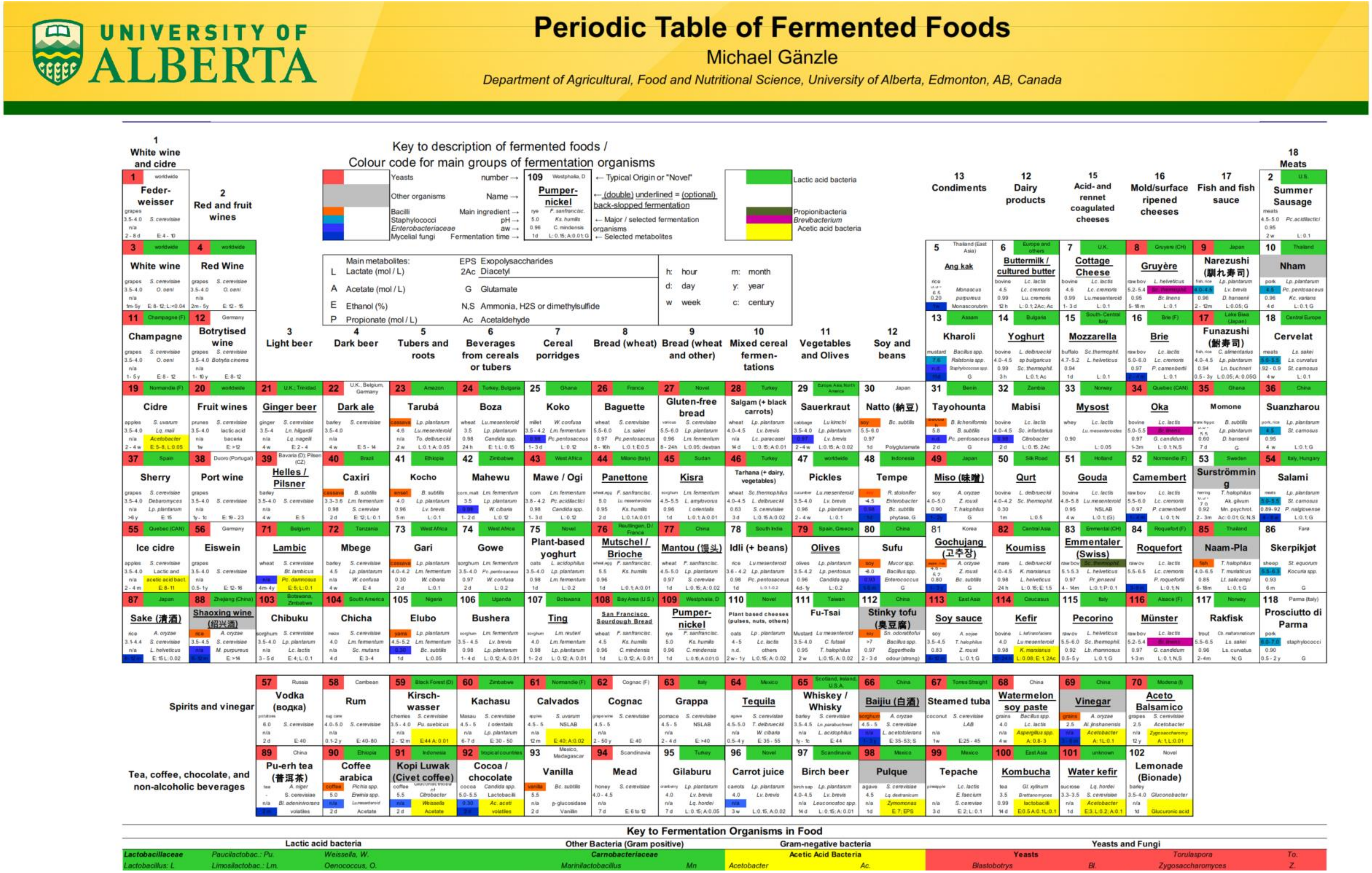
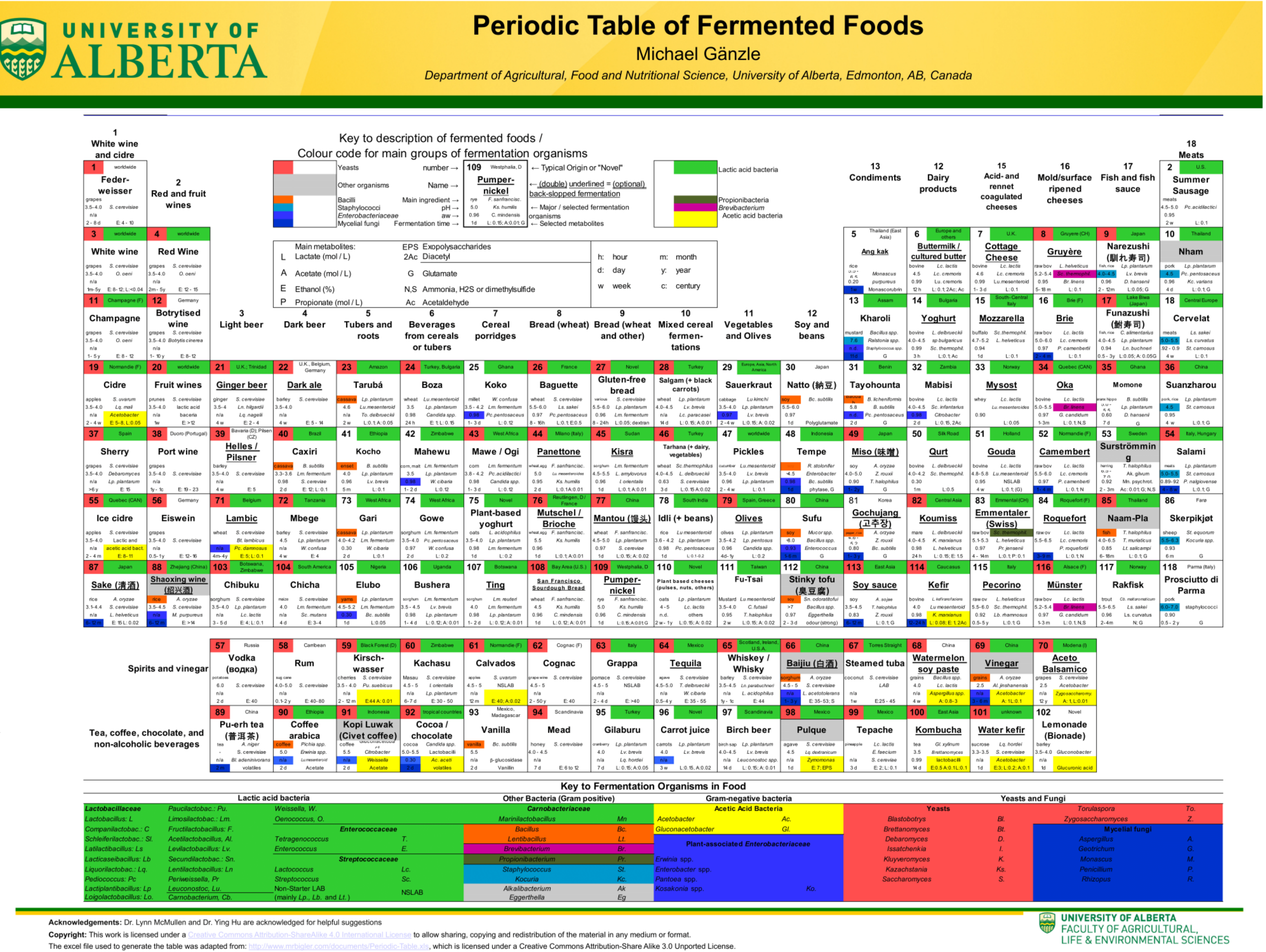


Figure: Ito, K., & Matsuyama, A. (2021). Koji Molds for Japanese Soy Sauce Brewing: Characteristics and Key Enzymes. *Journal of Fungi*, *7*(8), 658. https://doi.org/10.3390/jof7080658


UNIVERSITY OF ALBERTA
Periodic Table of Fermented Foods
Michael Gänzle
Department of Agricultural, Food and Nutritional Science, University of Alberta, Edmonton, AB, Canada
Key to description of fermented foods / Colour code for main groups of fermentation organisms
1 White wine and cidre
2 Red and fruit wines
3 Light beer
4 Dark beer
5 Tubers and roots
6 Beverages from cereals or tubers
7 Cereal porridges
8 Bread (wheat)
9 Bread (wheat and other)
10 Mixed cereal fermentations
11 Vegetables and Olives
12 Soy and beans
13 Condiments
12 Dairy products
15 Acid- and rennet coagulated cheeses
16 Mold/surface ripened cheeses
17 Fish and fish sauce
18 Meats
1 Federweisser
2 Summer Sausage
3 White wine
4 Red Wine
5 Ang kak
6 Buttermilk / cultured butter
7 Cottage Cheese
8 Gruyère
9 Narezushi (馴れ寿司)
10 Nham
11 Champagne
12 Botrytised wine
13 Kharoli
14 Yoghurt
15 Mozzarella
16 Brie
17 Funazushi (鮒寿司)
18 Cervelat
19 Cidre
20 Fruit wines
21 Ginger beer
22 Dark ale
23 Tarubá
24 Boza
25 Koko
26 Baguette
27 Gluten-free bread
28 Salgam (+ black carrots)
29 Sauerkraut
30 Natto (納豆)
31 Tayohounta
32 Mabisi
33 Mysost
34 Oka
35 Momone
36 Suanzharou
37 Sherry
38 Port wine
39 Helles / Pilsner
40 Caxiri
41 Kocho
42 Mahewu
43 Mawe / Ogi
44 Panettone
45 Kisra
46 Tarhana (+ dairy, vegetables)
47 Pickles
48 Tempe
49 Miso (味噌)
50 Qurt
51 Gouda
52 Camembert
53 Surströmming
54 Salami
55 Ice cidre
56 Eiswein
71 Lambic
72 Mbege
73 Gari
74 Gowe
75 Plant-based yoghurt
76 Mutschel / Brioche
77 Mantou (馒头)
78 Idli (+ beans)
79 Olives
80 Sufu
81 Gochujang (고추장)
82 Koumiss
83 Emmentaler (Swiss)
84 Roquefort
85 Naam-Pla
86 Skerpikjøt
87 Sake (清酒)
88 Shaoxing wine (绍兴酒)
103 Chibuku
104 Chicha
105 Elubo
106 Bushera
107 Ting
108 San Francisco Sourdough Bread
109 Pumpernickel
110 Plant based cheeses (pulses, nuts, others)
111 Fu-Tsai
112 Stinky tofu (臭豆腐)
113 Soy sauce
114 Kefir
115 Pecorino
116 Münster
117 Rakfisk
118 Prosciutto di Parma
Spirits and vinegar
57 Vodka (водка)
58 Rum
59 Kirschwasser
60 Kachasu
61 Calvados
62 Cognac
63 Grappa
64 Tequila
65 Whiskey / Whisky
66 Baijiu (白酒)
67 Steamed tuba
68 Watermelon soy paste
69 Vinegar
70 Aceto Balsamico
Tea, coffee, chocolate, and non-alcoholic beverages
89 Pu-erh tea (普洱茶)
90 Coffee arabica
91 Kopi Luwak (Civet coffee)
92 Cocoa / chocolate
93 Vanilla
94 Mead
95 Gilaburu
96 Carrot juice
97 Birch beer
98 Pulque
99 Tepache
100 Kombucha
101 Water kefir
102 Lemonade (Bionade)
Key to Fermentation Organisms in Food
Lactic acid bacteria
Other Bacteria (Gram positive)
Gram-negative bacteria
Yeasts and Fungi



Gänzle, M. The Periodic Table of Fermented Foods: Limitations and Opportunities. *Appl Microbiol Biotechnol* **2022**, *106* (8), 2815–2826. https://doi.org/10.1007/s00253-022-11909-y.

Concept of the Periodic Table of Fermentation

Goal: map diversity of fermented foods

Represent and organize major fermentation substrates, processes, and organisms

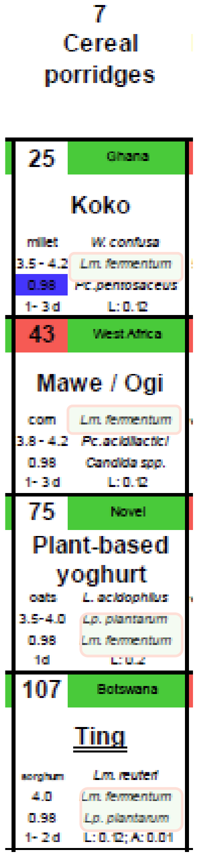
Find common patterns

Guide development of novel food using traditional fermentation techniques (gluten-free bread, plant-based yogurt, insect proteins)

Example: Plant-based **yogurt** – more similar to fermentation of cereal porridges than traditional dairy products/**yogurts**

Similar pH (3.5-4.2)
Similar fermentation time (1-3 days)

Dairy products: pH 4.0-4.5
Traditional yogurt: several hours



Similar microbial organisms

Dairy products: different microbes!

Gänzle, M. The Periodic Table of Fermented Foods: Limitations and Opportunities. *Appl Microbiol Biotechnol* **2022**, *106* (8), 2815–2826. https://doi.org/10.1007/s00253-022-11909-y.

Examples

Key to description of fermented foods / Colour code for main groups of fermentation organisms

Yeasts	number →	109 / Westphalia, D	← Typical Origin or "Novel"
Other organisms	Name →	Pumper-nickel	← (double) underlined = (optional) back-slopped fermentation
Bacilli	Main ingredient →	rye / *F. sanfrancisc.*	← Major / selected fermentation organisms
Staphylococci	pH →	5.0 / *Ks. humilis*	
Enterobacteriaceae	aw →	0.96 / C. mindensis	
Mycelial fungi	Fermentation time →	1d / L: 0.15; A:0.01; G	← Selected metabolites

Lactic acid bacteria; Propionibacteria; *Brevibacterium*; Acetic acid bacteria

Bread (wheat)

26	France
Baguette	
wheat	*S. cerevisiae*
5.5-6.0	*Ls. sakei*
0.97	*Pc.pentosaceus*
8 - 16h	L:0.1; E:0.5
44	Milano (Italy)
Panettone	
wheat,egg	*F. sanfrancisc.*
5.0	*Lu. mesenteroides*
0.95	*Ks. humilis*
2 d	L:0.1A:0.01
76	Reutlingen, D / France
Mutschel / Brioche	
wheat,egg	*F. sanfrancisc.*
5.5	*Ks. humilis*
0.96	
1d	L:0.1; A:0.01
108	Bay Area (U.S.)
San Francisco Sourdough Bread	
wheat	*F. sanfrancisc.*
4.5	*Ks. humilis*
0.96	*C. mindensis*
1d	L: 0.12; A: 0.01

Mold/surface ripened cheeses

8	Gruyere (CH)
Gruyère	
raw bov	*L. helveticus*
5.2-5.4	*Sc. thermophil.*
0.95	*Br. linens*
5-18 m	L: 0.1
16	Brie (F)
Brie	
raw bov	*Lc. lactis*
5.0-6.0	*Lc. cremoris*
0.97	*P. camenbertii*
2 - 4 m	L: 0.1
34	Quebec (CAN)
Oka	
bovine	*Lc. lactis*
5.0-5.5	*Br. linens*
0.97	*G. candidum*
1-3m	L: 0.1; N,S
52	Normandie (F)
Camembert	
raw bov	*Lc. lactis*
5.5-6.0	*Lc. cremoris*
0.97	*P. camenberti*
1 - 4 m	L: 0.1; N

Spirits and vinegar →

69	China	70	Modena (I)
Vinegar		**Aceto Balsamico**	
grains	*A. oryzae*	grapes	*S. cerevisiae*
2.5	*Al. jinshanensis*	2.5	*Acetobacter*
n/a	*Acetobacter*	n/a	*Zygosaccharomy.*
3 - 6 m	A: 1L:0.1	12 y	A: 1, L:0.01

Tea, coffee, chocolate, and non-alcoholic beverages →

101	unknown	102	Novel
Water kefir		**Lemonade (Bionade)**	
sucrose	*Lq. hordei*	barley	
3.3-3.5	*S. cerevisiae*	3.5-4.0	*Gluconobacter*
n/a	*Acetobacter*	n/a	
1d	E:3; L:0.2; A:0.1	1d	Glucuronic acid

Periodic Table of Fermentation - Limitations

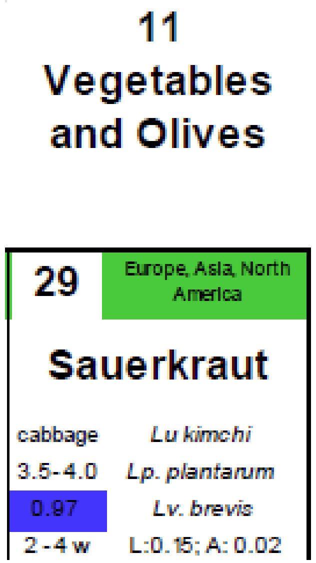
Impossible to represent all fermented foods from different cultures/continents (Africa and Asia are underrepresented)

Selection of fermented foods is arbitrary

Difficult to represent different ingredients and spices used during fermentation processes

Alternative periodic table tries to emphasize diversity, but lacks information about detailed processes

Example: Sauerkraut



Original: emphasis on production process

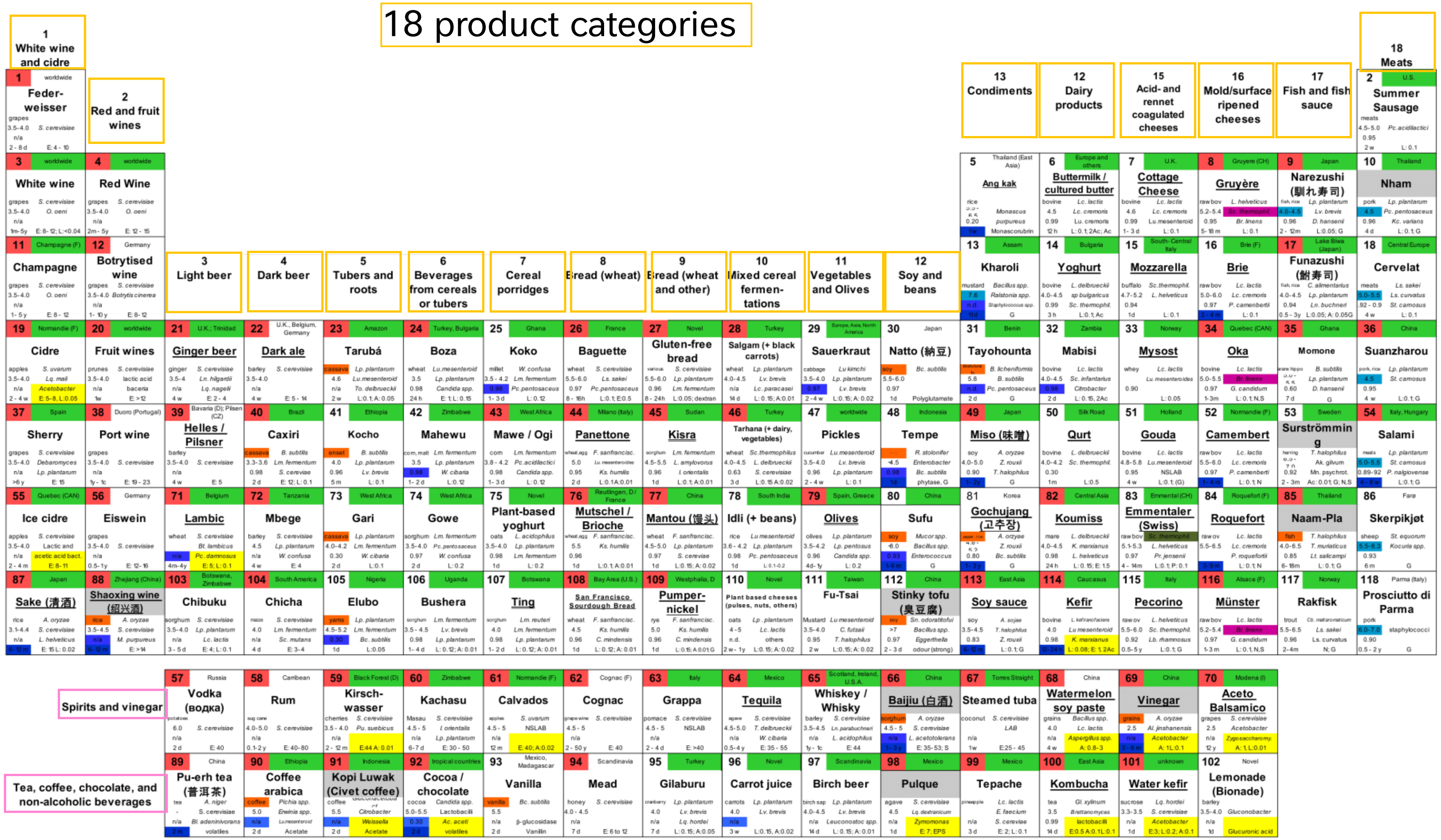
Alternative: emphasis on cultural diversity

Gänzle, M. The Periodic Table of Fermented Foods: Limitations and Opportunities. *Appl Microbiol Biotechnol* **2022**, *106* (8), 2815–2826. https://doi.org/10.1007/s00253-022-11909-y.

The periodic table of fermented foods

Structure of the periodic table itself:

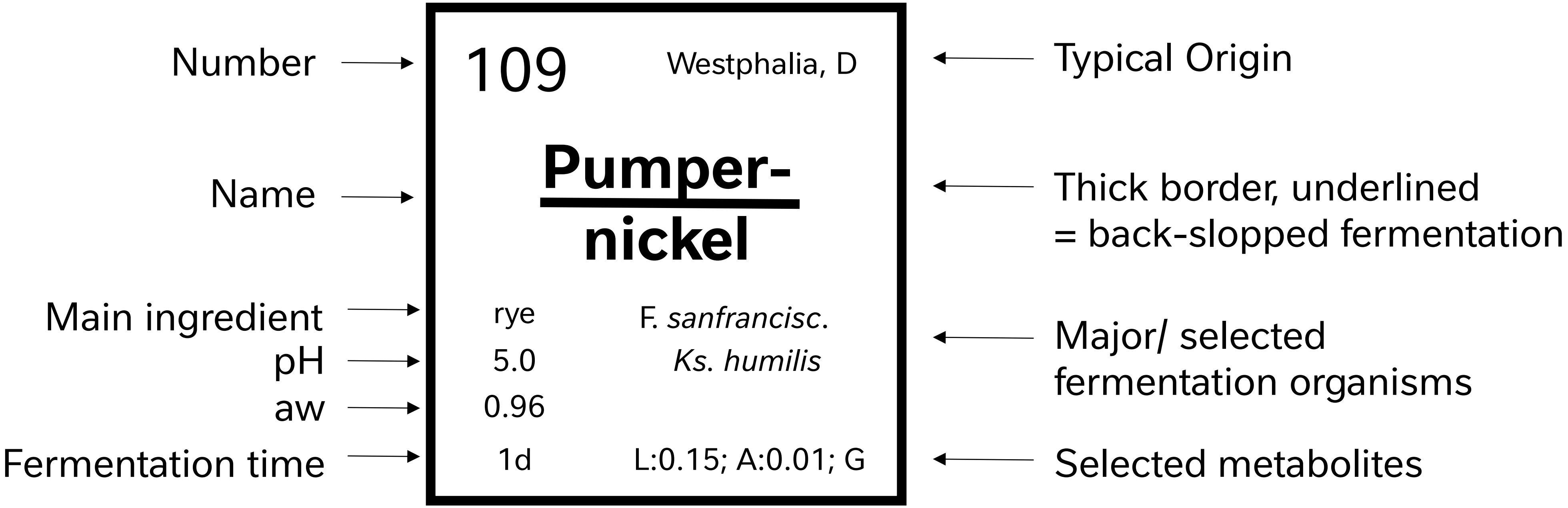
18 product categories



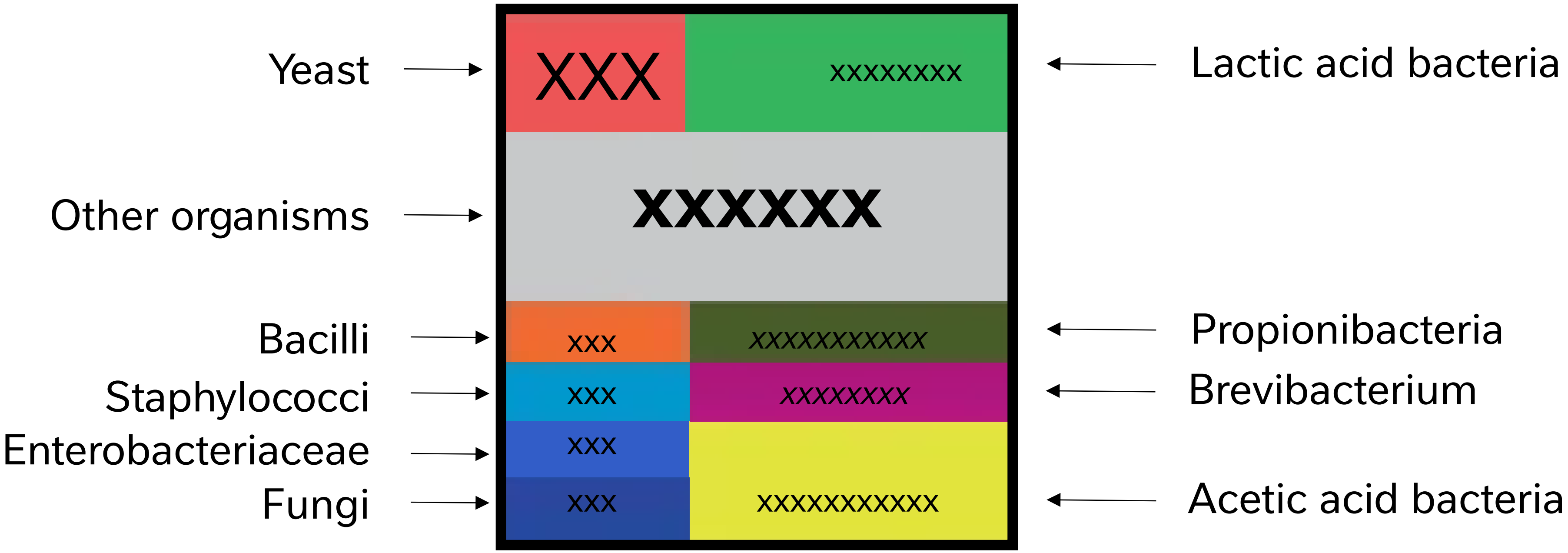
2 specialty product categories

Legend for Organisms

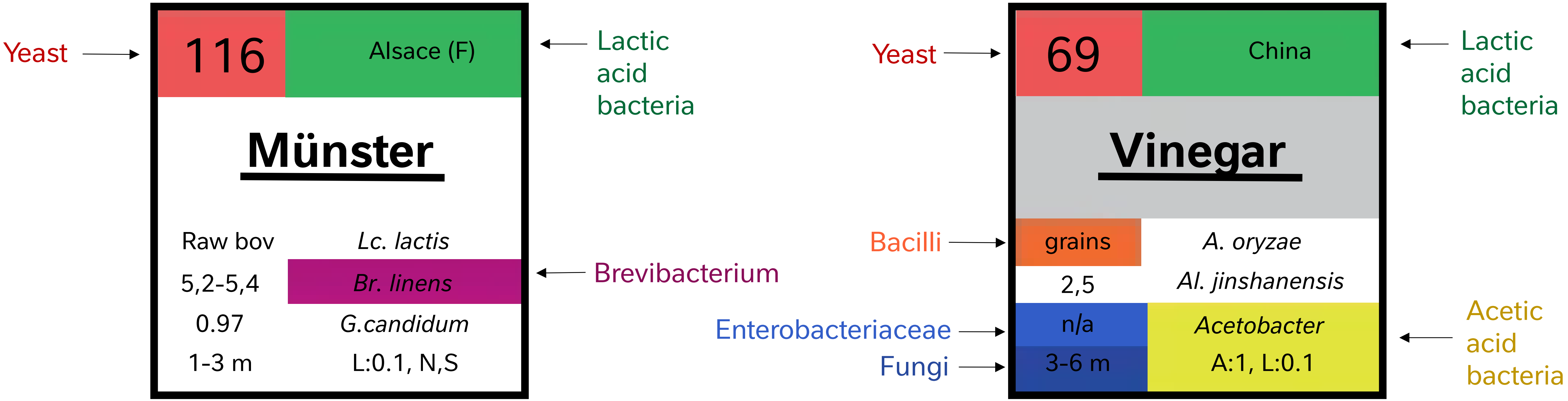
Key description



Colour code


Yeast
XXX
xxxxxxxx
Lactic acid bacteria
Other organisms
xxxxxx
Bacilli
xxx
xxxxxxxxxxx
Propionibacteria
Staphylococci
xxx
xxxxxxxx
Brevibacterium
Enterobacteriaceae
xxx
Fungi
xxx
xxxxxxxxxxx
Acetic acid bacteria

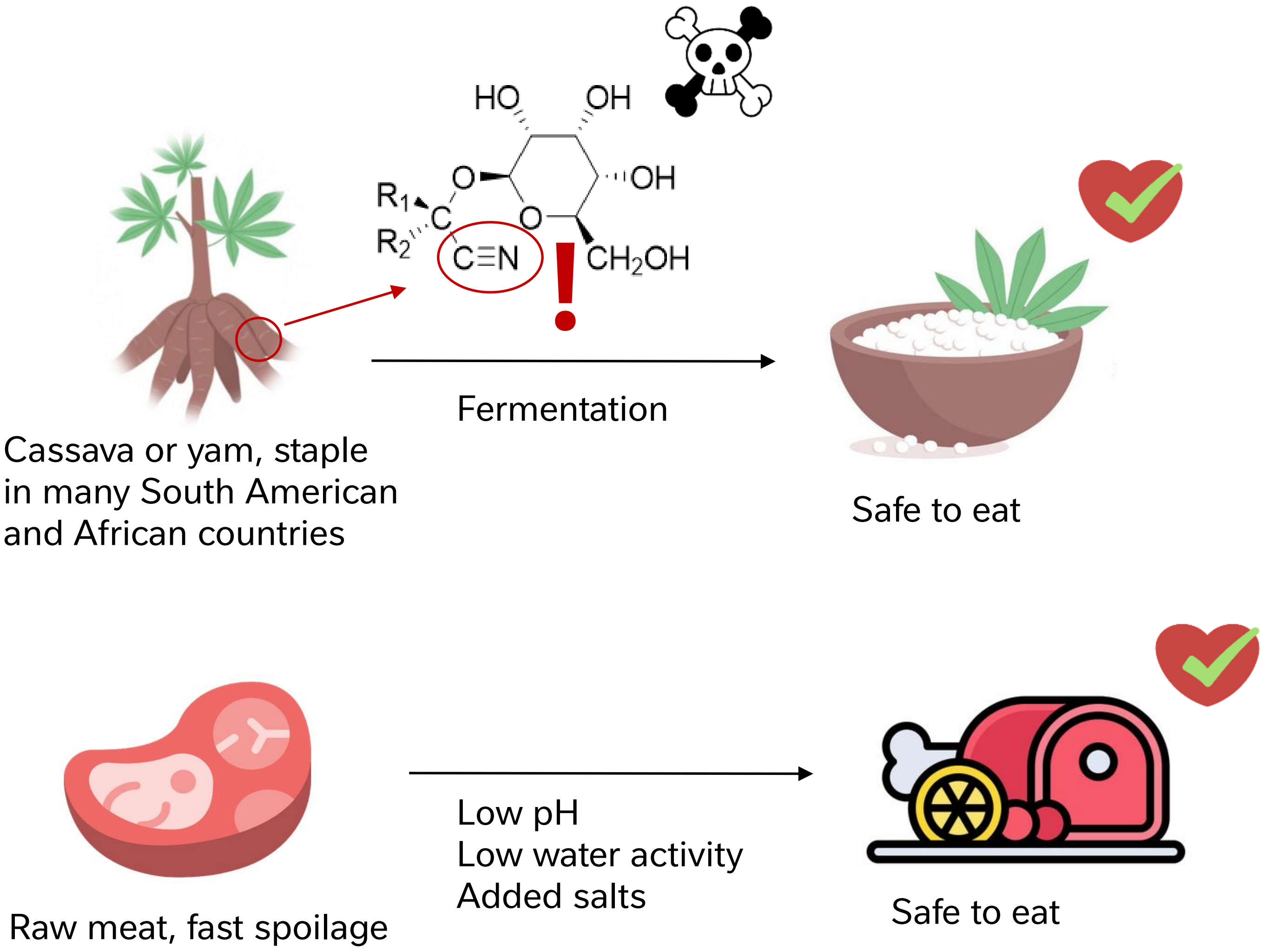
Examples



Yeast
116
Alsace (F)
Lactic acid bacteria
Münster
Raw bov
Lc. lactis
5,2-5,4
Br. linens
Brevibacterium
0.97
G.candidum
1-3 m
L:0.1, N,S
Yeast
69
China
Lactic acid bacteria
Vinegar
Bacilli
grains
A. oryzae
2,5
Al. jinshanensis
Enterobacteriaceae
n/a
Acetobacter
Acetic acid bacteria
Fungi
3-6 m
A:1, L:0.1

Fermentation and Food Safety and Security

- Cassava and certain yam varieties contain cyanogenic glucosides, which release cyanide after hydrolysis of the glycosidic bond.
- Hydrolysis by the intestinal microbiome after ingestion releases cyanide and leads to chronic intoxication
- Fermenting the food, however, enables hydrolysis of the cyanogenic glucosides, releasing the cyanide prior to ingestion and making the product safe.
- Lacticaseibacillus mannihotivorans and Lactiplantibacillus plantarum are particularly effective at this process.



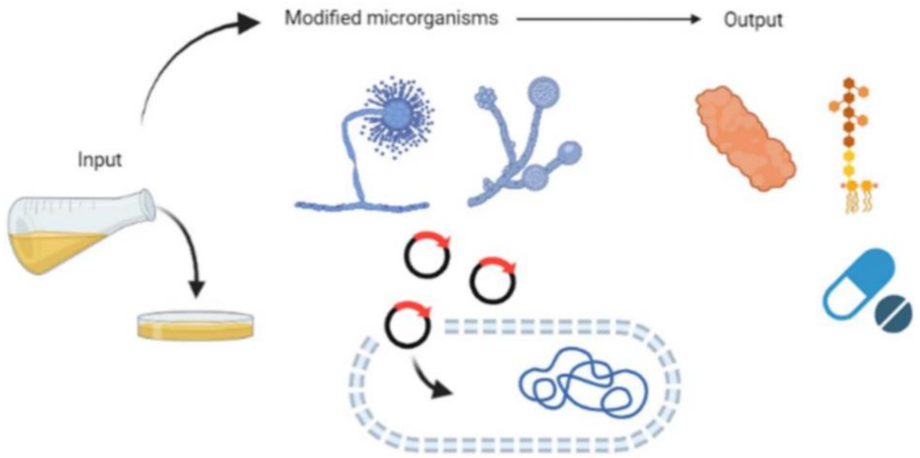
Gänzle, M. G.; Seifert, J.; Weiss, J.; Zijlstra, R. T. Food Fermentation: An Essential Unit Operation towards Secure, Sustainable, Safe, and Sustaining Food Systems. *Front Sci* **2025**, *3*. https://doi.org/10.3389/fsci.2025.1693920.

Precision fermentation

Use of genetic engineering, to insert specific genes into the DNA backbone of single-celled organisms and microorganisms to produce desired fermentation properties and products

- Aim: designing optimized metabolic pathways and assembling the genes involved in the microbial chassis
- To analyze and characterize microbial genomes and metabolic functions, this technology relies heavily on artificial intelligence, bioinformatics, systems biology, and computational biology

- Applications:
  - Production of specific compounds such as biotin, folic acid, riboflavin
  - Production of complex organic molecules, e. g. oligosaccharides
  - ...



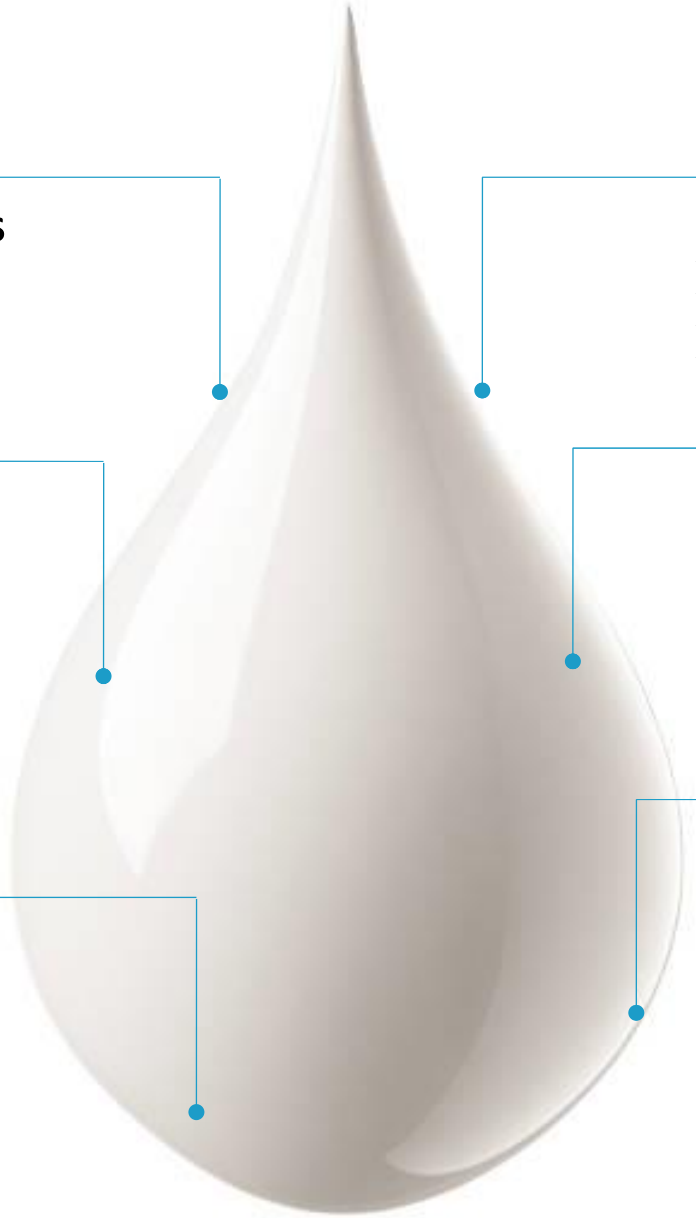
Process-Structure-Property Relationships in Food Derived From Milk

Get an understanding of the:

- Process-Structure-Property relationships in foods derived from milk
- Parameters to control to produce foods from milk
- Complexity in real food products and how to deal with it

MILK - OUR FIRST FOOD

A DROP OF THE GOOD STUFF



CARBOHYDRATES
Lactose
Oligosaccharides
Bifidus factors
Glycopeptides

FAT-SOLUBLE VITAMINS
Vitamin A & carotene
Vitamin D
Vtiamin E
Vtiamin K

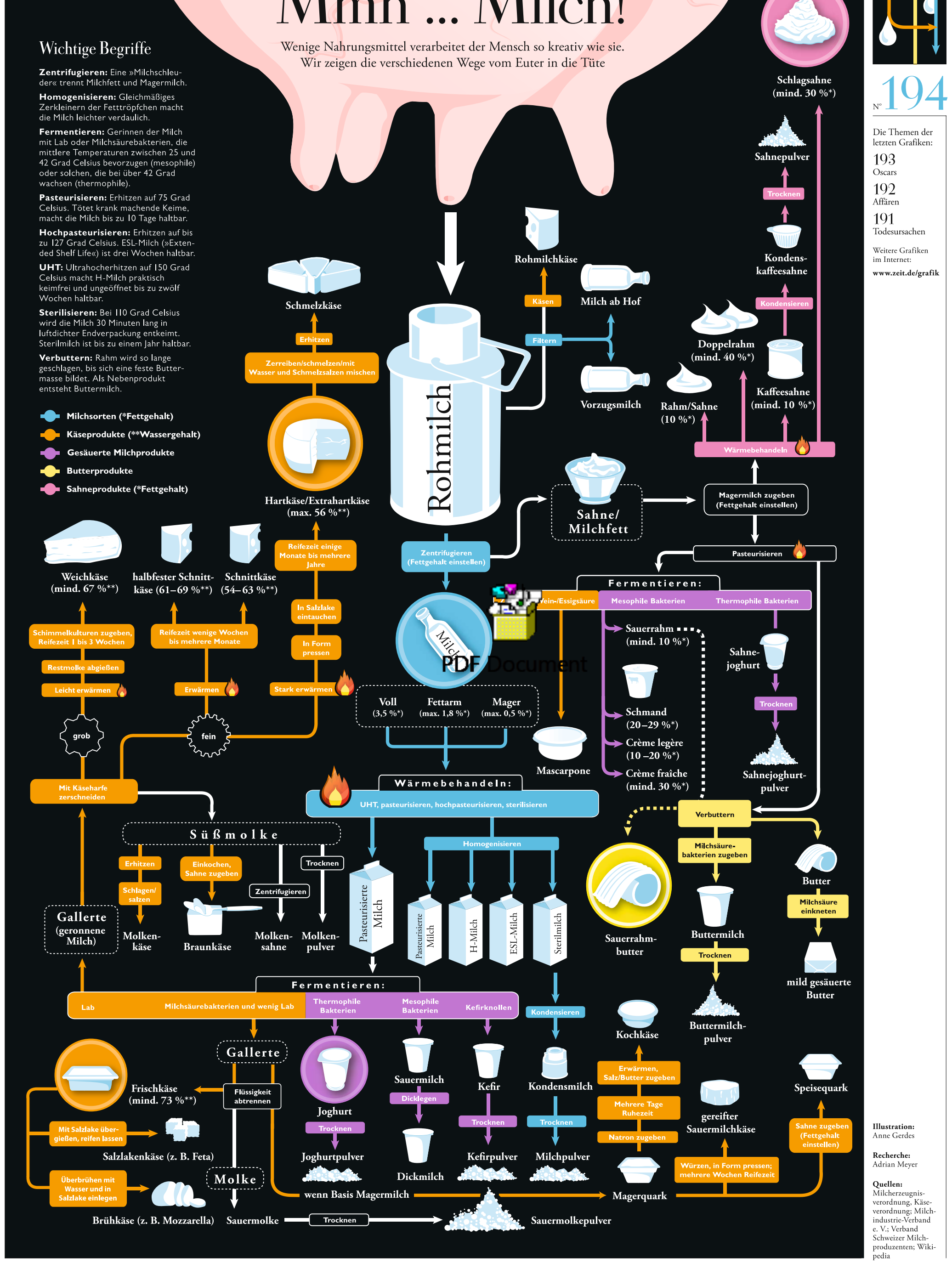
PROTEINS
Caseins
α-Lactalbumin
β-Lactoglobulin
Lactoferrin
Immunoglobulins
Enzymes
Hormones

N-COMPOUNDS
Urea
Creatine
Creatinine
Uric acid
Glucosamine
Nucleic acids
Nucleotides
Polyamines

WATER-SOLUBLE VITAMINS
Thiamin
Riboflavin
Niacin
Pantothenic acid
Biotin
Folate
Vitamin B6
Vitamin B12
Vitamin C
Inositol
Choline

LIPIDS
Triglycerides
Fatty acids
Phospholipids
Sterols

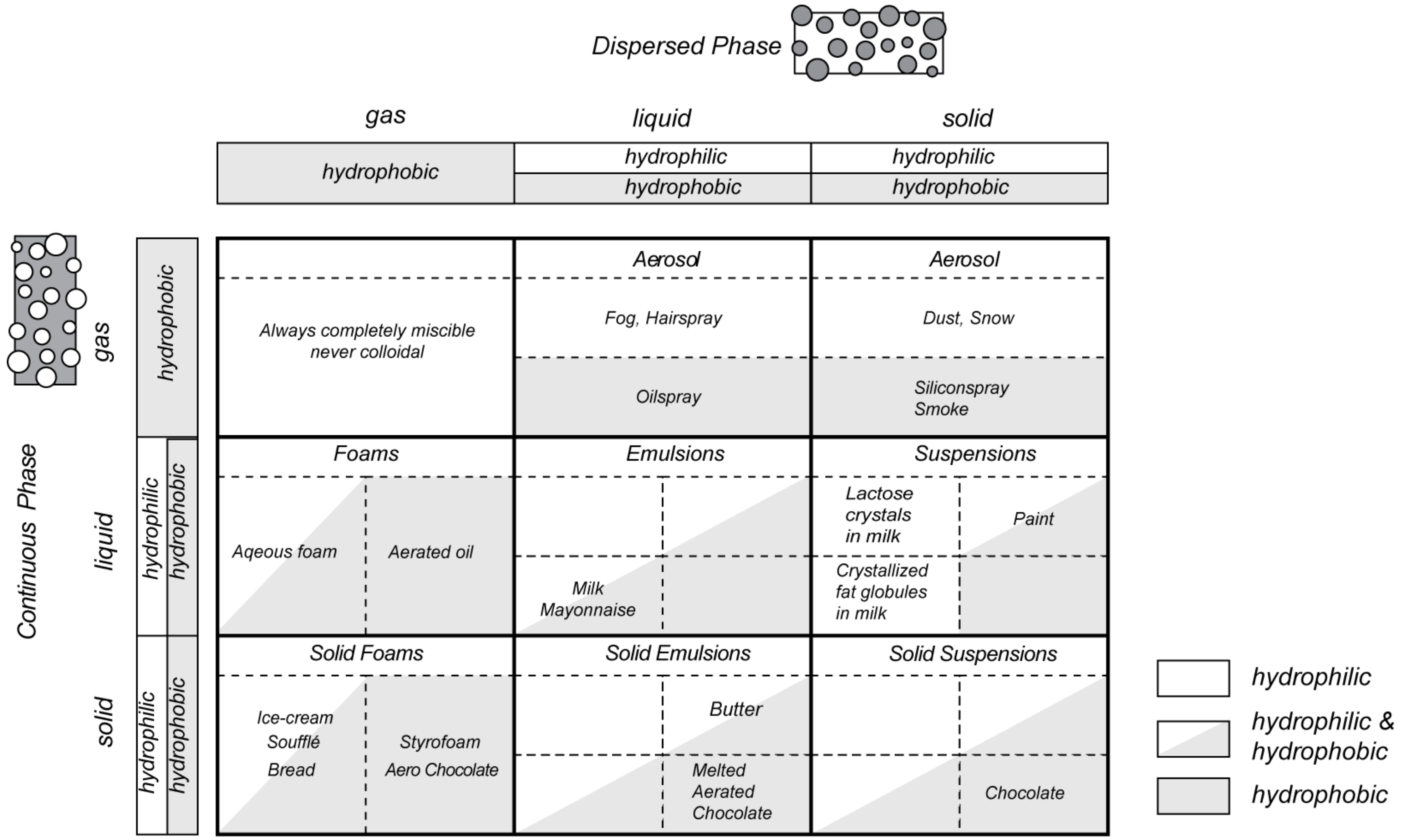
MINERALS
Calcium
Phosphorus
Magnesium
Potassium
Sodium
Chlorine
Sulfur
Iodine
Iron
Copper
Zinc
Manganese
Selenium
Chromium
Cobalt



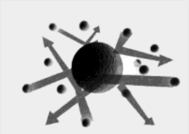
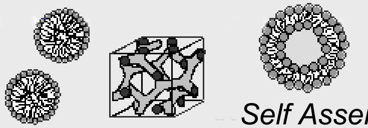
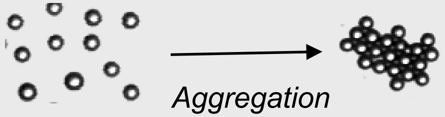
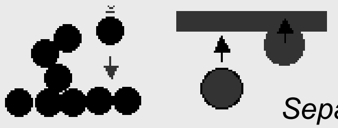
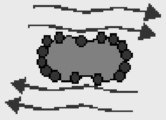
PDF Document

Research and Development

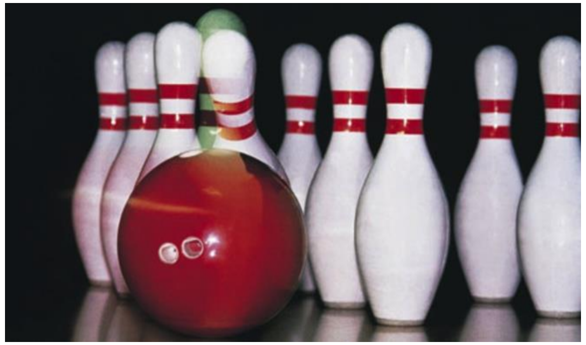
CONCEPT MAP - THE COLLOID WORLD

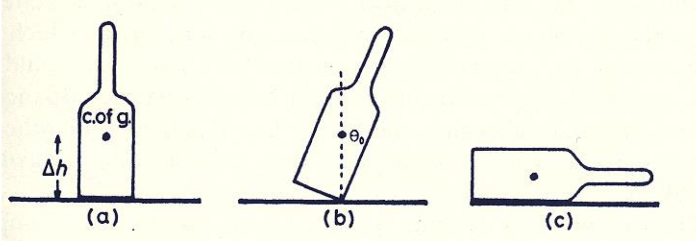


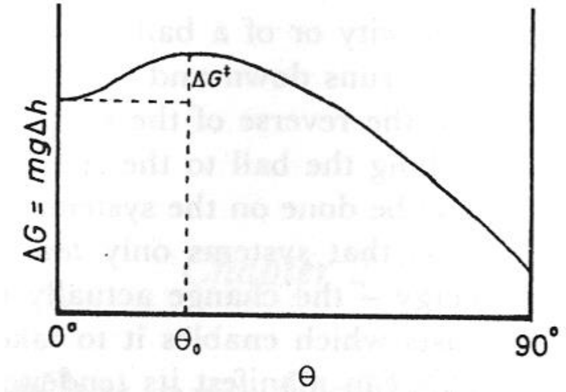
CONCEPT MAP - IMPORTANCE OF FORCES

Physical Interactions **Brownian movements due to random thermal forces**	
Molecular Interactions **van der Waals, Electrostatic and Hydration Forces (short range)**	
Particle Interactions **van der Waals, Electrostatic and Steric Forces (short range)**	
Gravitational forces **(long range)**	
Hydrodynamic forces **(long range)**	

Weak physical forces play an important role in dispersion and association colloids. Various forces act on different length scales.

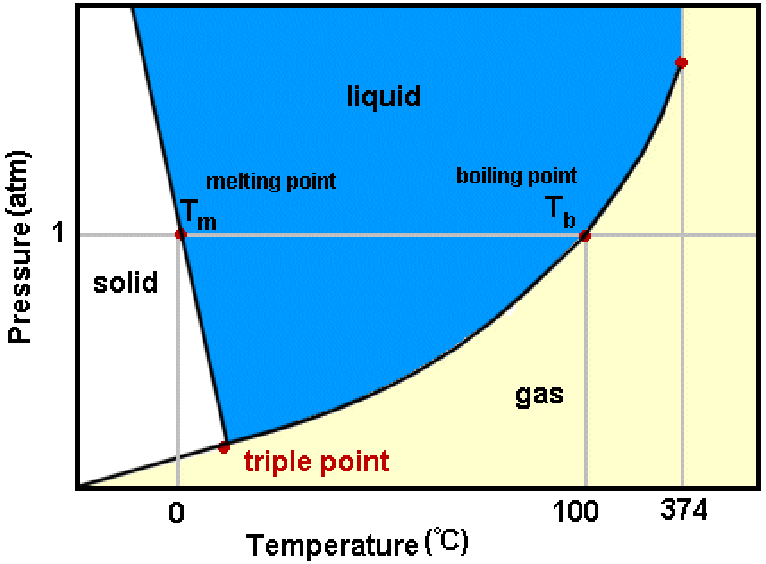






CONCEPT MAP - IMPORTANCE OF STATE OF MATTER

Phase Diagram of Water



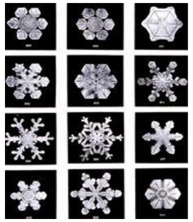
Gel

- Covalent polymeric network
- Polymer networks formed through physical aggregation
- Particle networks
- Mesophase structures

Crystalline materials

- Most ordered state of a molecular arrangement
- Incorporation of foreign molecules is excluded, except water in hydrated crystals


Sugar Crystal


Snow flakes

Amorphous materials

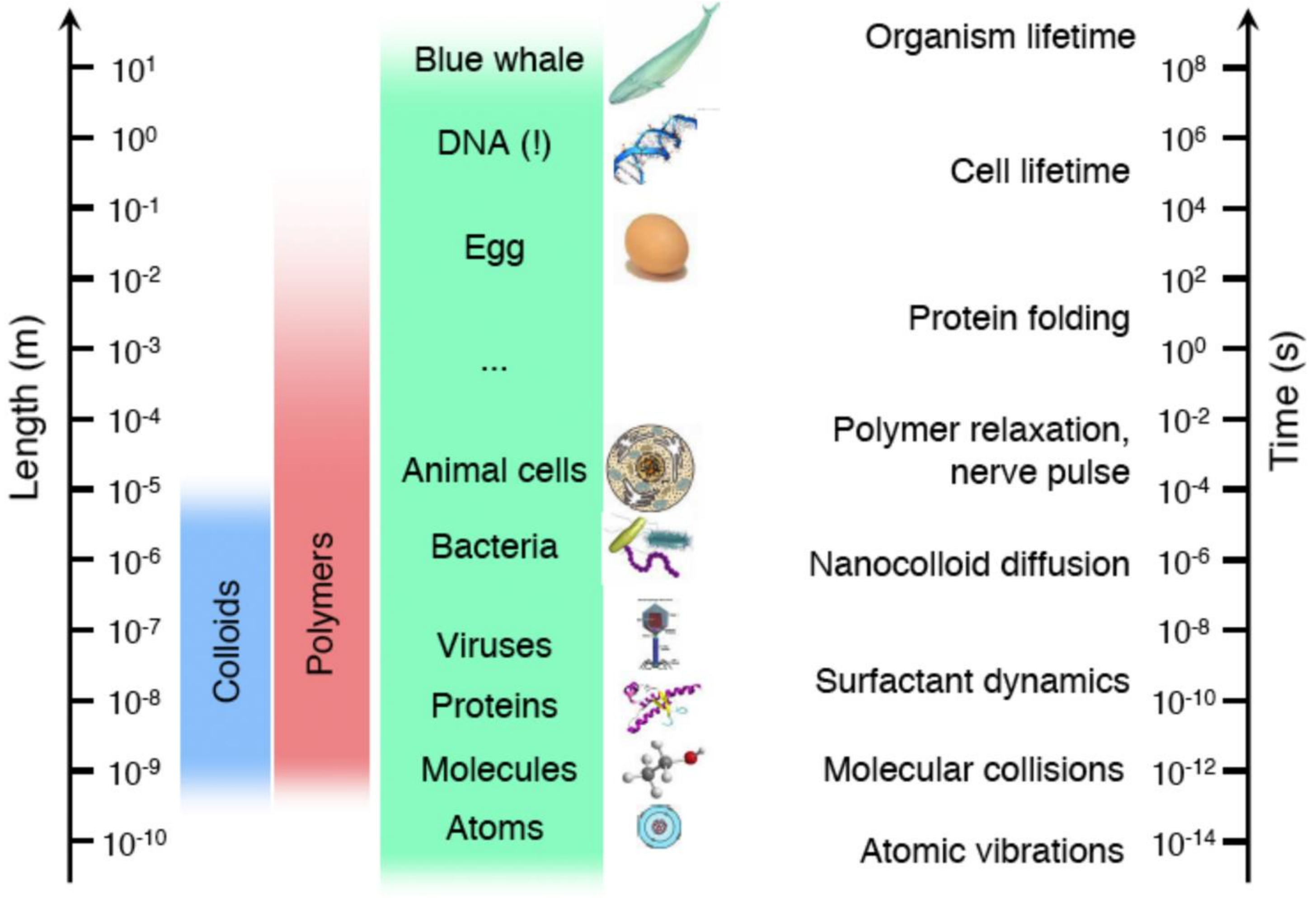
- No long-range molecular order
- Possibility to incorporate foreign molecules


Wax


Cotton candy

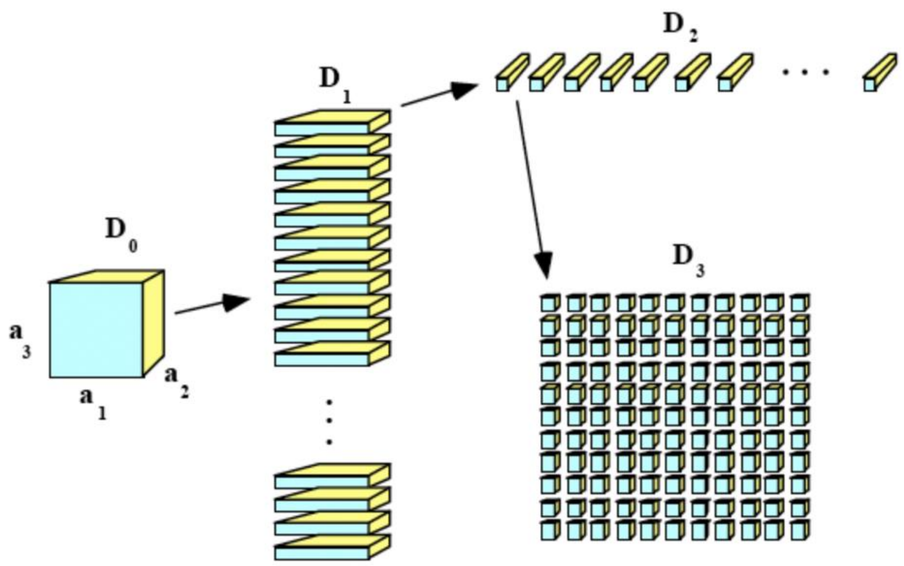
Research and Development

CONCEPT MAP - IMPORTANCE OF SCALE



- Scales in Dispersions
- Size of the dispersed phase particles in foods is from nanometers to several micrometers
- The time scale for production is rather short (micro to milliseconds)
- Separation process can range from minutes to years.
- **Most dispersions are characterized by a large surface area**

CONCEPT MAP - IMPORTANCE OF SURFACE AREA



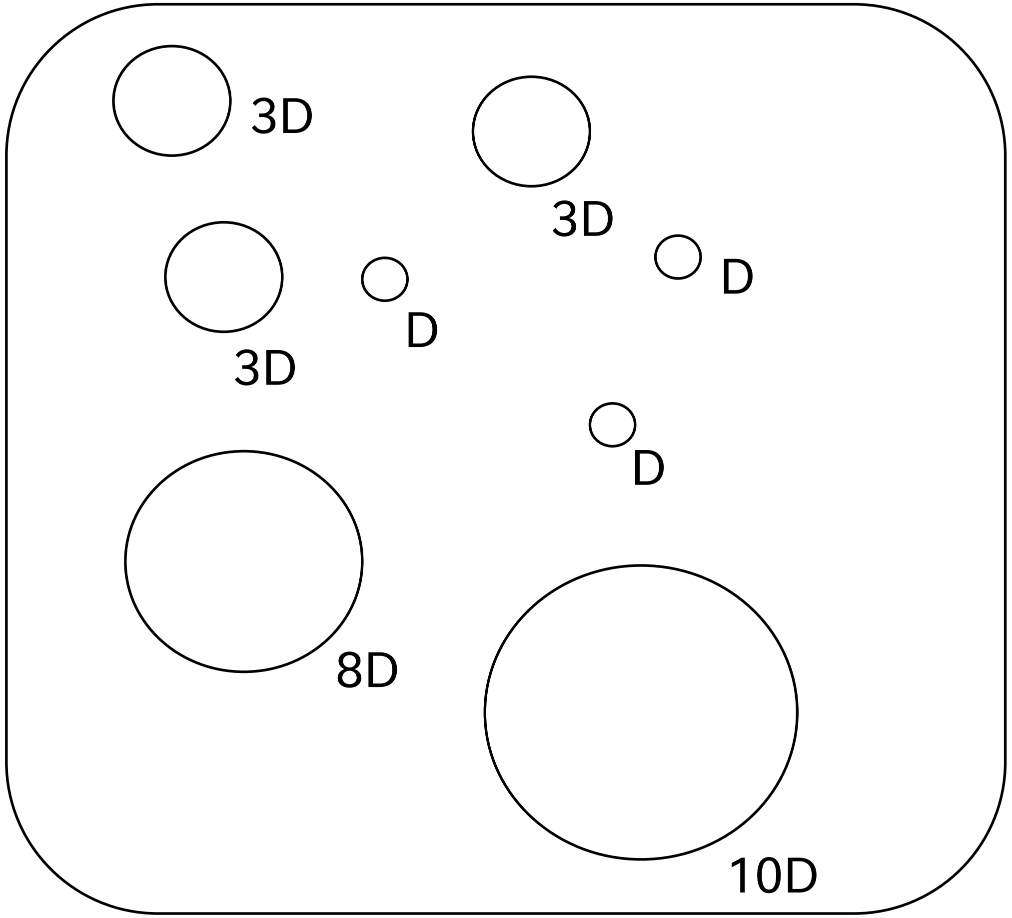
length of cube	amount	overall surface
1 cm	1	6 cm2
1 mm	1000	60 cm2
0,1 mm	1'000'000	600 cm2
10 µm	1'000'000'000	6000 cm2
1 µm	1'000'000'000'000	6 m2
0,1 µm	1 e+15	60 m2
10 nm	1 e+18	600 m2

Sauter Diameter: the diameter of a sphere that has the same volume-to-surface ratio as the entire particle distribution.

$$D_{3,2} = \frac{\sum_i^{N_p} n_i D_i^3}{\sum_i^{N_p} n_i D_i^2}$$

How can you calculate the surface-to-volume ratio from the Sauter diameter ?

Sauter Diagram Example



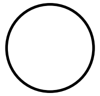
$$D_{3/2} = \frac{(3 * D^3 + 3 * (3D)^3 + 1 * (8D)^3 + 1 * (10D)^3)}{(3 * D^2 + 3 * (3D)^2 + 1 * (8D)^2 + 1 * (10D)^2)}$$

$$= \frac{D^3 \quad * \quad 3 + 3 * 3^3 + 8^3 + 10^3}{D^2 \quad * \quad 3 + 3 * 3^2 + 8^2 + 10^2}$$

$$= D \quad * \frac{3 + 3^4 + 8^3 + 10^3}{3 + 3 * 3^2 + 8^2 + 10^2}$$

$$= D \quad * \frac{1596}{194}$$

$$= 8.22 * D$$

 = Drops

XD = X*Diameter

CONCEPT MAP – PARAMETERS TO CONTROL

Time

Temperature

Mechanical Stress

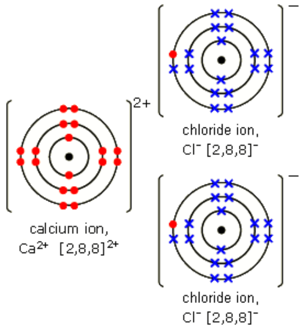
Ionic Strength

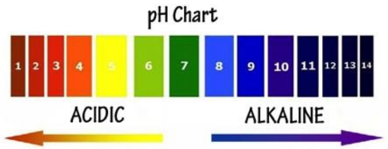
$$I = \frac{1}{2}\sum c_i z_i^2$$

where:

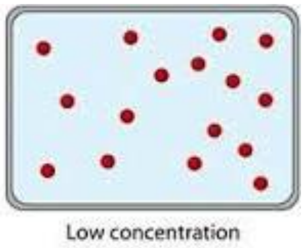
c_i =molar concentration of ion i

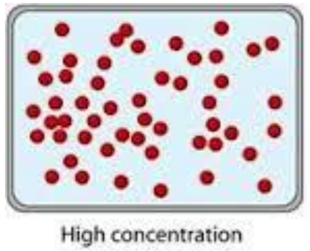
z_i =charge of ion i





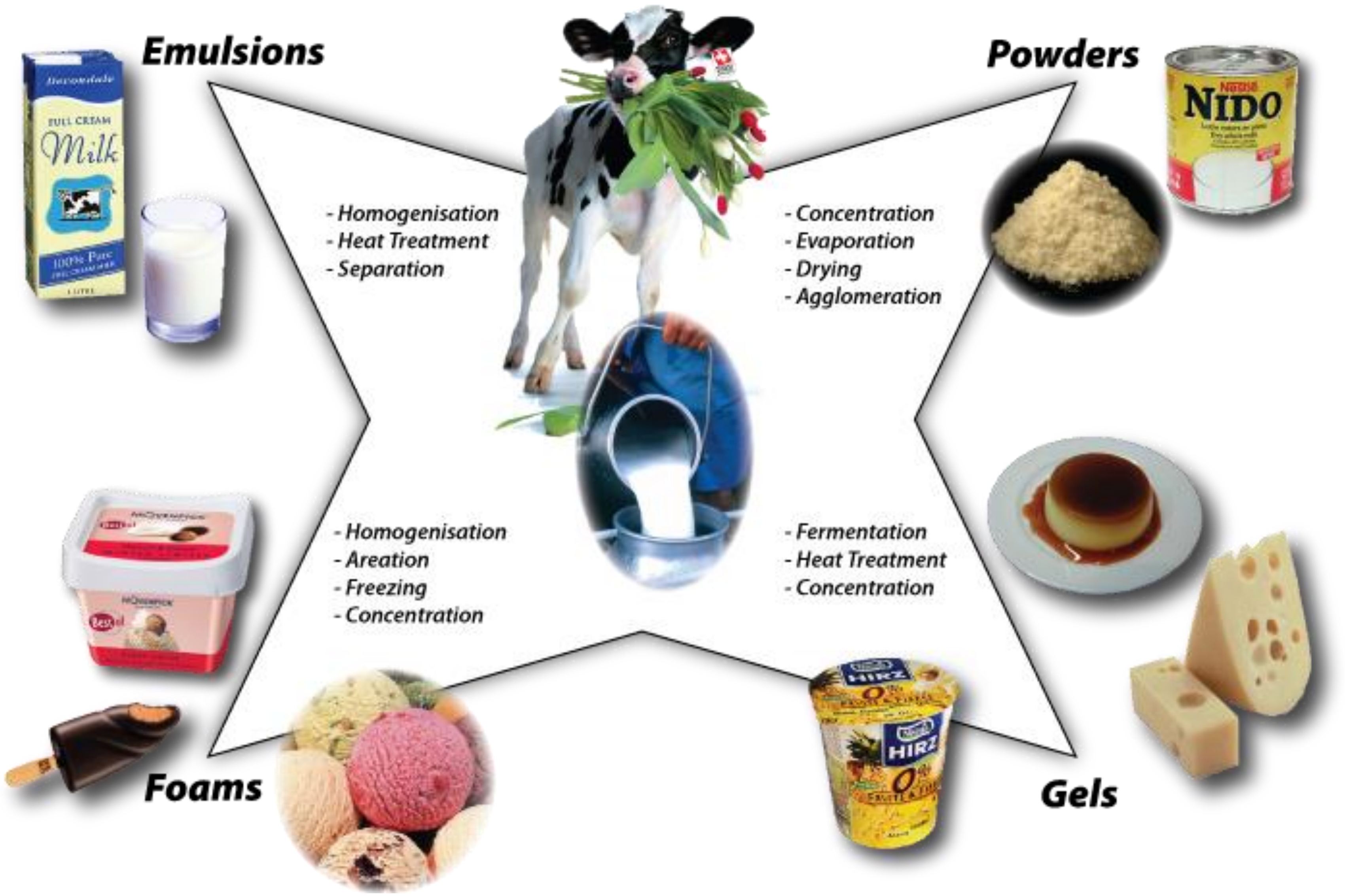
Concentration





Research and Development

FOODS DERIVED FROM MILK



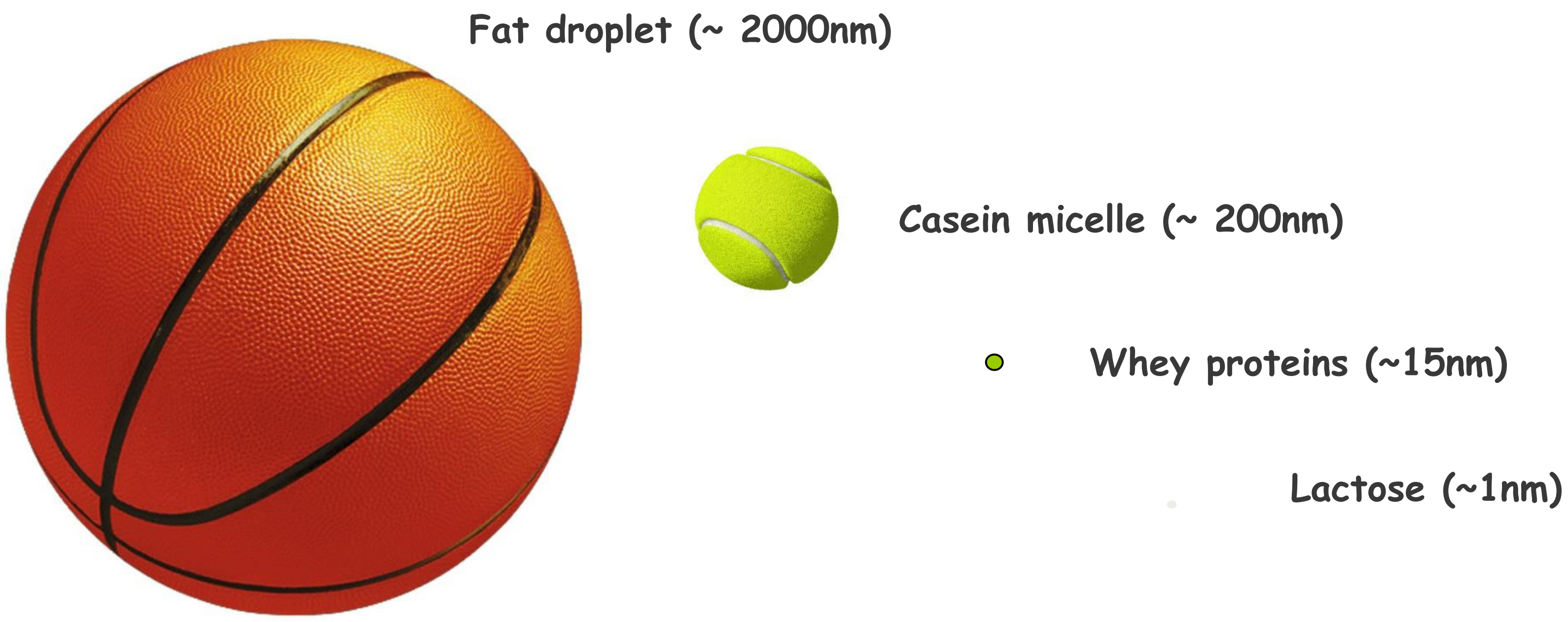
COMPOSITION OF MILK

Component	Average Content in Milk (% w/w)	Range (% w/w)	Average Content in Dry Matter (% w/w)
Water	87.1	85.3-88.7	-
Solutes non-fat	8.9	7.9-10.0	-
Fat	4.1	3.2-5.0*	-
Lactose	4.6	3.8-5.3	36
Fat	4.1	2.5-5.5	31
Protein	3.3	2.3-4.4	25
of which Casein	2.6	1.7-3.5	20
Minerals	0.7	0.57-0.83	5.4
Organic acids	0.17	0.12-0.21	1.3

* Holstein ca. 3.6-3.8%, Simmental 3.9-4.2%, Jersey 4.5–5.0%

MILK – A SIZE COMPARISON

Milk' s native delivery structures

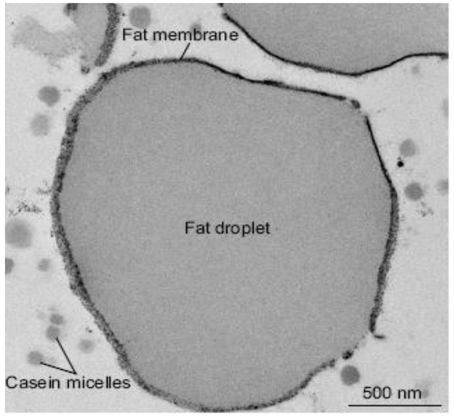


Milk is the ideal delivery system for a growing organism

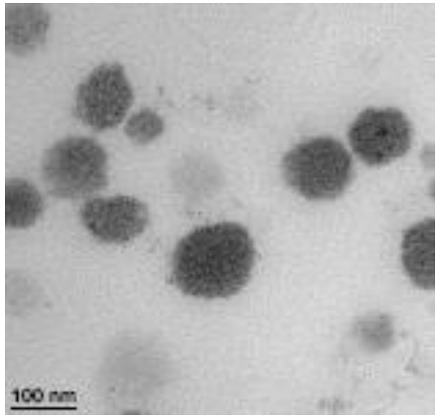
(scheme paraphresing de Kruif scheme)

BUILDING BLOCKS IN MILK

Fat droplet
(~ 2000nm)

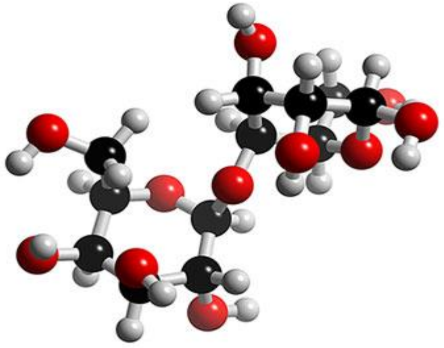


Casein micelle
(~ 200nm)



Whey proteins
(~ 15nm)

Lactose
(~ 1nm)



Fat droplet membrane

lipo-protein - bilayer structures

Supramolecular aggregate

Casein aggregates &
Ca phosphate clusters

Casein: 2.7 of 3.3 % protein in dairy milk (cow)

Protein oligomers

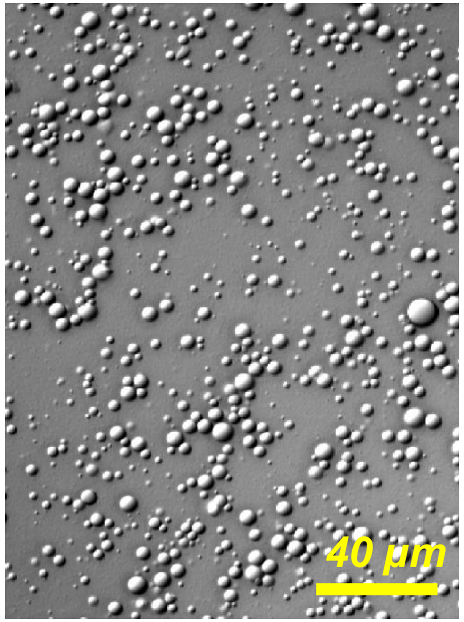
Tetramer aggregation

Of 0.6 % whey protein in dairy milk (cow):
α-Lactalbumin ca. 20 %
β-Lactoglobulin ca. 45 %
Immunglobuline ca. 10 %
Proteose-Pepton ca. 20 %
Serumalbumin ca. 5 %

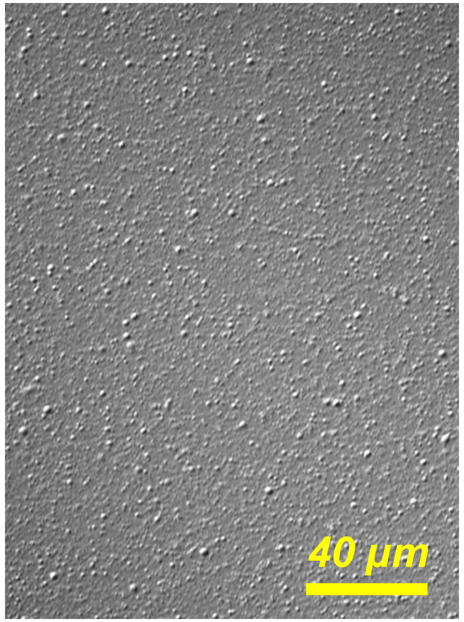
MILK - A NATURAL COLLOID SYSTEM

Milk is an emulsion of tiny fat droplets in water. It is also a suspension of soft protein particles: the casein micelles and the whey proteins

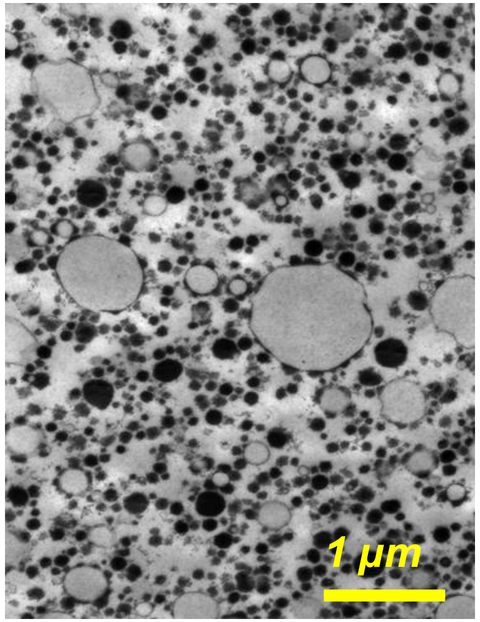
Fat globules in milk strongly scatter light



Fat globules in raw milk



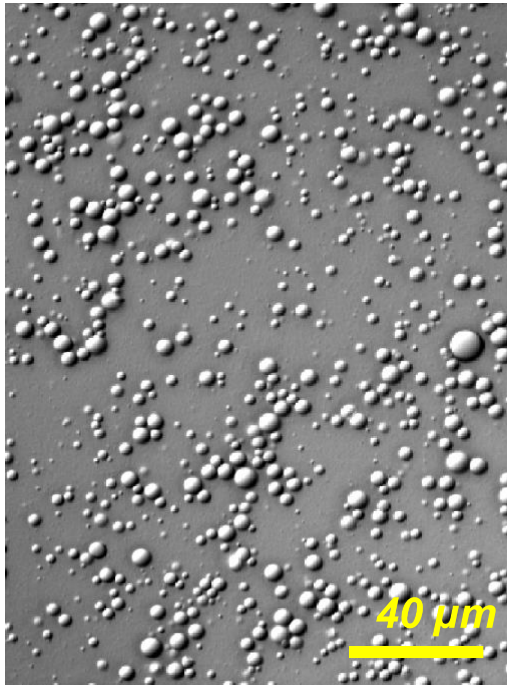
Fat globules in homogenised milk



Ultrastructure of milk

EMULSIONS - RAW MILK IS UNSTABLE

Problem



Raw milk is unstable and forms a cream layer within a few hours.

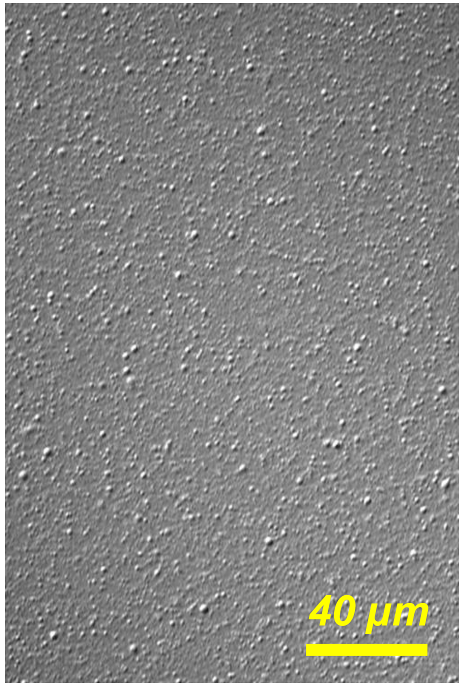
Reason

$$v_s = \frac{g\Delta\rho d^2}{18\eta_c}$$

d	=	*Particle diameter*
g	=	*Gravity*
$\Delta\rho$	=	*Density difference*
η	=	*Viscosity*
v_s	=	*Velocity of creaming or sedimentation*

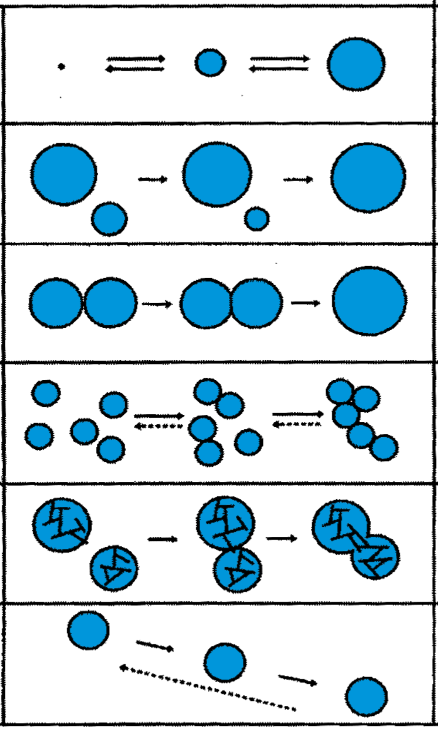
Effect of gravity force due to density difference between continuous and dispersed phase

How to solve?



1. *Reduce fat globule size*
2. *Increase continuous phase viscosity*
3. *Decrease density differences*

DESTABILISATION MECHANISMS - OVERVIEW

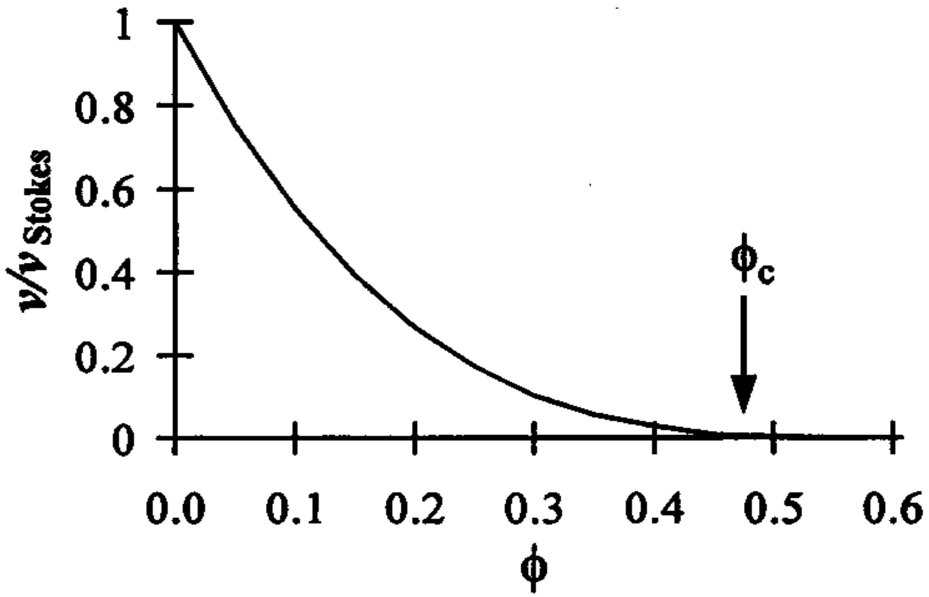


Type of change	Particles involved	Effect of agitation
a. Growth/dissolution	S, L, G	(↑)
b. Ostwald ripening	S, L, G	(↑)
c. Coalescence	L, G	↓ or ↑
d. Aggregation	S, L	↑ or ↓
e. Partial coalescence	L / S	↑
f. Sedimentation	S, L, G	↓

S = solid
L = liquid
G = gaseous

- Growth/Dissolution
- Ostwald ripening
- Coalescence
- Aggregation
- Partial Coalescence
- Creaming/Sedimentation

HOW TO RETARD CREAMING & SEDIMENTATION?

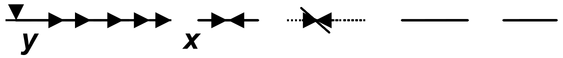


Effect of volume fraction on creaming rate. At a volume fraction of approx. 0.5 creaming is completely stopped

From P. Walsta 'Physical Chemistry of Foods'

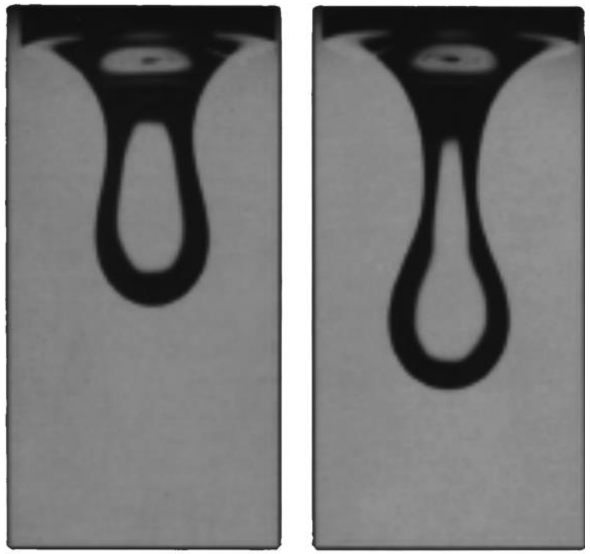
- **Reduce buoyancy:**
  - Decrease particle size
  - Lower density difference
  - Use emulsifiers which build up a thick and heavy surface layer
- **Increase friction:**
  - Increase viscosity of continuous phase
  - Give liquid a yield stress (weak gel)
  - Increase dispersed phase volume fraction
  - Create a "jammed" polymer – particle network (at high Φ)
  - Prevent particle aggregation (at low Φ)
- **Last remedy:**
  - Keep the liquid mildly agitated ("upside down and up again")
  - Sell in microgravity market

BREAKING UP DROPS & BUBBLES



Problem

Making large drops is fairly simple but breaking up small drops is difficult.



Reason

Breaking up drops creates new surface area

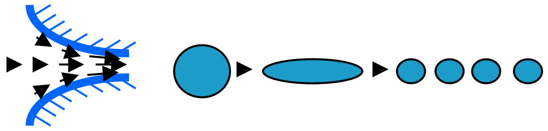
$$D_{3,2} = \frac{6V_p}{A_p}$$

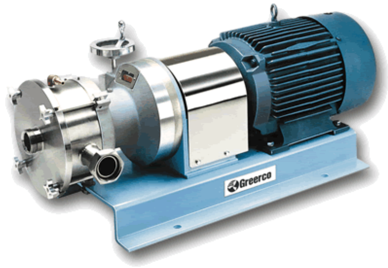
Laplace pressure rises in smaller drops

$$\Delta p = \gamma \frac{2}{r}$$

How to solve?

1. Apply external forces



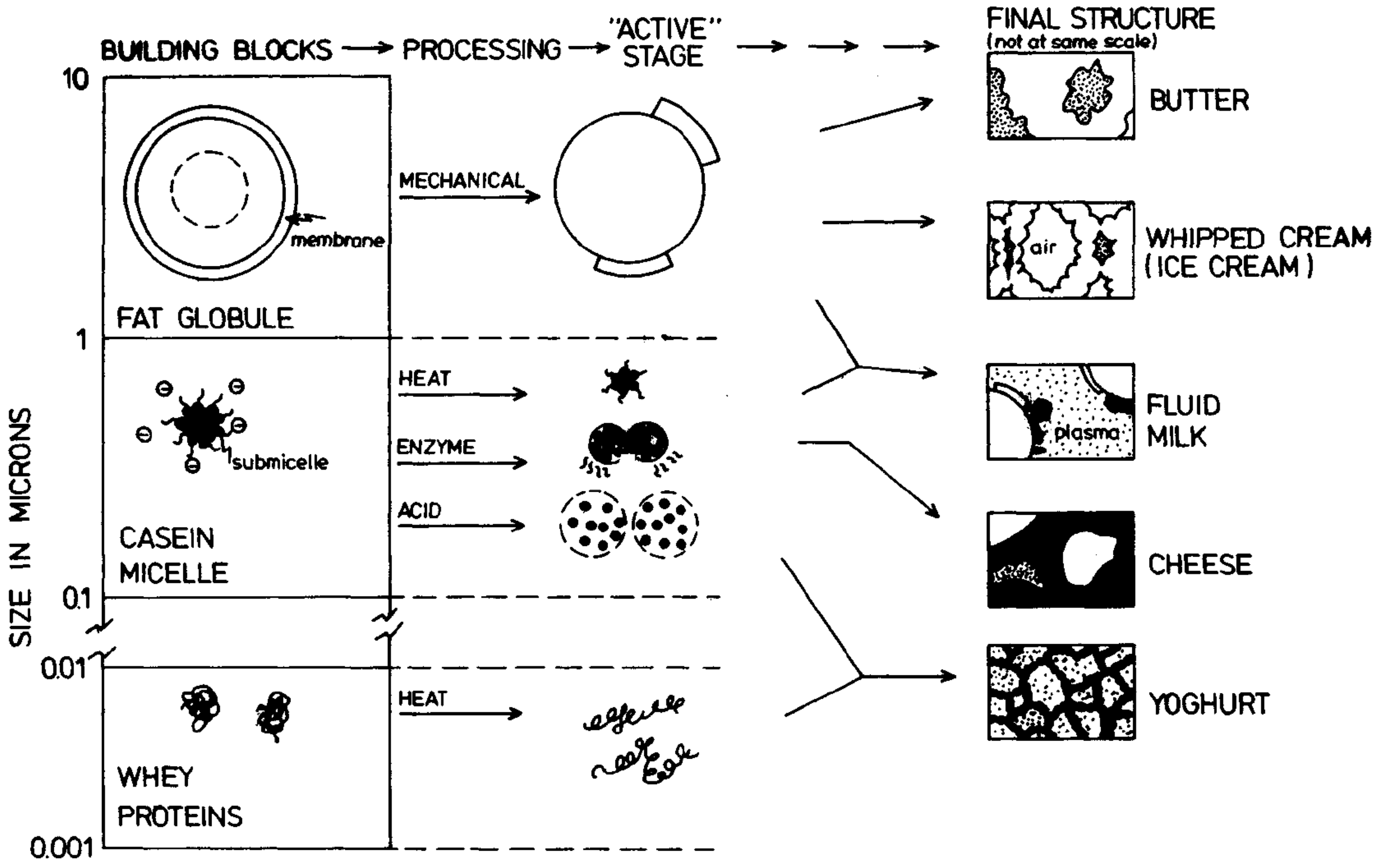


2. Lower interfacial tension with the help of surface active molecules

SURFACE AREA OF HOMOGENIZED MILK

1 liter of milk with 3% fat volume phase dispersed in fat globules of 0.3 μm diameter there are $3x10^{15}$ globules representing 600 m^2 of interface area

MILK - PROCESS, STRUCTURE, PROPERTY

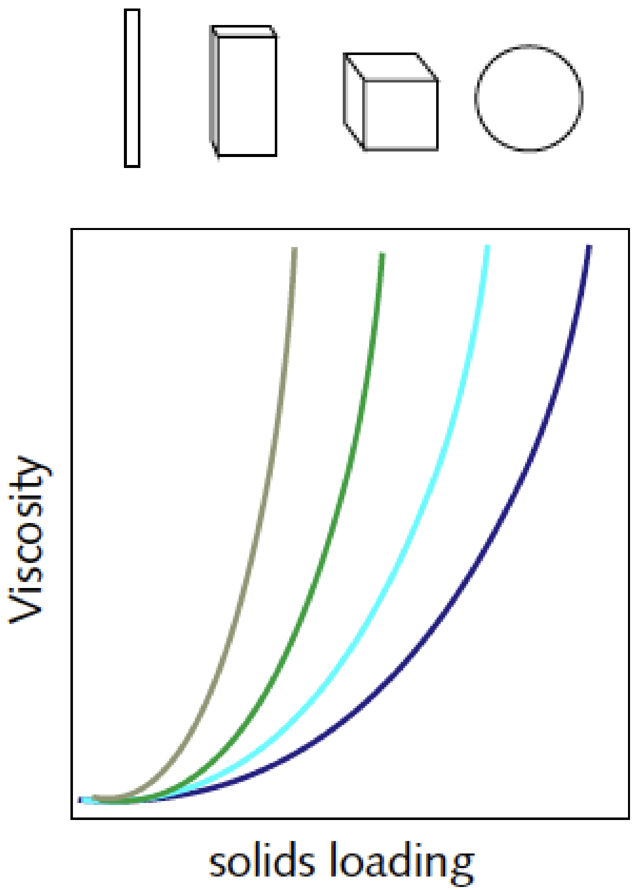


From P. Walsta 'Physical Chemistry of Foods'

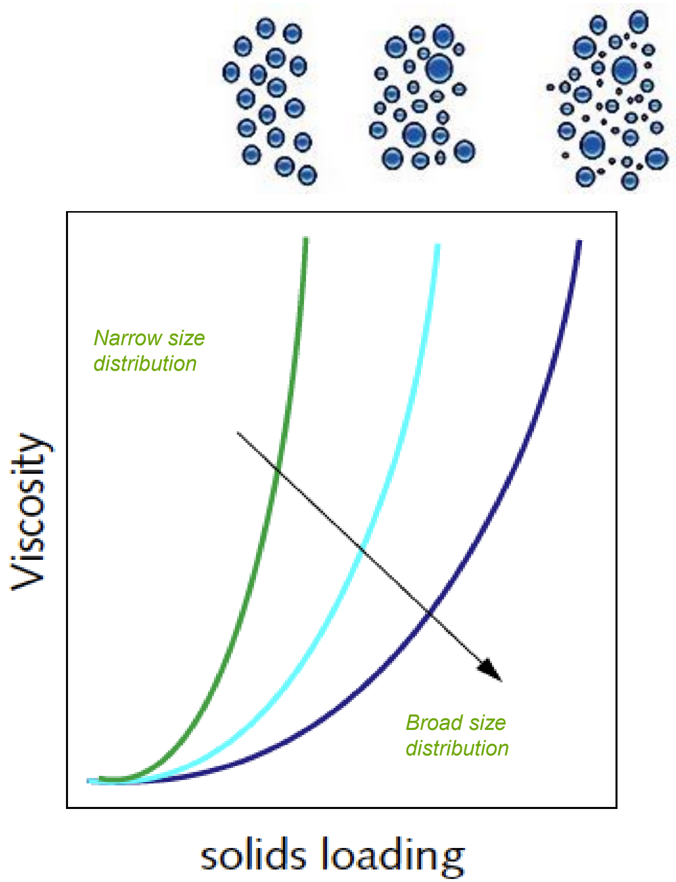
CONDENSED MILK

INFLUENCE OF STRUCTURE ON VISCOSITY

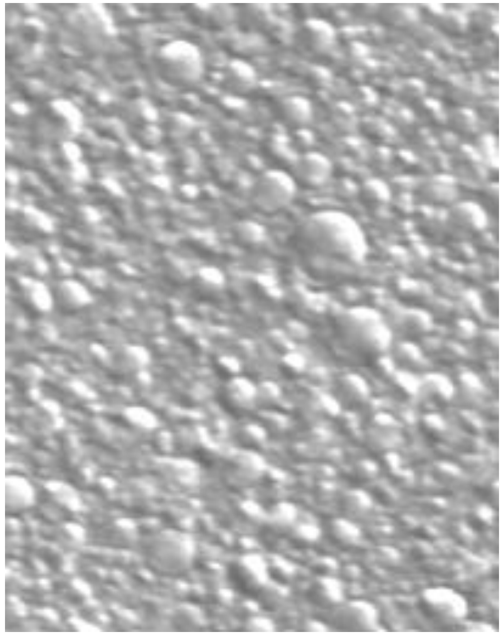
Particle Shape



Polydispersity

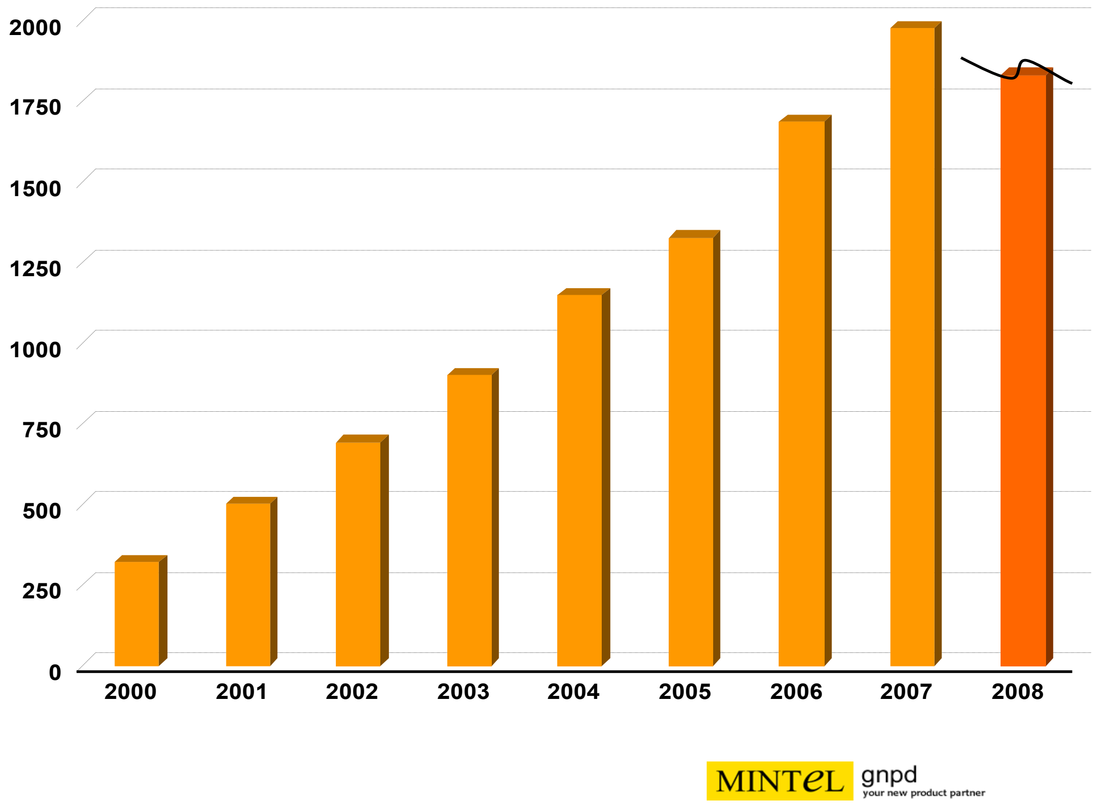


Concentrated milk



MILK BASED POWDERS

THE SUCCESS OF FOOD POWDERS



Advantages:

consumers' convenience

separate production from consumption locations

reduced transportation costs

bacteriological stable

Needs:

free flowing

easily wettable

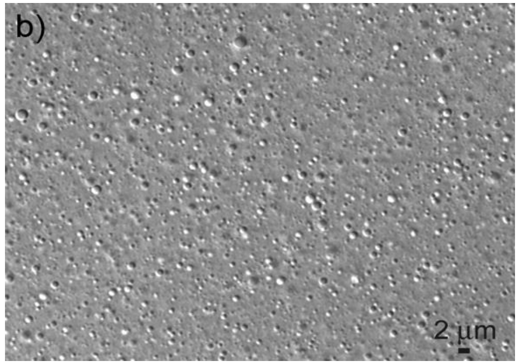
quick to disperse

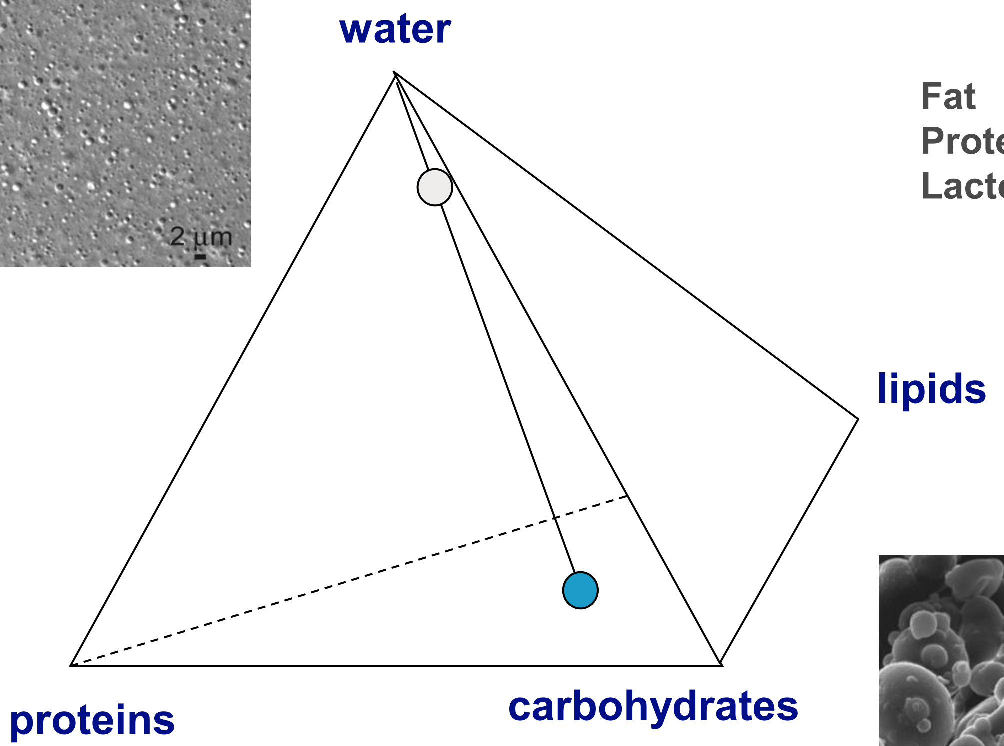
rapidly soluble

similar to original product after reconstitution

From A. Marabi, NRC Lausanne

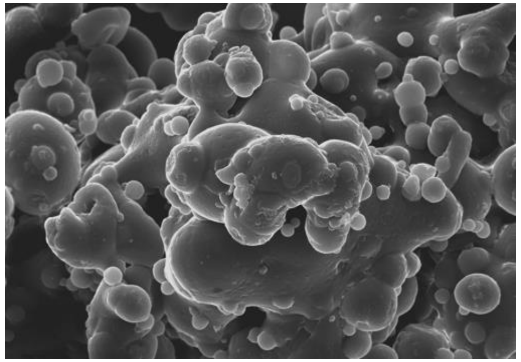
MILK POWDER





Cow's Milk Composition (%):

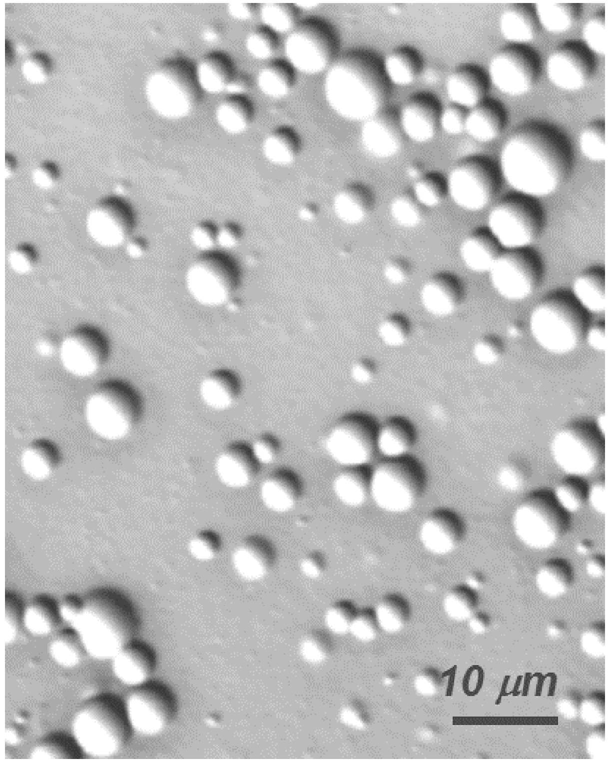
	dry	liquid
Fat	32	4
Protein	28	3.6
Lactose	40	5



Product Structure Space

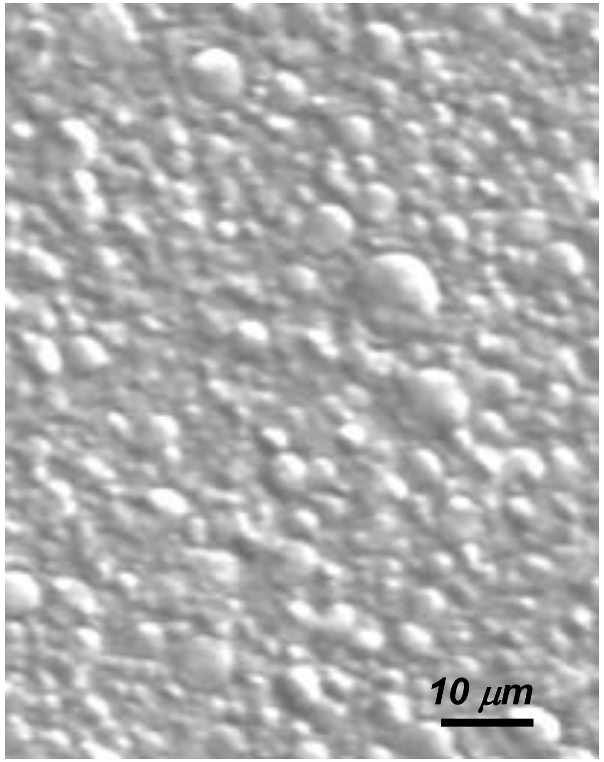
FROM RAW MILK TO MILK POWDER

Raw milk



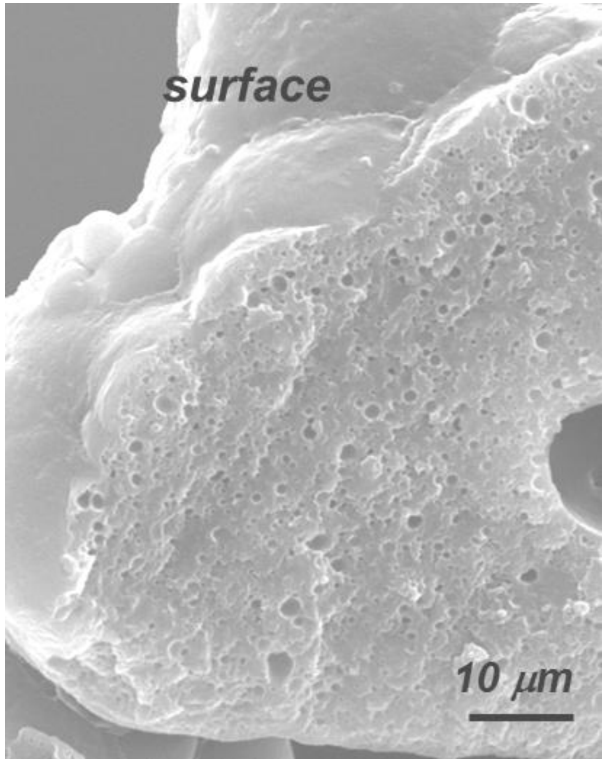
13% total solids
lactose (dissolved)
proteins (dispersed)

Concentrated milk



50% total solids
lactose (dissolved)
proteins (dispersed)

Milk powder (SEM)

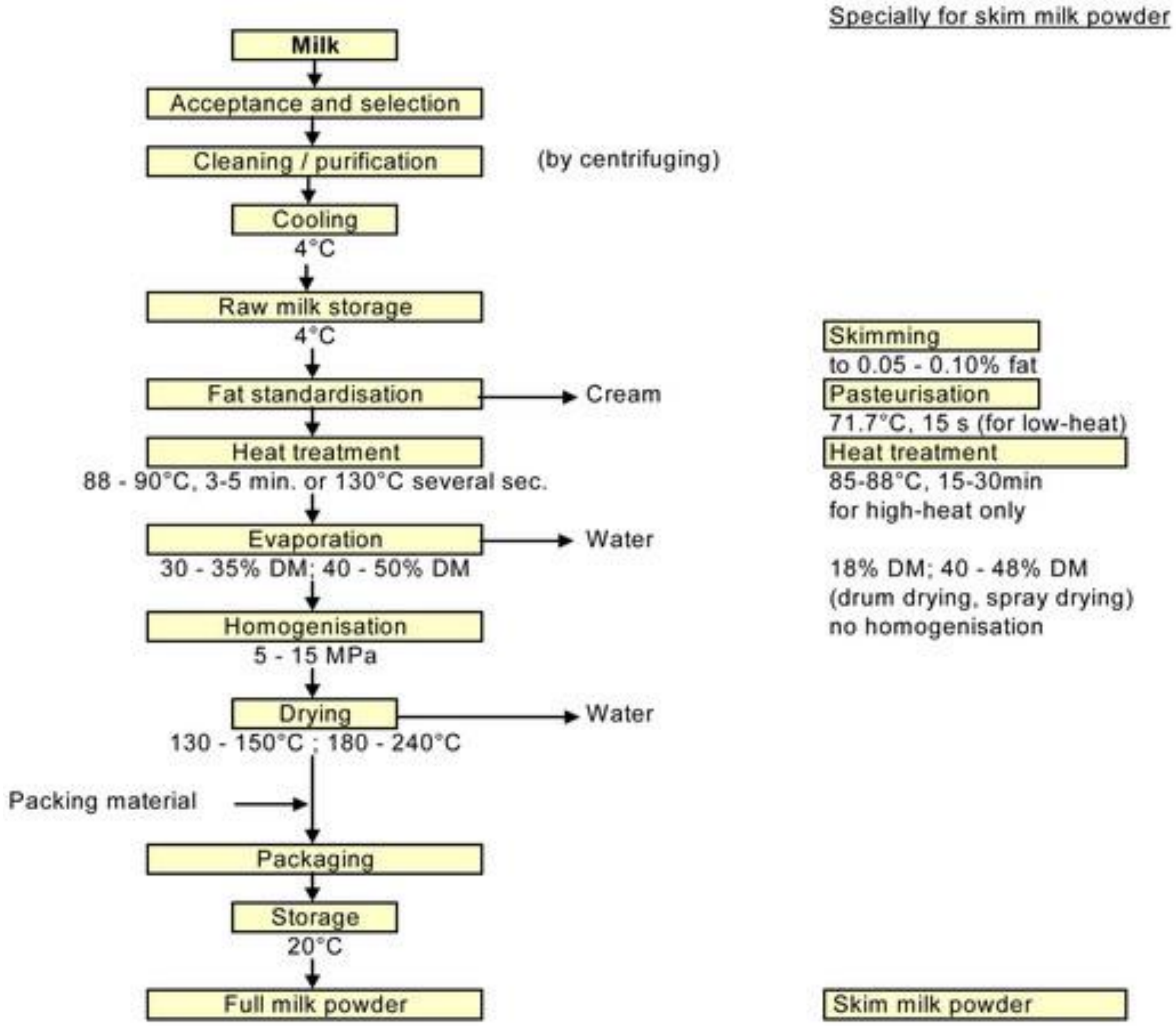


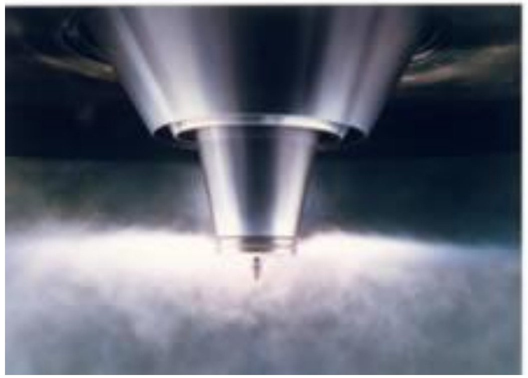
97% total solids
lactose (glassy)
proteins (dispersed)

COMPOSITION OF SOME TYPES OF POWDERS

Constituent	*Whole Milk*	*Skim Milk*	*Whey*	*Sweet Cream Buttermilk*
Fat	26	1	1	5
Lactose	38	51	72	48
Casein	19.5	27	0.6	26
Serum protein	4.8	6.6	8.5	6.2
“Ash”	6.3	8.5	8	8
Lactic acid	-	-	0.2-2	-
Water	2.5	3	3	3

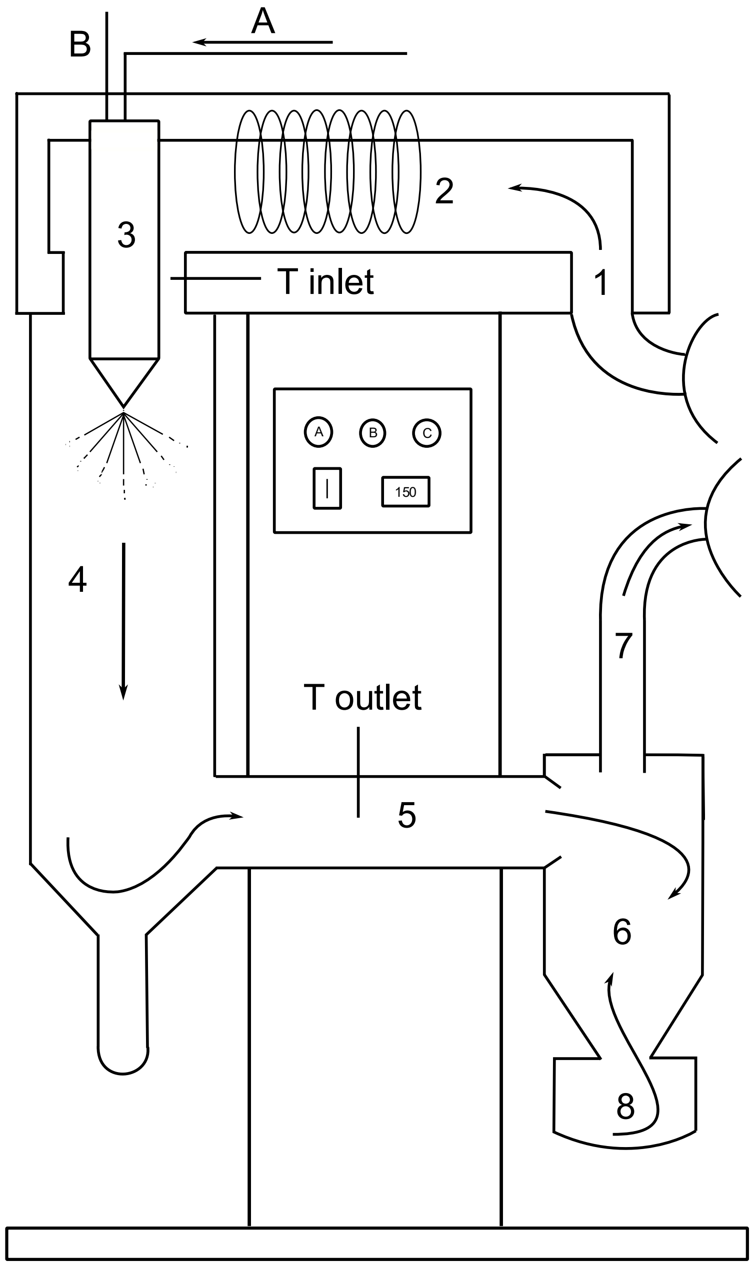
SPRAY DRYING OF MILK



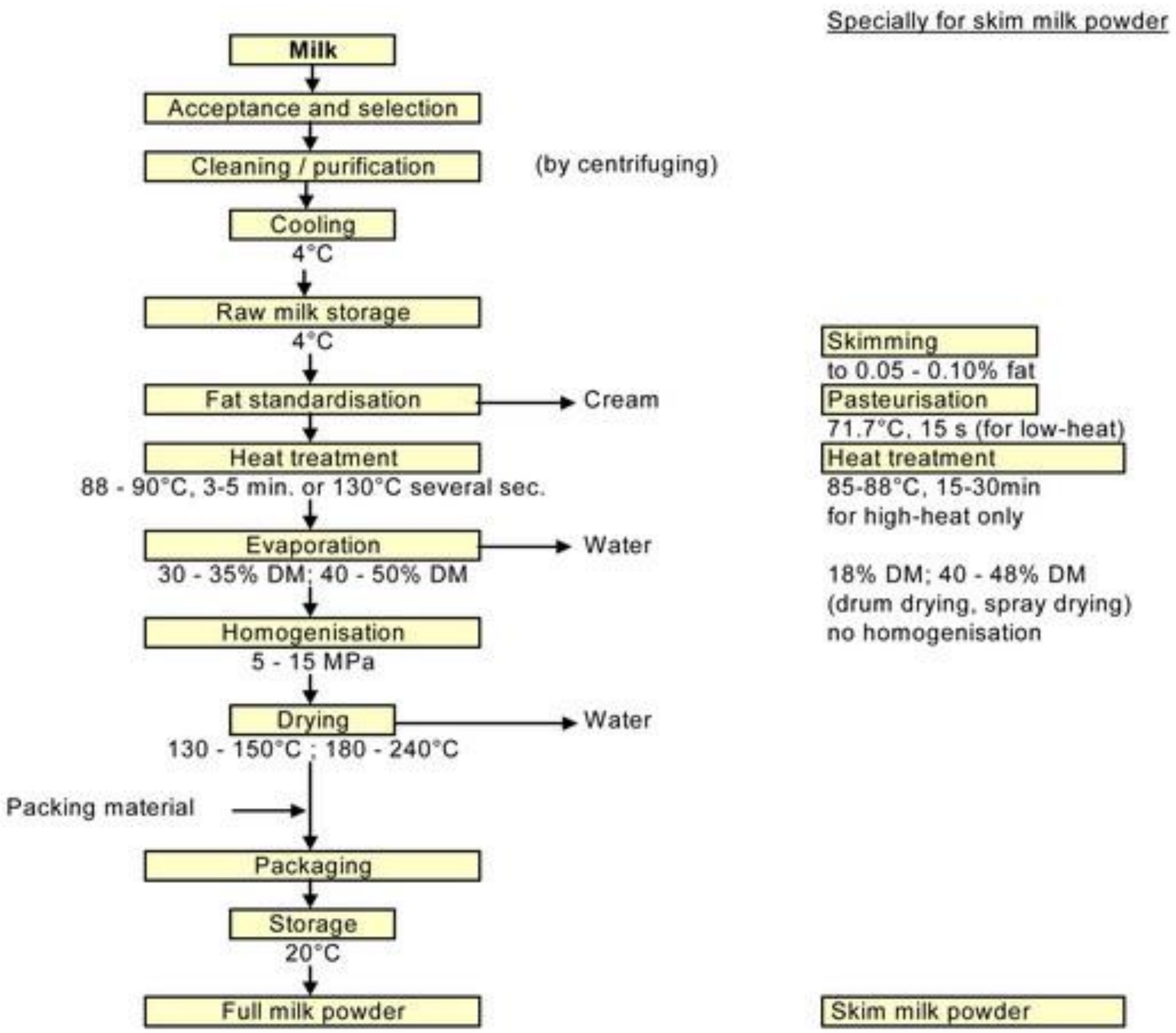


Research and Development

SPRAY DRYING



PHYSICOCHEMICAL PROPERTIES THAT CAN BE OPTIMIZED



Particle size distribution
Specific surface area
Density
Mechanical stability
Compressibility
Thermal conductivity
Porosity
Flowability
Wettability
Solubility
Tg
Water content
a_w

Research and Development

MILK POWDER – QUALITY DEFECTS FROM PROCESSING

Good Reconstitution Properties

Reconstituted milk

Sieve residues

Bad Reconstitution Properties

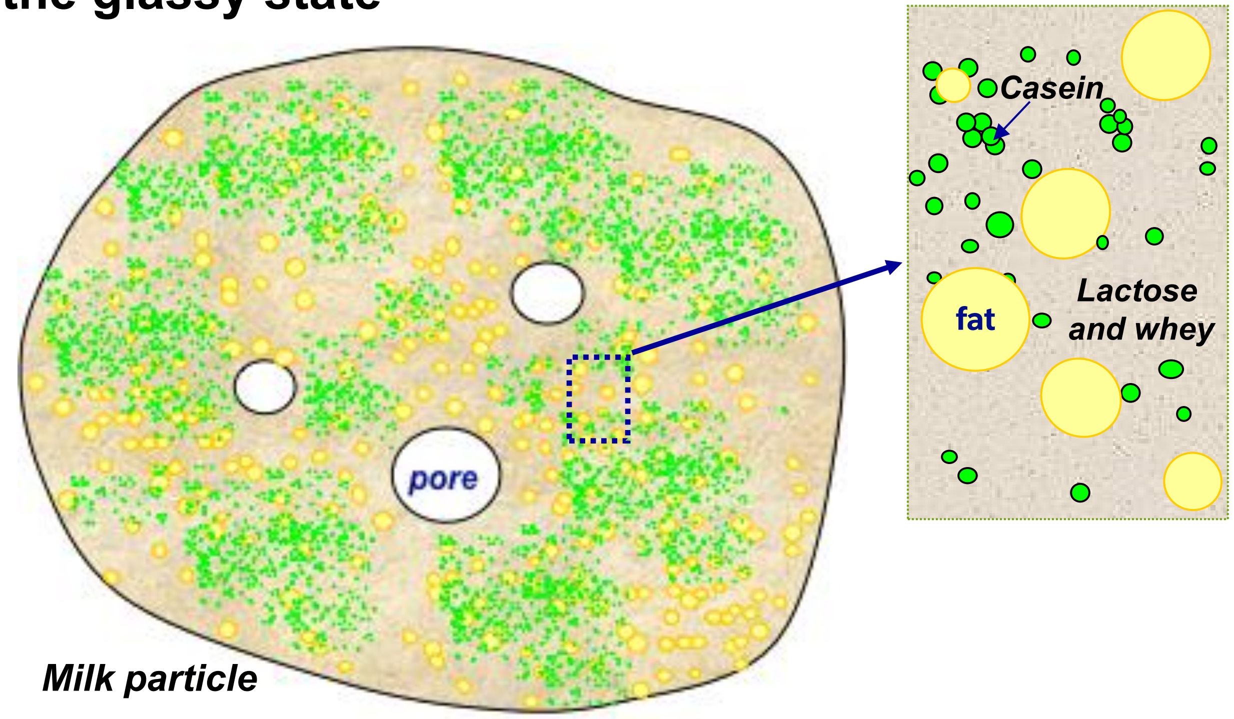
Reconstituted milk

Sieve residues

From S. Guertler, NRC Lausanne

SCHEMATIC STRUCTURE OF MILK POWDER PARTICLE

Spray dried milk particles are in the glassy state



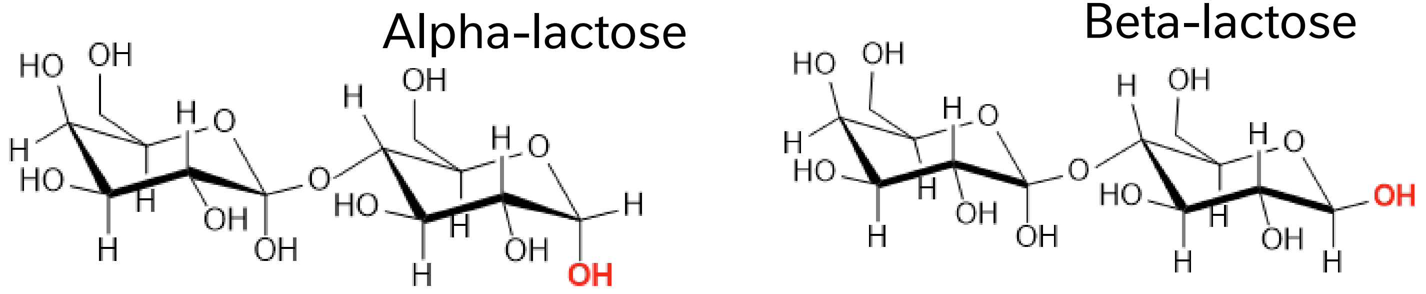
A milk powder particle is a solid glassy matrix made of:

- **a continuous phase: lactose, whey protein and salts**
- **a dispersed phase: fat globules and casein**

The continuous phase is in the glassy state, mainly governed by the properties of the lactose, which is in a metastable amorphous state (may crystallize)

From V. Meunier, NRC Lausanne

Making Milk Powders: The Role of Lactose



- Two forms of lactose:

- In whole milk, lactose may undergo two phase transitions:
  - Nucleation of alpha hydrate lactose crystals in a supersaturated milk concentrate
  - Nucleation of beta anhydrous lactose

- To make milk powder: concentration of milk and **spray-drying**
  - Fat globules in milk: encapsulated in amorphous lactose matrix
    - This encapsulation protects fat globules from burning during spray drying process.
    - **Important: lactose crystallization must not occur! Otherwise, fat globules will burn.**

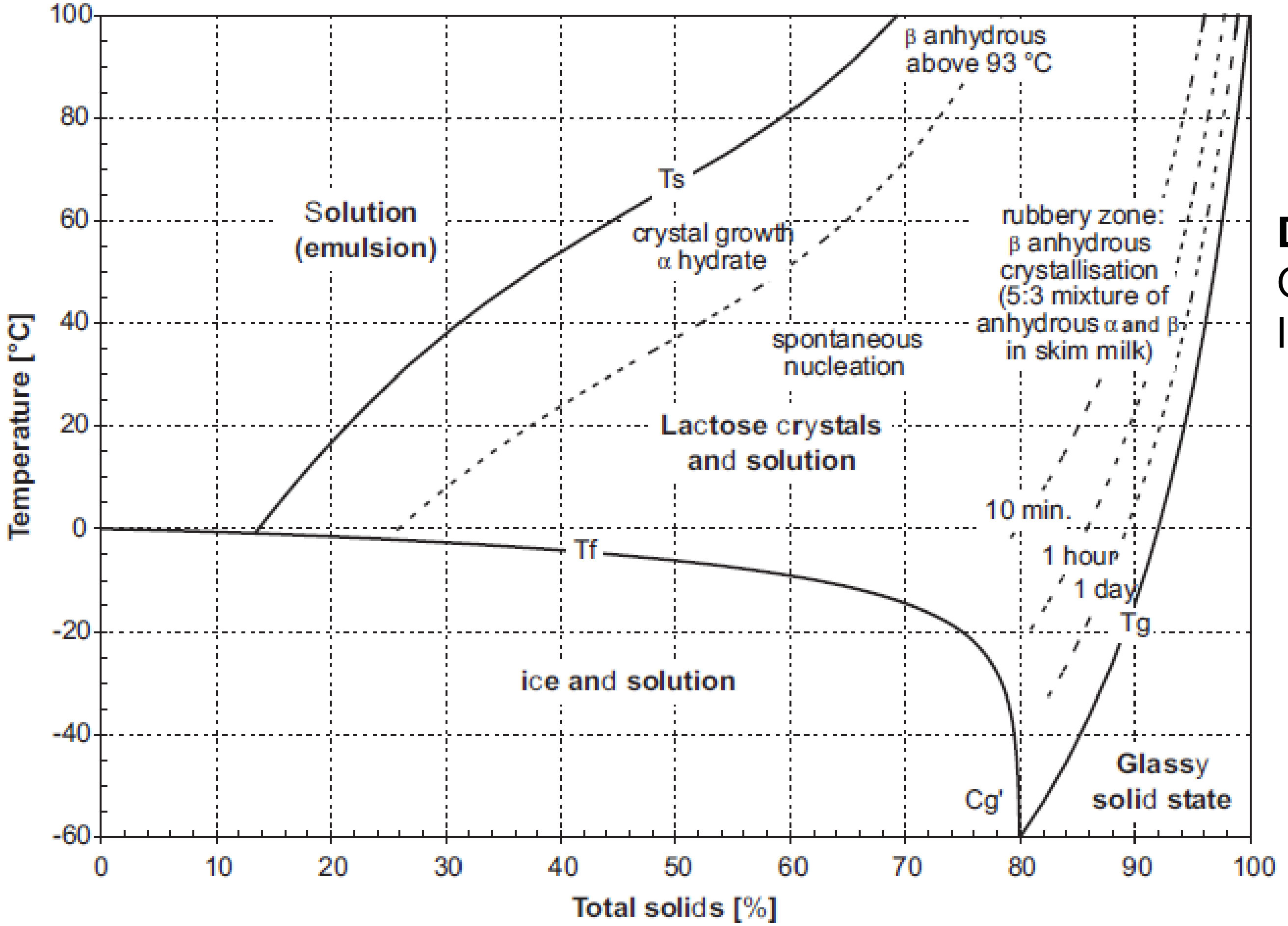
- To avoid lactose crystallization, we ask:
  - Which temperature to use? How does the concentration of milk solids affect the structure of lactose?
  - To optimize the spray-drying protocol, use the **state diagram of milk**

Vuataz, G. The phase diagram of milk: a new tool for optimising the drying process. *Lait* **2002**. *82*(4), 485-500.

Making Milk Powders: The Role of Lactose

- Understand the physical changes that occur during milk dehydration

T_s = solubility line



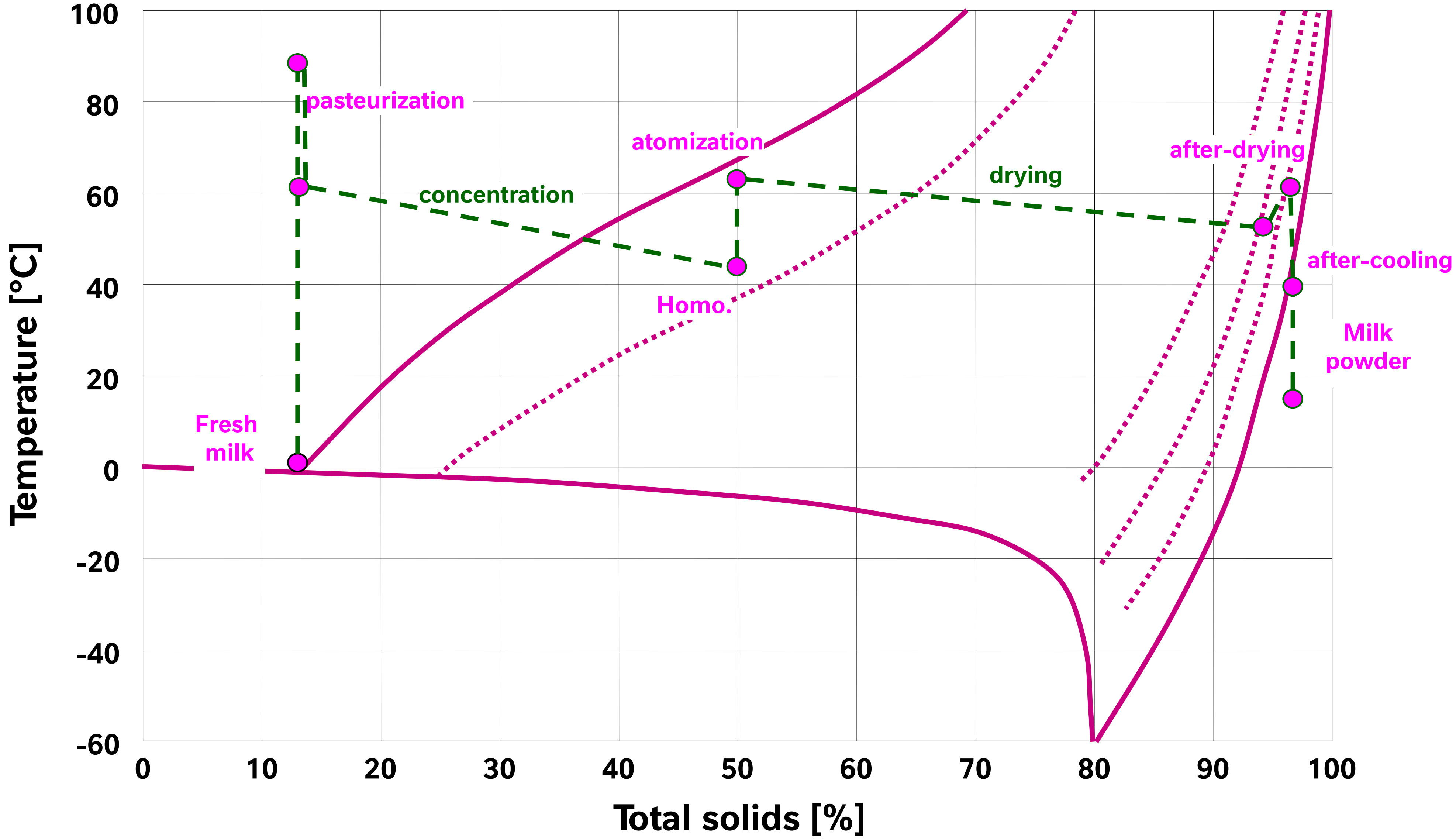
DANGER ZONE
Crystallization of lactose occurs

T_g = glass transition

State diagram of whole milk (lactose and water phase transitions)

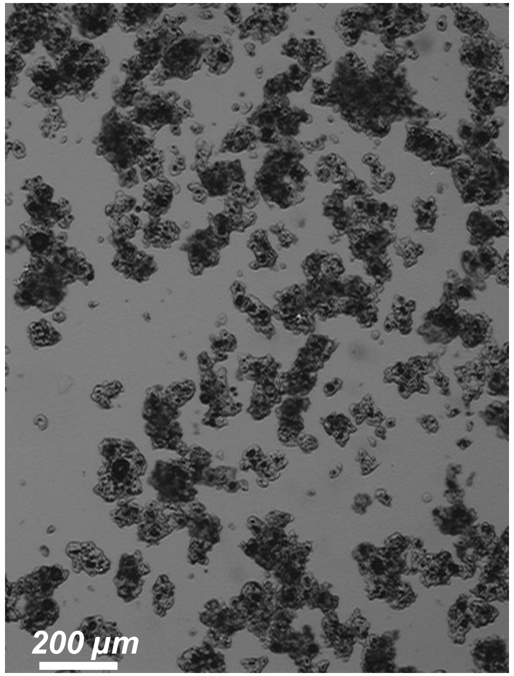
Vuataz, G. The phase diagram of milk: a new tool for optimising the drying process. *Lait* **2002**. *82*(4), 485-500.

THE STATE DIAGRAM OF MILK

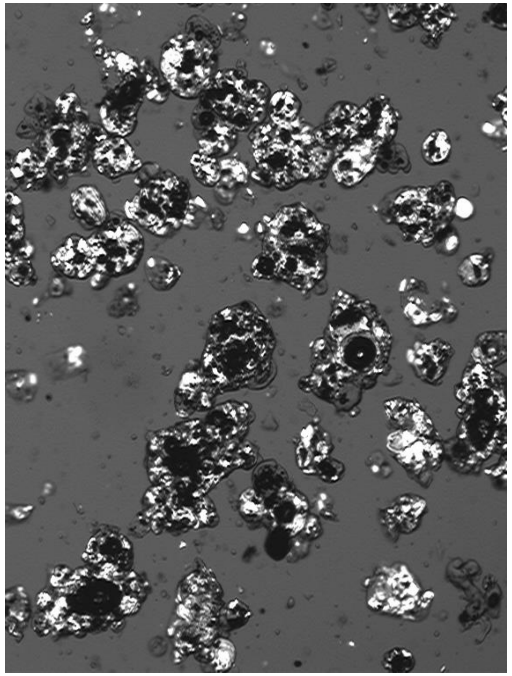


Gilles Vuataz, 2002, Lait 82, 485–500

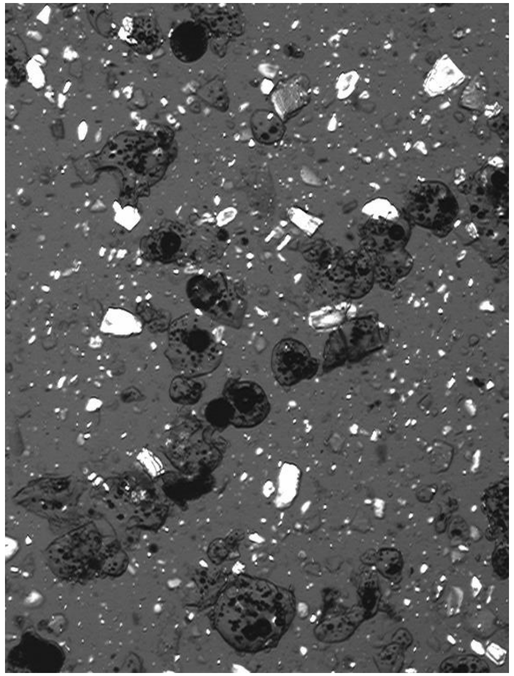
CRYSTALLINE AND AMORPHOUS LACTOSE



Amorphous powder



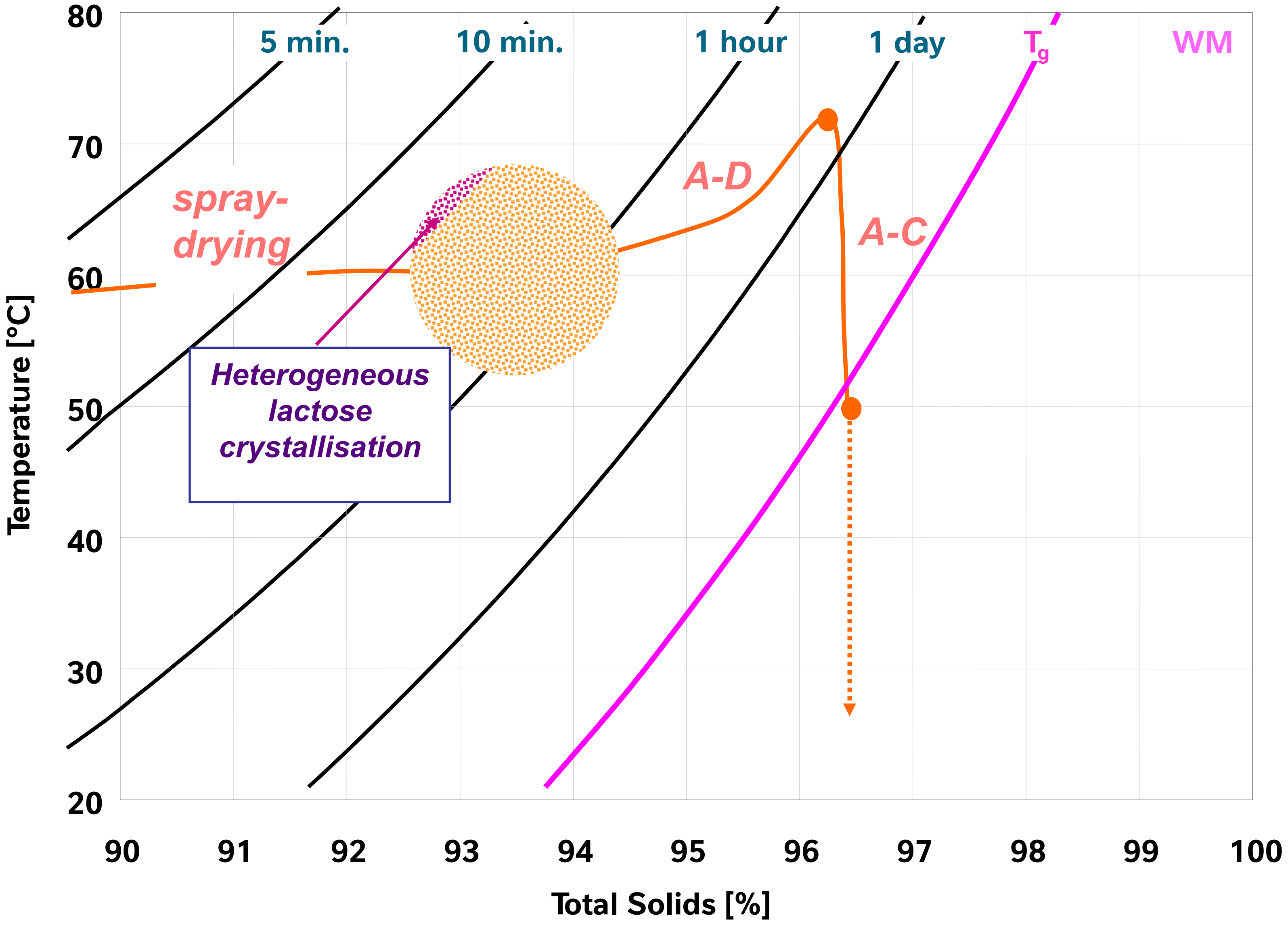
Powder with heterogeneous crystallisation



Dry-mix of amorphous powder with crystalline powder

From V. Meunier, NRC Lausanne

DELAY OF LACTOSE CRYSTALLISATION IN RUBBERY REGION



Gilles Vuataz, Lait 82, (2002), 485–500

Research and Development

STORAGE OF HIGH MOISTURE MILK POWDER AT HIGH TEMPERATURE

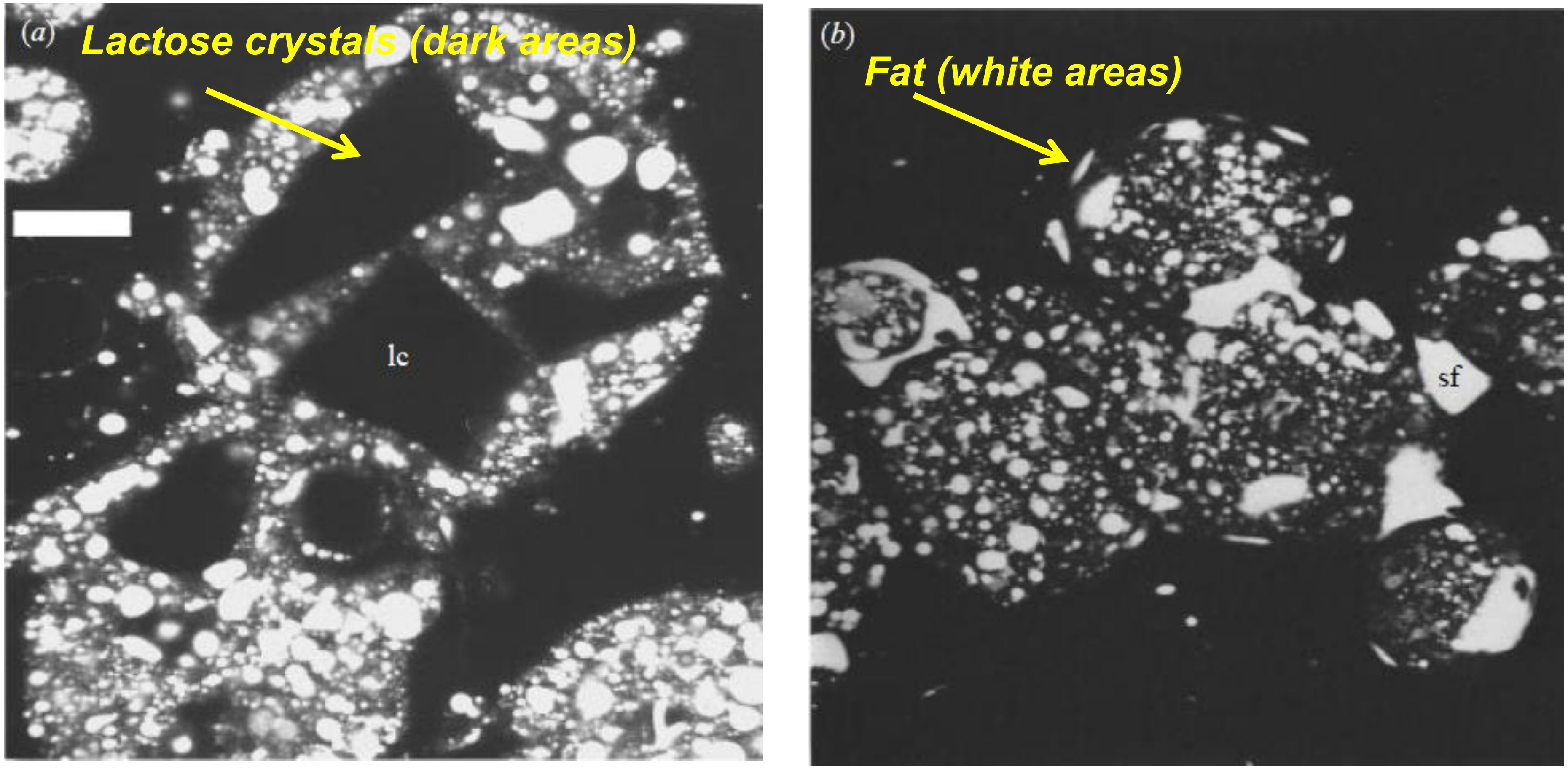
Lump formation due to caking

Browning due to Maillard reaction

Research and Development

LACTOSE CRYSTALLISATION INFLUENCES STRUCTURE

Light microscopy of milk powder with fluorescence staining of milk fat

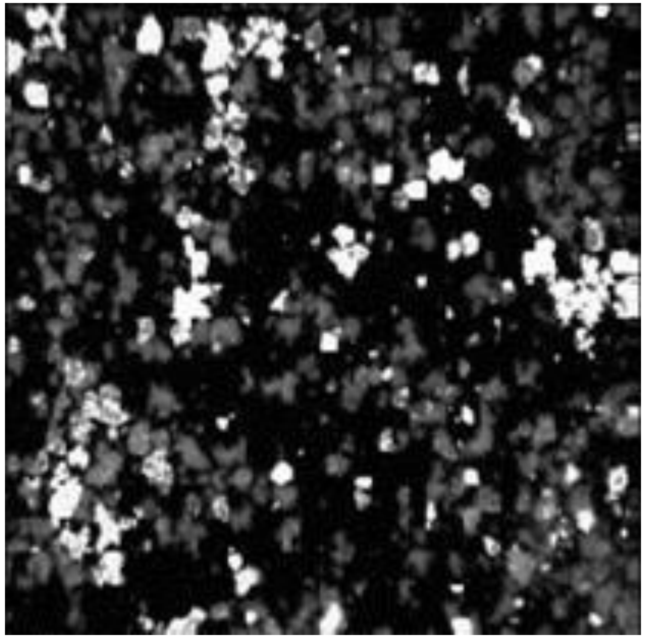


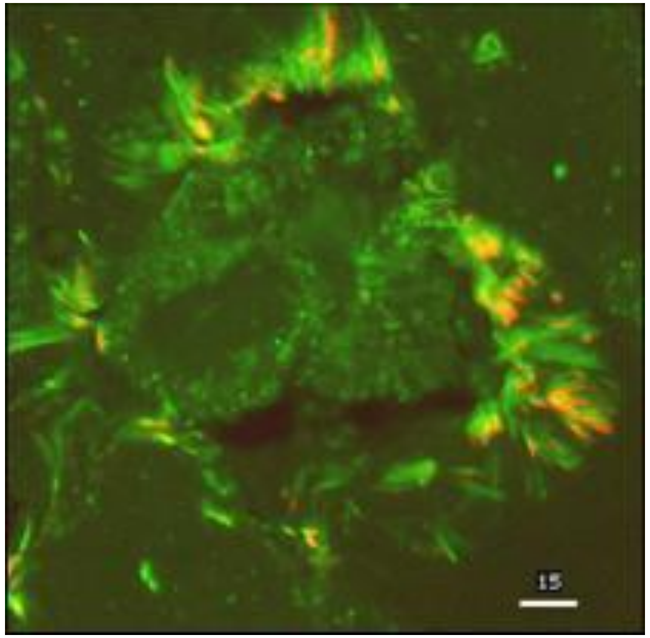
A. McKenna, J. Dairy Research, 64, (1997), 423-432

Research and Development

HETEROGENEOUS LACTOSE CRYSTALLIZATION MAY INDUCE A BAD POWDER RECONSTITUTION

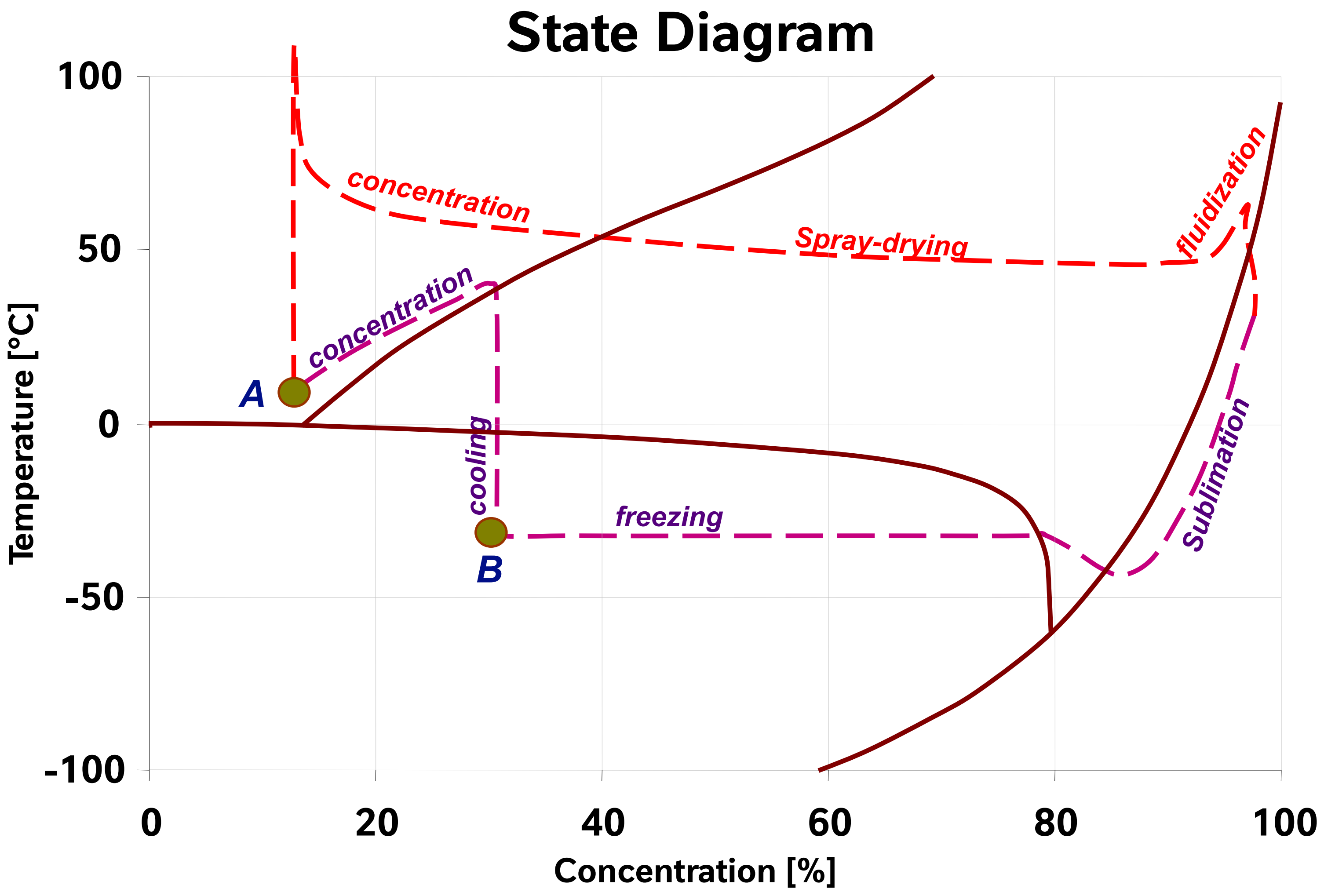
Heterogeneous lactose crystallization → **Free fat formation leads to fat crystals around particle** → **White specks !**

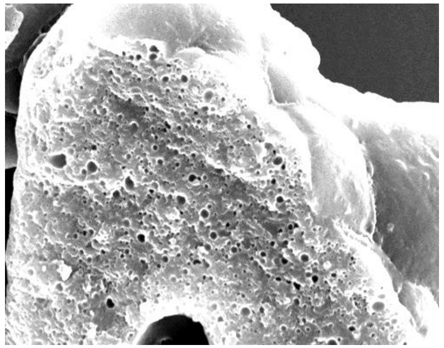


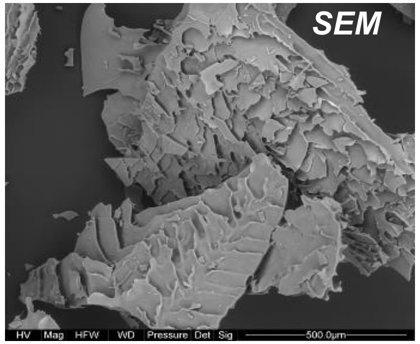


From E. Kolodziecjyk, NRC Lausanne

SPRAY- VERSUS FREEZE-DRYING





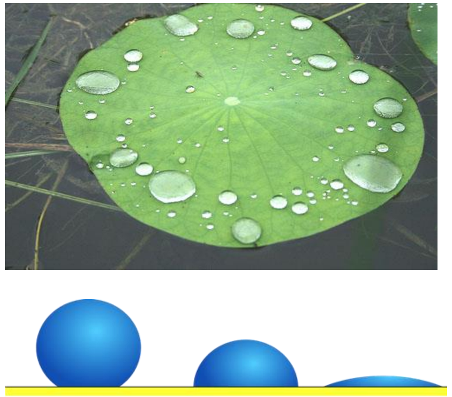
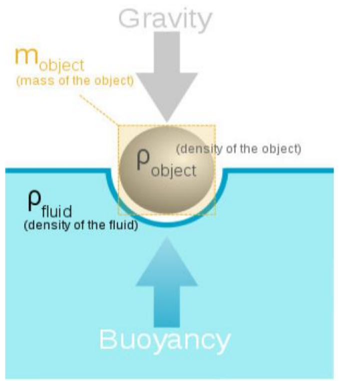
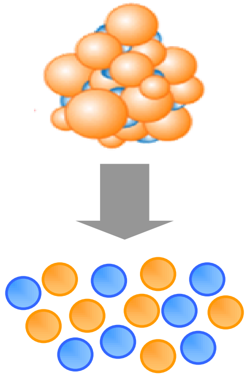
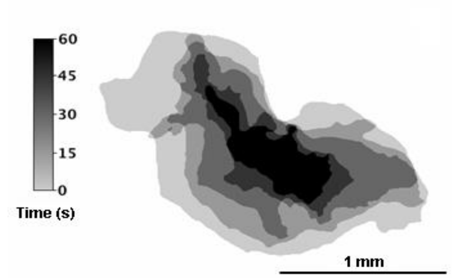


From V. Meunier, NRC Lausanne

THE “CLASSICAL” STEPS TO MASTER RECONSTITUTION PROPERTIES

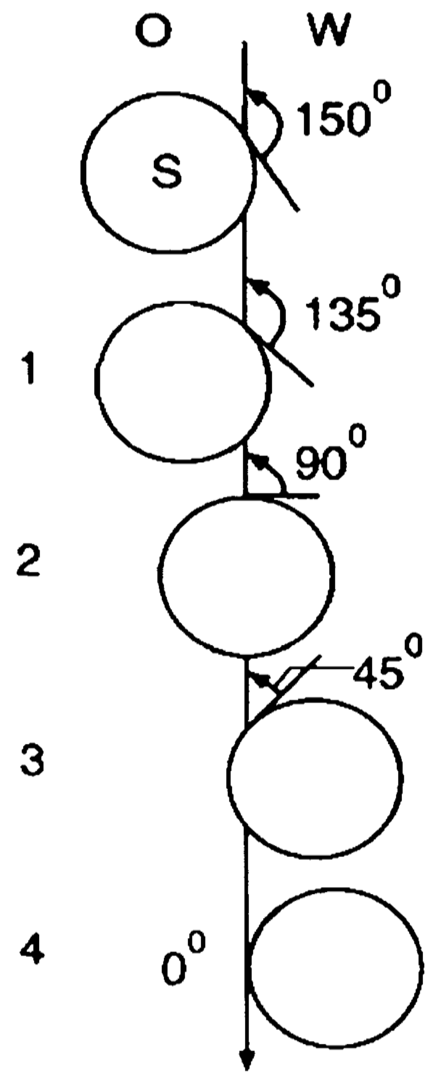
1. Wetting
2. Sinking
3. Dispersing
4. Dissolving

Optimal Reconstitution Time

1. Wetting	2. Sinking	3. Dispersing	4. Dissolving
			
Surface energy, added surfactants, pore structure, fat content	**Particle density, capillarity effects, liquid imbibition**	**Bridge strength, agglomeration/sintering process, binders**	**Physical state, solubility, temperature, mixing, liquid viscosity**

From A. Marabi, NRC Lausanne

WETTING OF PARTICLES

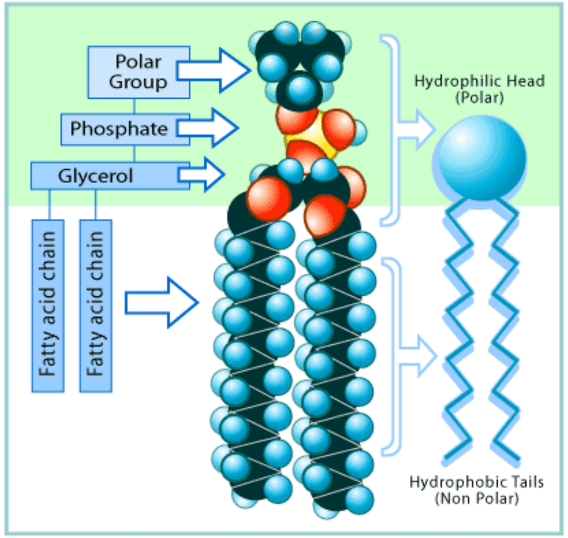


	Contact angle	*Surfactant concentration*
	$\gamma_{ow} \approx$ 30	$c \approx 0$
1	13	0.3
2	3.5	7
3	2	20
4	1	35

From P. Walsta 'Physical Chemistry of Foods'

- *Contact angle can be influenced by the addition of amphiphiles.*
- *Contact angle decreases as the amphiphile concentration in the liquid increases*
- *At contact angle zero the particle enters the aqueous phase*

Phospholipids are used to improve wetting properties of milk powders (contact angle water/solid should be smaller than approx. 30°)



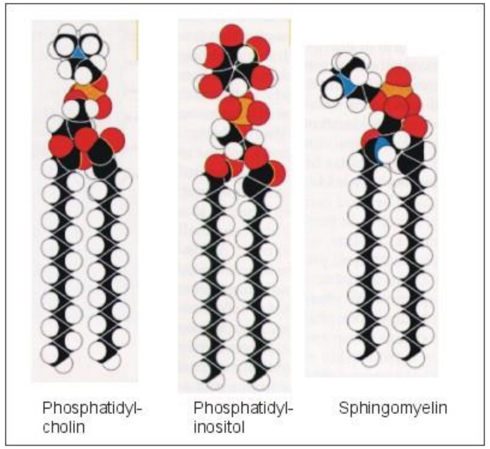
FUNCTIONALITY OF LECITHIN

Functionalities

- Adhesion aid
- Antibleed agent (as in fat bloom)
- Anticorrosive
- Antidusting agent
- Antioxidant
- Antispatter agent
- Biodegradable additive
- Catalyst
- Colour intensifier
- Conditioning agent
- Dispersing agent, mixing aid
- Emollient, softening agent
- Emulsifier, Surfactant
- Flocculant
- Grinding aid
- Lubricant
- Encapsulating agent (Liposomes)
- Machining aid
- Modifier
- Moisturizer
- Nutritional Supplement
- Penetrating agent
- Plasticizer
- Promoter
- Release Agent (antisticking)
- Spreading agent
- Stabilizer
- Strengthening agent
- Suspending Agent
- Synergist
- Viscosity modifier
- Water repellent
- Wetting agent

Physico-chemical properties

self-assembly
adsorption at surfaces/interfaces
wetting
co-crystallization
complex formation

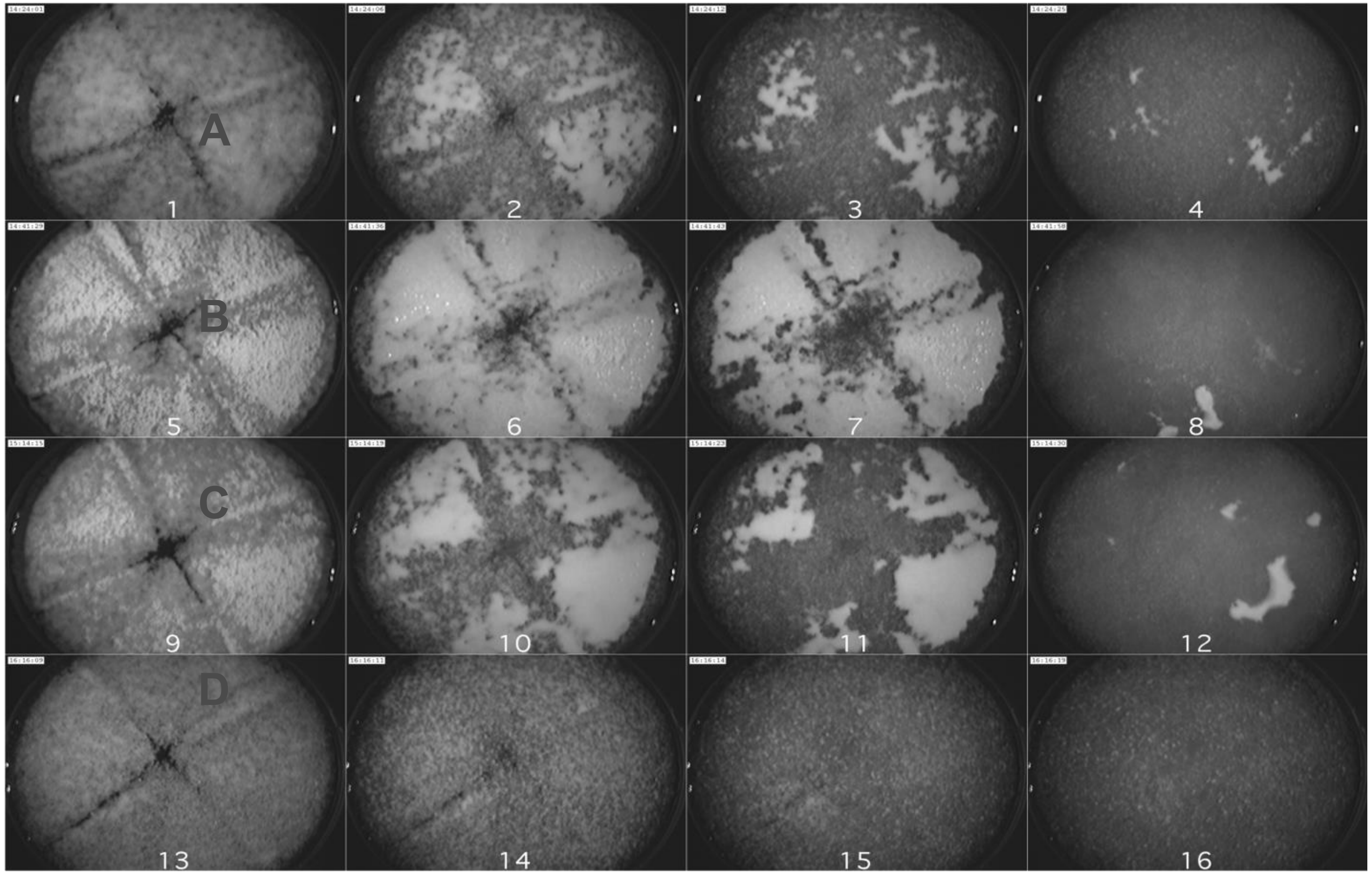


From: Schmidt, JC and Orthofer, FT (1985), In Szuhaj, BF and List, GR (eds) Lecithins pp. 187; Champaign: American Oil Chemists' Society

GETTING QUANTITATIVE DATA

From G. Mayor, NRC Lausanne

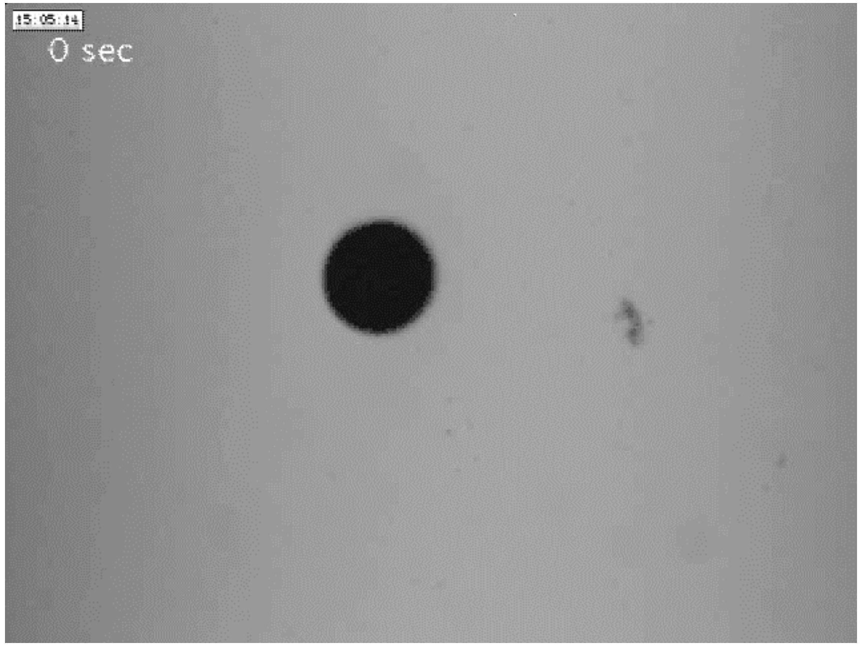
IMPORTANCE OF PARTICLE SIZE AND DENSITY

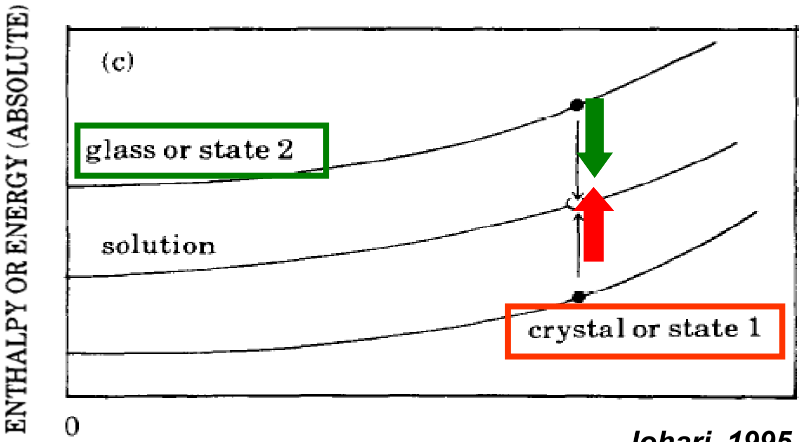


Time

A) Original Powder
B) Fraction < 300 µm
C) Fraction 300 to 500 µm
D) Fraction > 500 µm

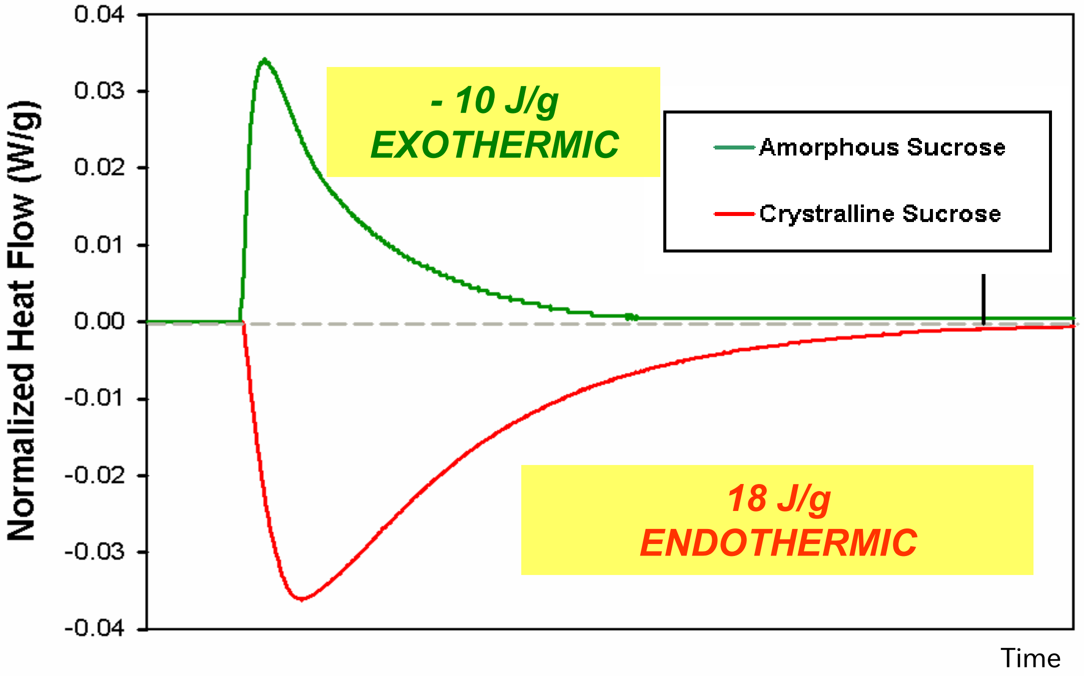
DISSOLUTION OF CRYSTALLINE *VS.* AMORPHOUS SUCROSE





Johari, 1995

The dissolution rate is related to the physical state of the solid and its dissolution enthalpy.

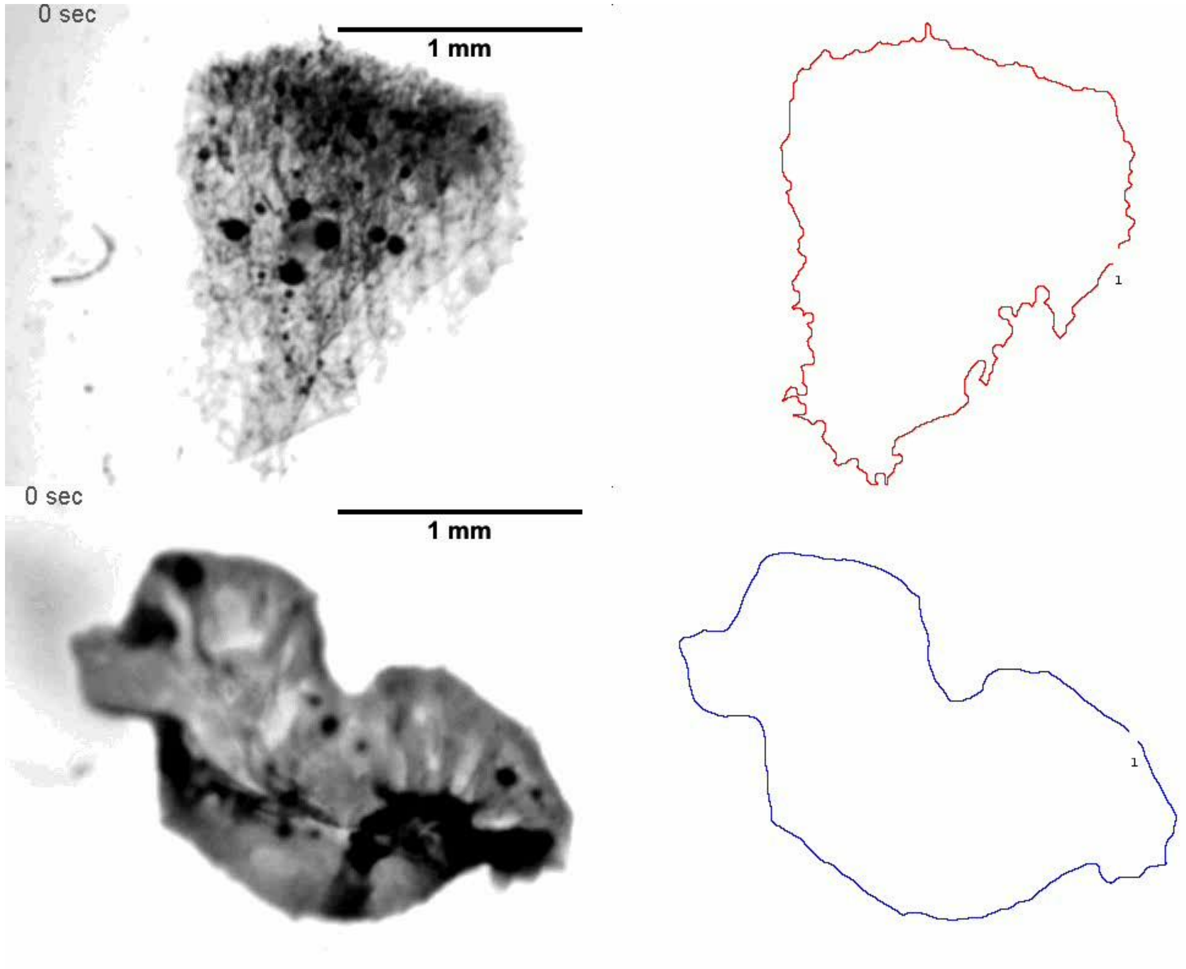


A. Marabi et al, Chemical Engineering Journal, 139, (2008), 118-127

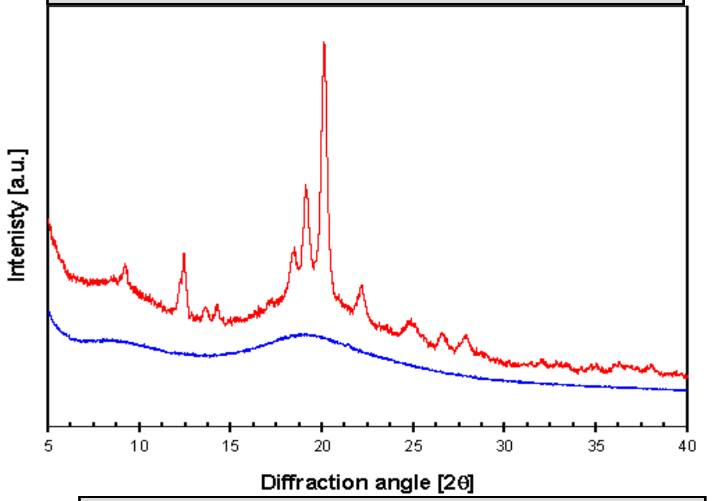
DISSOLUTION OF CRYSTALLINE *VS.* AMORPHOUS MILK POWDER

Dissolution kinetics at 30°C

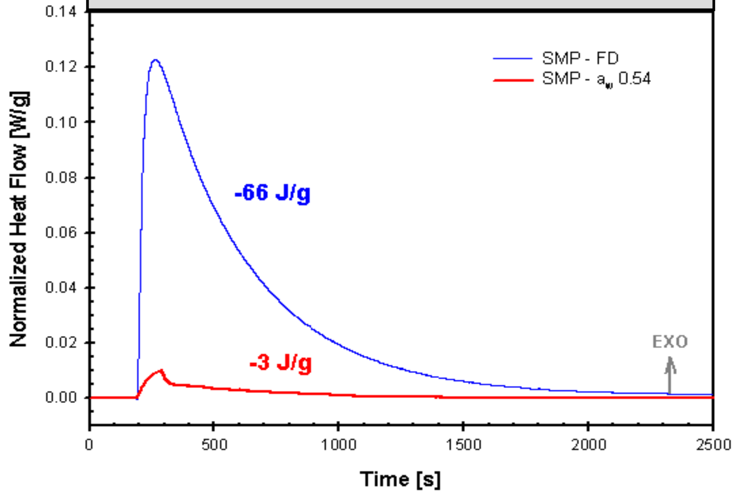
Equil a_w 0.54
W%~10%



Amorphous vs. crystalline state

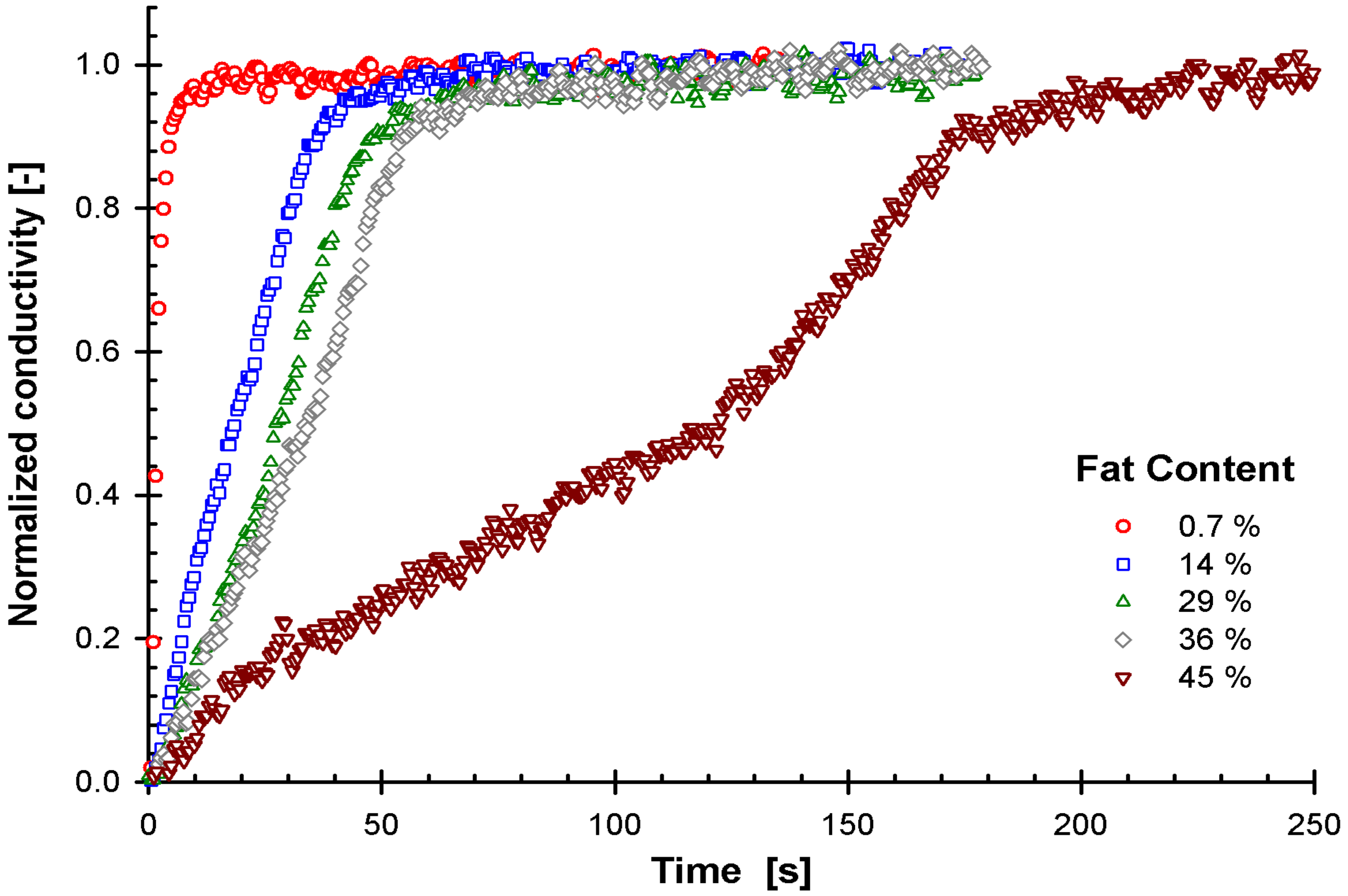


Enthalpy of dissolution at 30°C



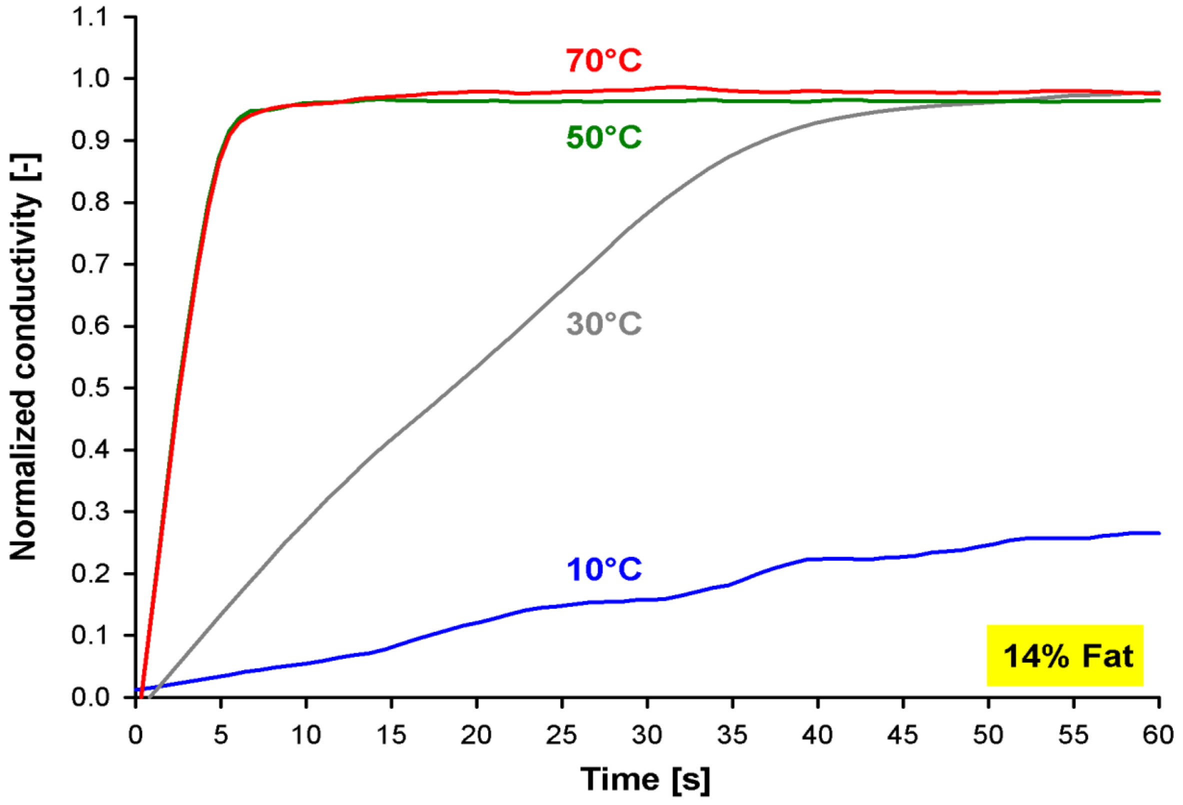
A. Marabi et al, Food Research International 40, (2007), 1286–1298

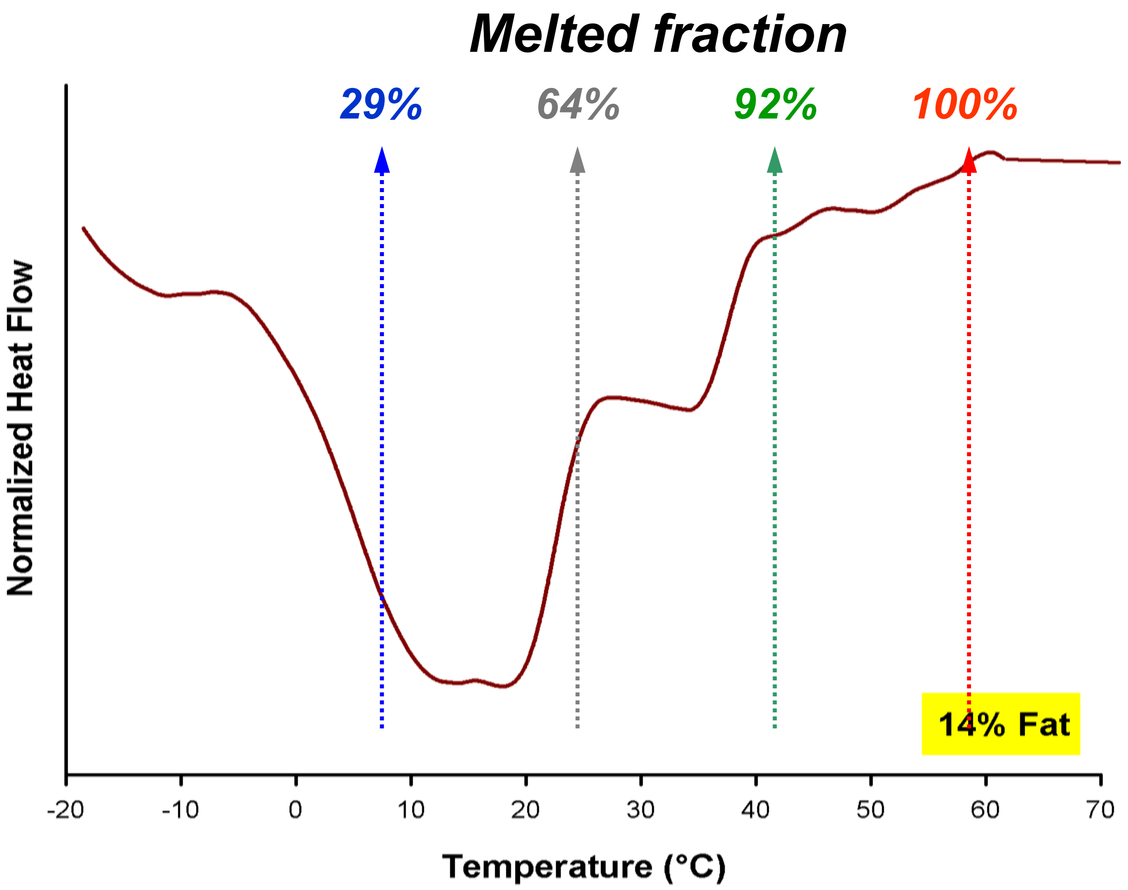
EFFECT OF FAT ON DISSOLUTION KINETICS



A. Marabi et al, Journal of Food Engineering, 85, (2008), 518–527

EFFECT OF TEMPERATURE ON DISSOLUTION KINETICS





A. Marabi et al, Journal of Food Engineering, 85, (2008), 518–527

FROM FORMULATION TO END-USE PROPERTIES

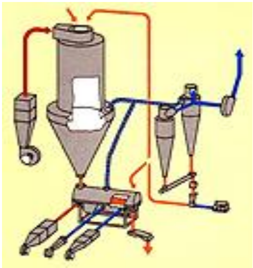
Formulation

Milk source, fat melting point, carbohydrate source, lecithin

↓

Processing

Drying, agglomeration, sintering, compaction, tableting



↓

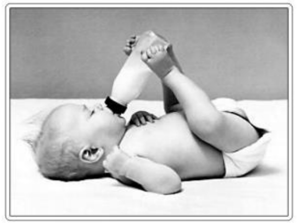
Structure

Porosity, pore size distribution, density, hardness, friability

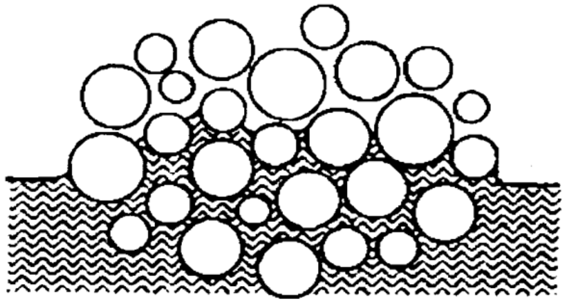
↓

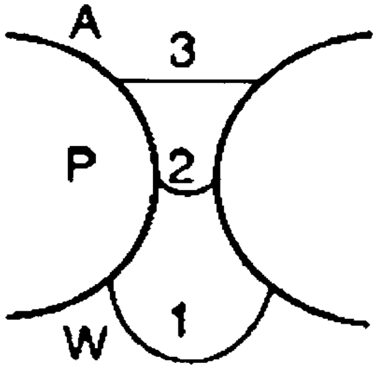
End-use Properties

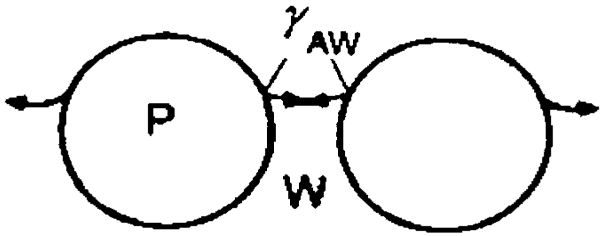
Fast dissolution, cold dissolution, physical stability, nutritional value



SUMMARY - DISPERSION OF A POWDER







Parameters to control:

- *Contact angle Air-Water-Powder particle (should be smaller than approx. 30°)*
- *Capillary contraction by wetting*
- *Swelling of powder particles*
- *Dissolution of powder particle (endothermic- exothermic)*
- *Density*
- *Degree of agglomeration*
- *Coating of surface with amphiphiles e.g. Lecithin*

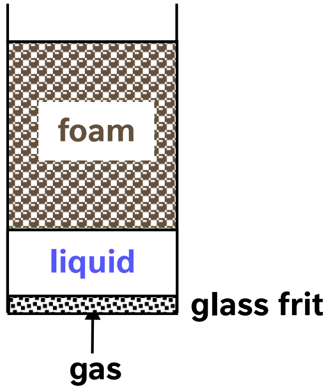
FOAMS FROM MILK

METHODS OF GENERATING FOAMS IN THE LABORATORY

Supersaturation (under pressure)

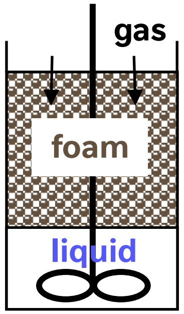
Sparging

- widely used in research. Initial liquid volume is controlled as well as air bubble size (size of the pores). The amount of gas is controlled (flow rate). Viscosity limitation, low shear, large bubbles (e.g. FoamScan from Teclis, Lyon)



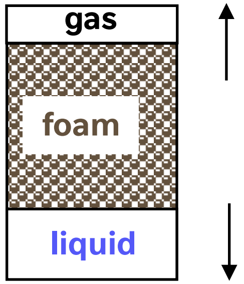
Whipping

- closest to industrial process. Gives quite stable foams and with very small air bubbles. Requires higher amount of foaming agent than sparging; the amount of incorporated gas is not controlled (e.g. Hobbart mixer)

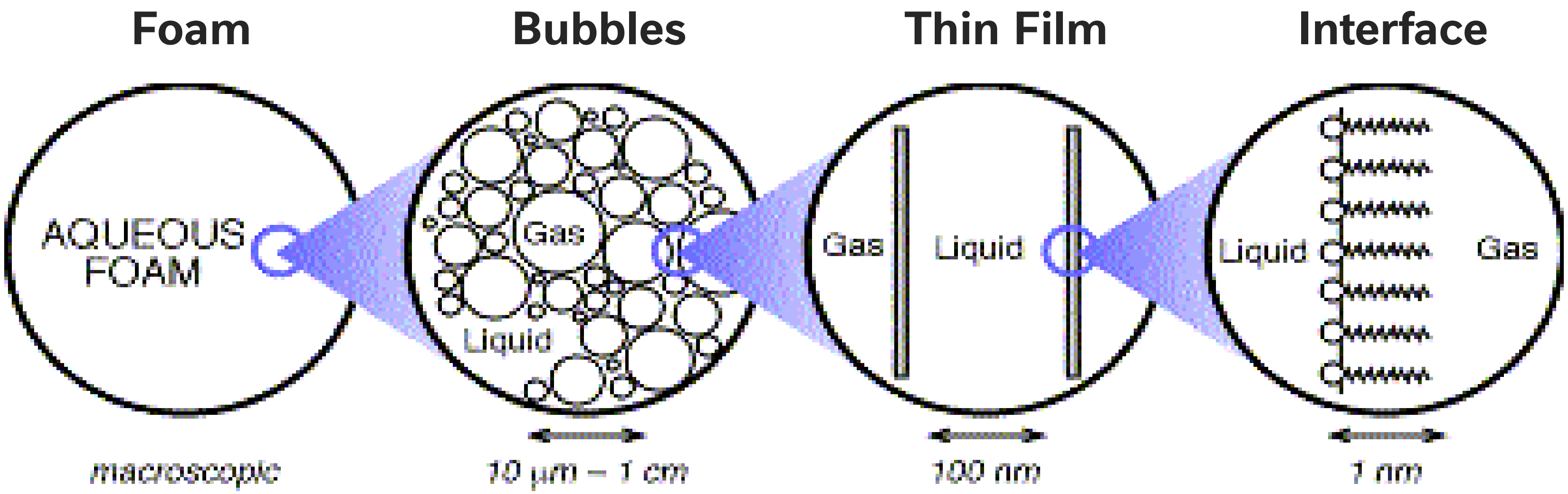


Shaking

- easiest method to generate a foam, but not very reproducible; amount of incorporated gas cannot be controlled



FOAMING IS A MULTI-LENGTH SCALE PROCESS



- Quality
- Stability
- Sensorial Properties
- Texture

- Mean size
- Size distribution
- Bubble interaction

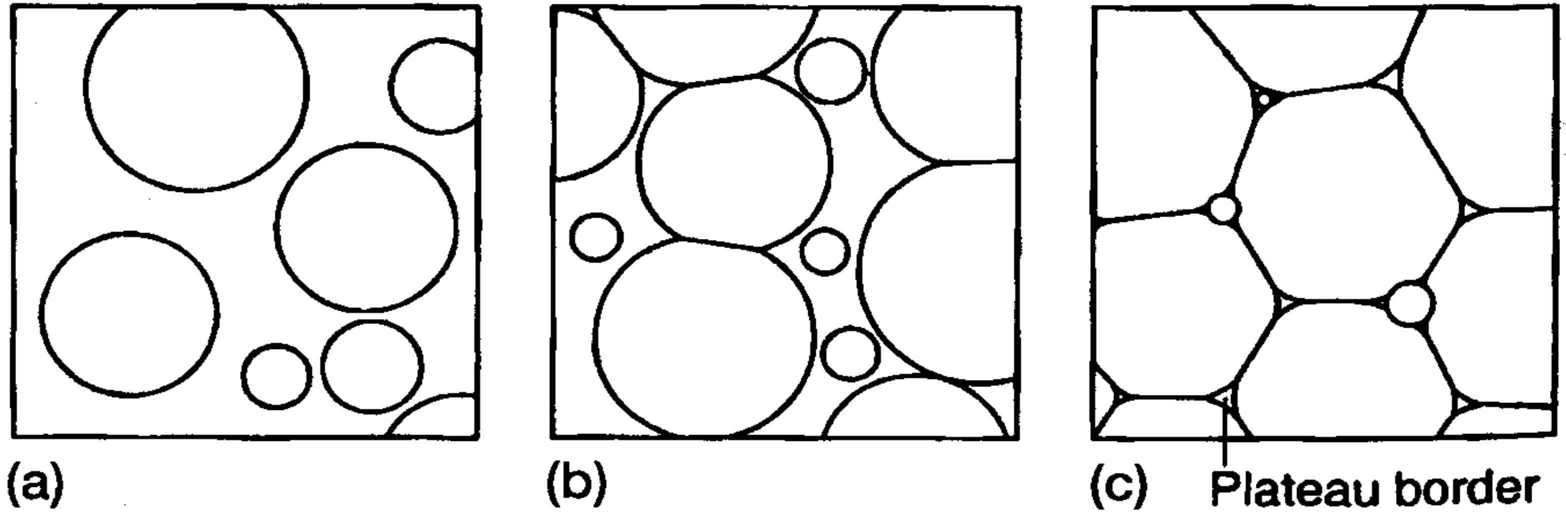
- Drainage (film thinning)
- Film rupture

- Surface tension
- Surface viscoelasticity

Source: http://www.physics.ucla.edu/~dws/foam.html

FOAM LIFE STAGES

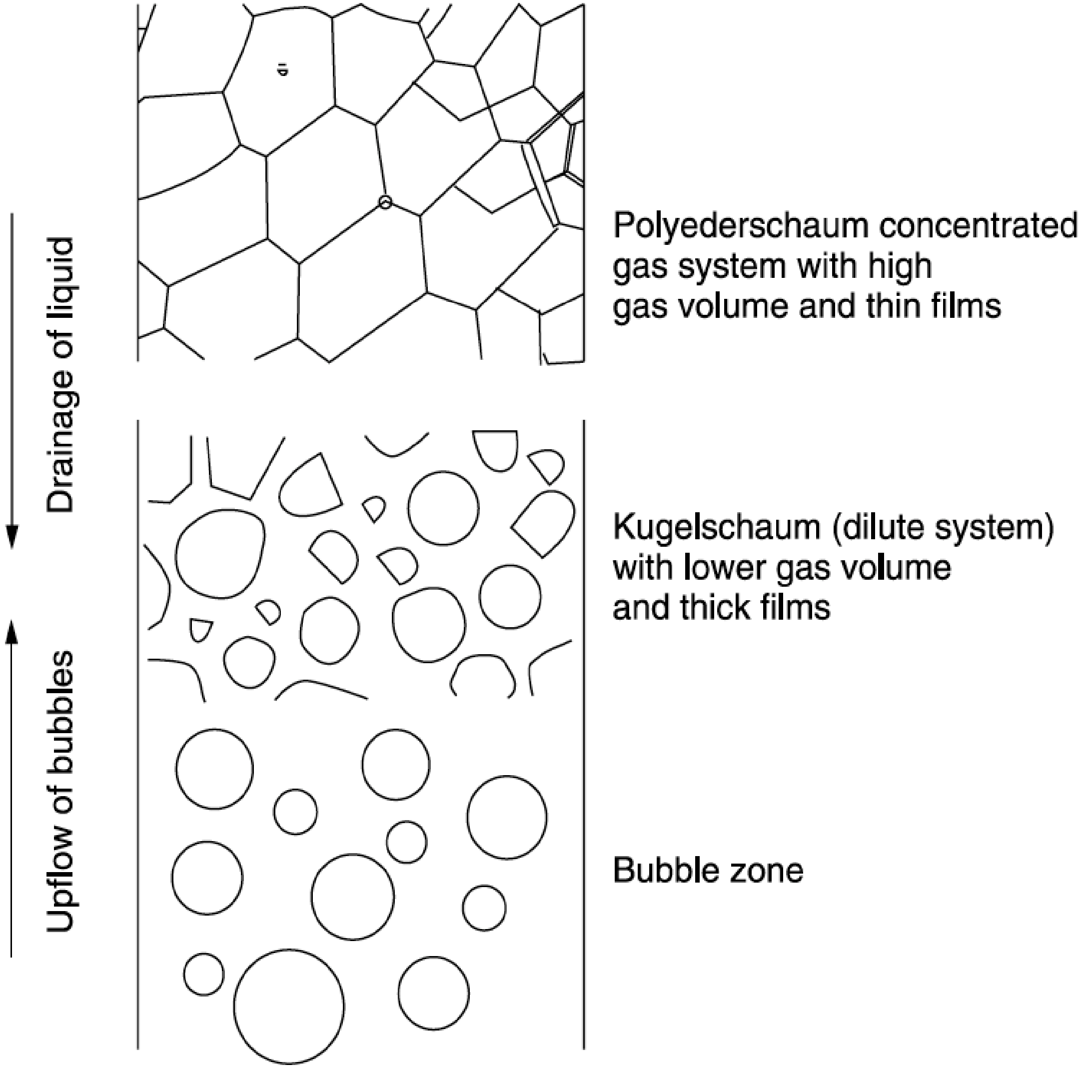
Subsequent stages of foam development from a) via b) via c) after bubbles have been made.



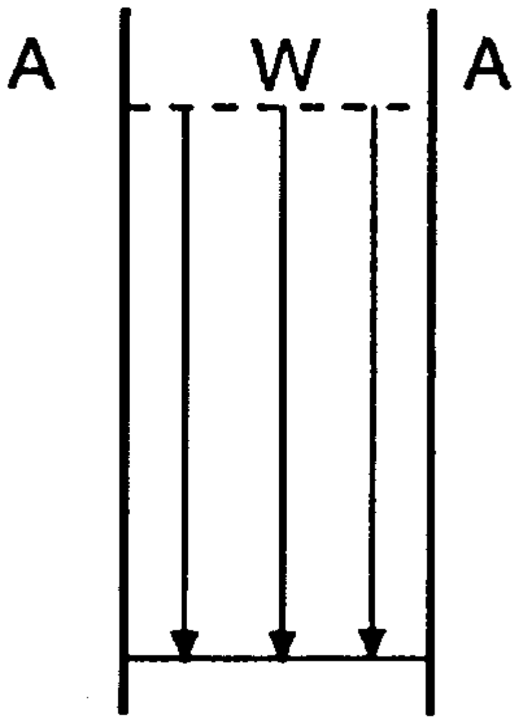
Liquid Foam → *Dry Foam*

From P. Walsta 'Physical Chemistry of Foods'

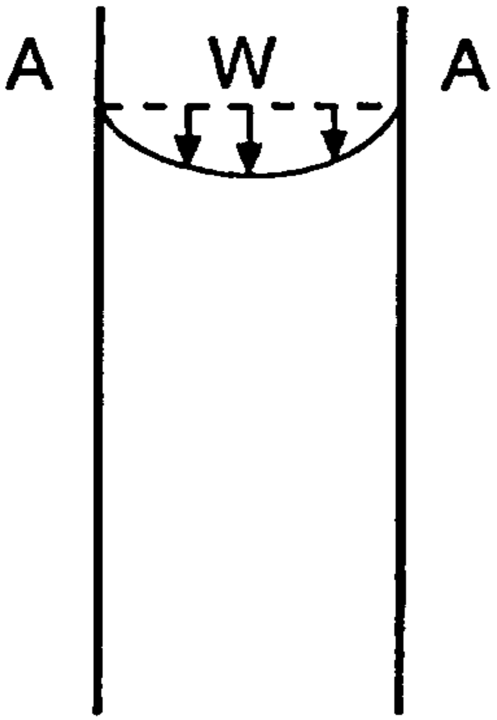
SCHEMATIC OF FOAM STRUCTURE IN A COLUMN



MECHANISMS OF FOAM STABILISATION



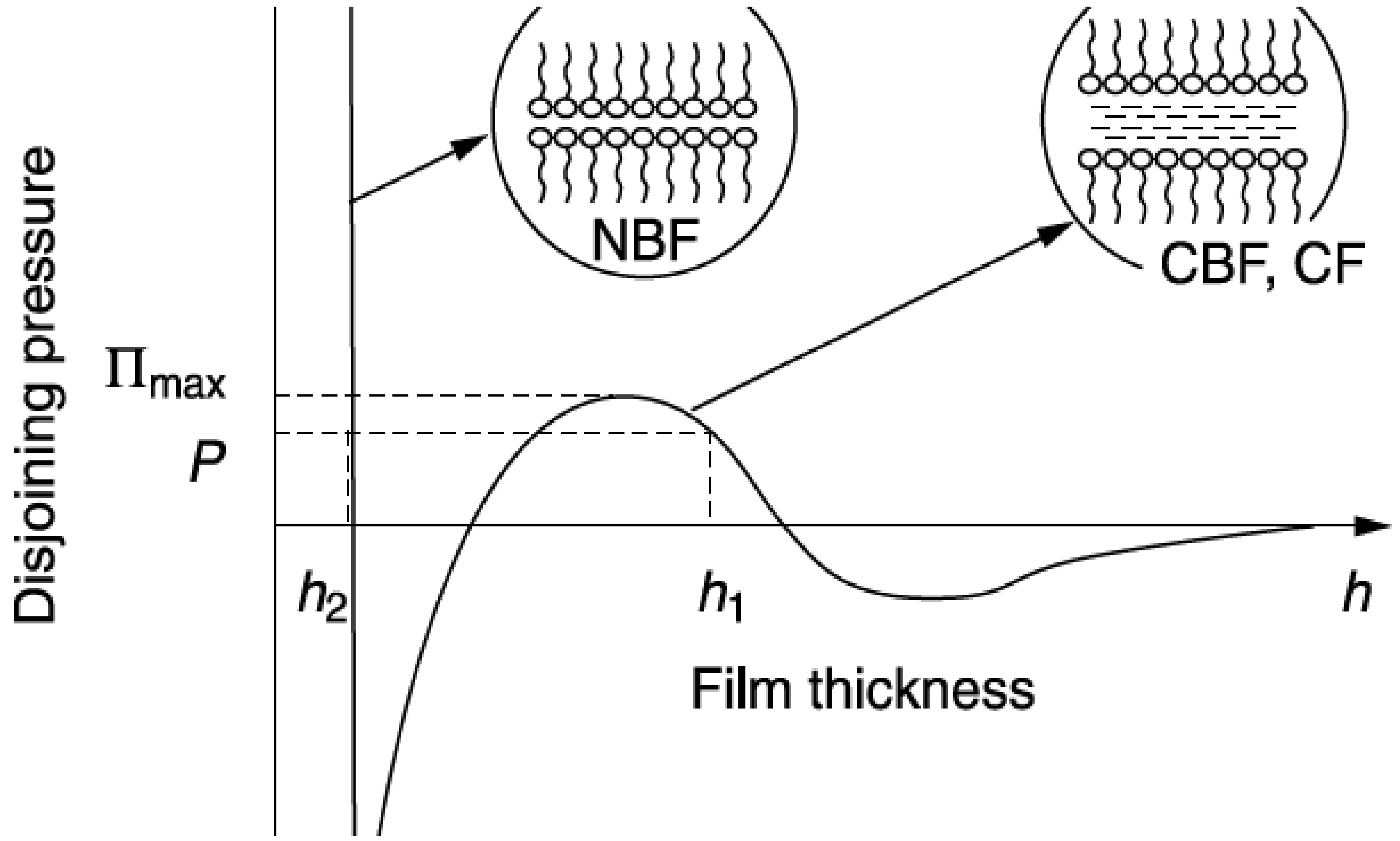
Flow profile in a thin film with-out surface active material



Flow profile in a thin film with surface active material

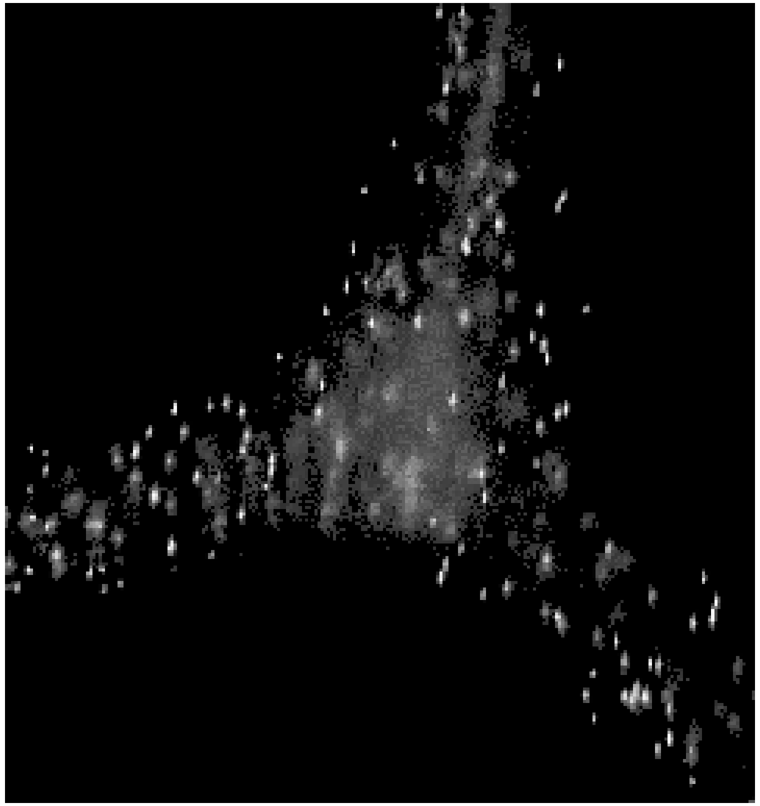
From P. Walsta ‘Physical Chemistry of Foods’

DISJOINING PRESSURE IN A THIN LIQUID FILM



Disjoining pressure versus film thickness showing the transition from common film (CF) to common black film (CBF) to Newton black film (NBF).

DRAINAGE WITHIN A SINGLE FILM



F_{gr} = *Gravity Force*
h = *Height of film*
q = *Width of film*
δ = *Film thickness*
ρ_w = *Density of water*

Π = *Surface pressure*
Q = *Flow rate*
η = *Viscosity*
t = *Time*

Shear stress on each film surface:

$$F_{gr} = \delta q h \rho_w g$$

$$\left(\frac{1}{2}\right)\frac{F}{hq} = \left(\frac{1}{2}\right) g \delta \rho_w$$

Maximum height for film not flowing down with liquid:

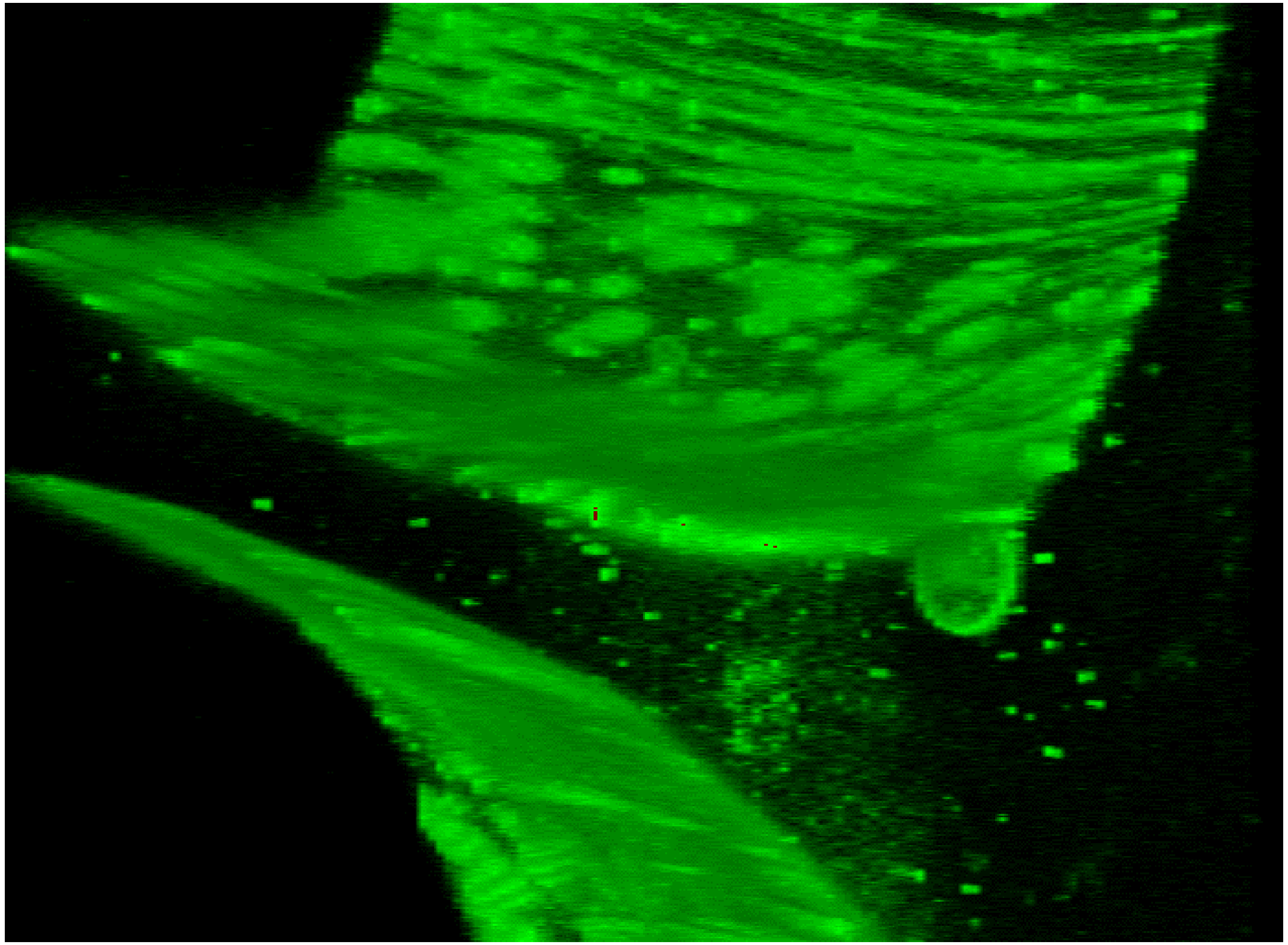
$$h_{\max} = 2\frac{\Pi}{\rho_w g \delta}$$

Flow rate Q out of a vertical film:

$$Q = 2\rho_w g q \delta^3 / 3\eta$$

$$t(\delta) \square 3\frac{\eta h}{\rho g \delta^2}$$

STRUCTURES AT FOAM INTERFACES



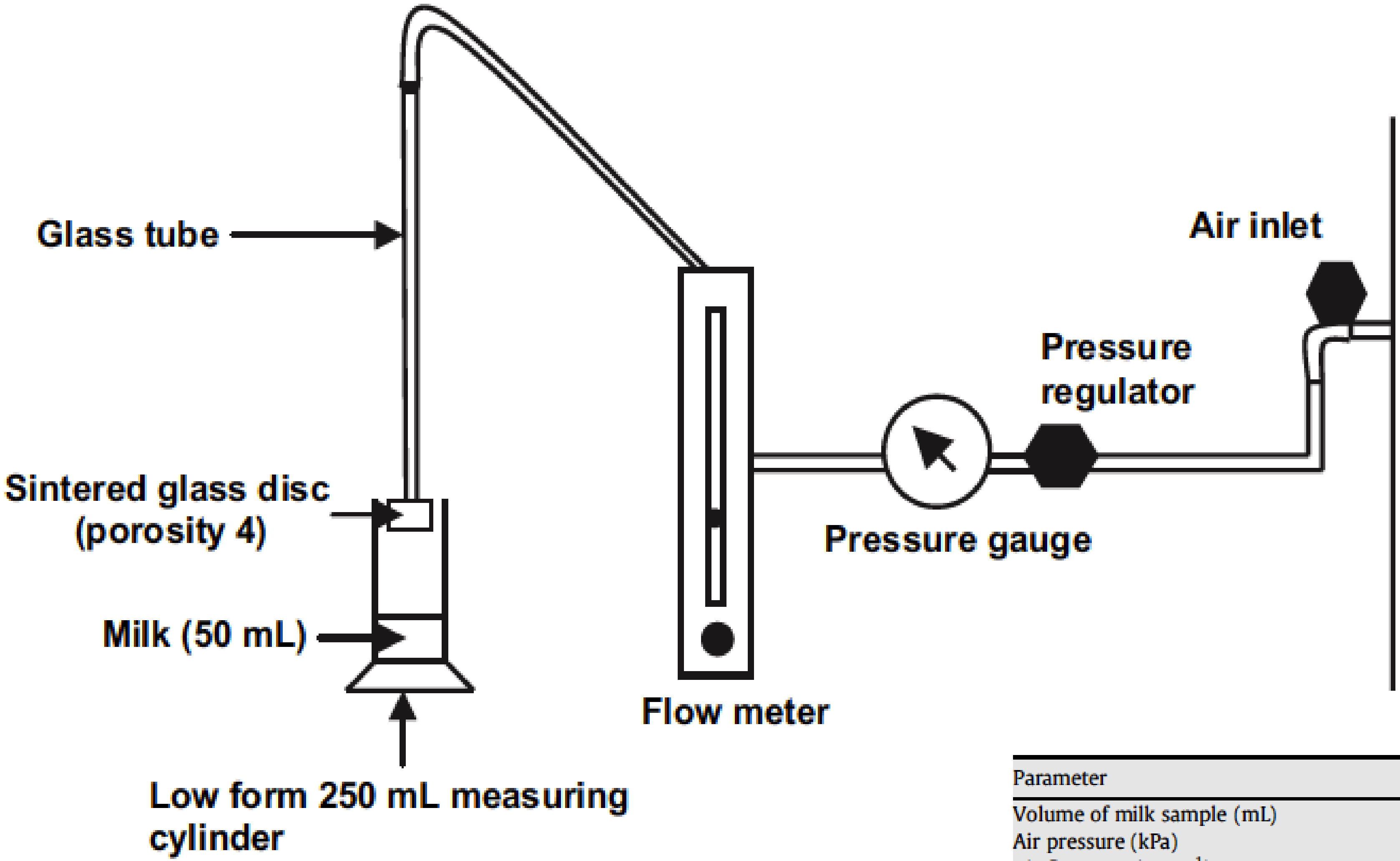
Observations:

Phase separation at interface

Different Structures formed in Plateau Border and in Lamellae

Courtesy of Dr. E. Koldziejczyk, NRC Lausanne

SETUP FOR STUDYING FOAMS



Parameter	
Volume of milk sample (mL)	50
Air pressure (kPa)	34–42
Air flow rate ($mL\,s^{-1}$)	2.4
Time of bubbling (s)	16

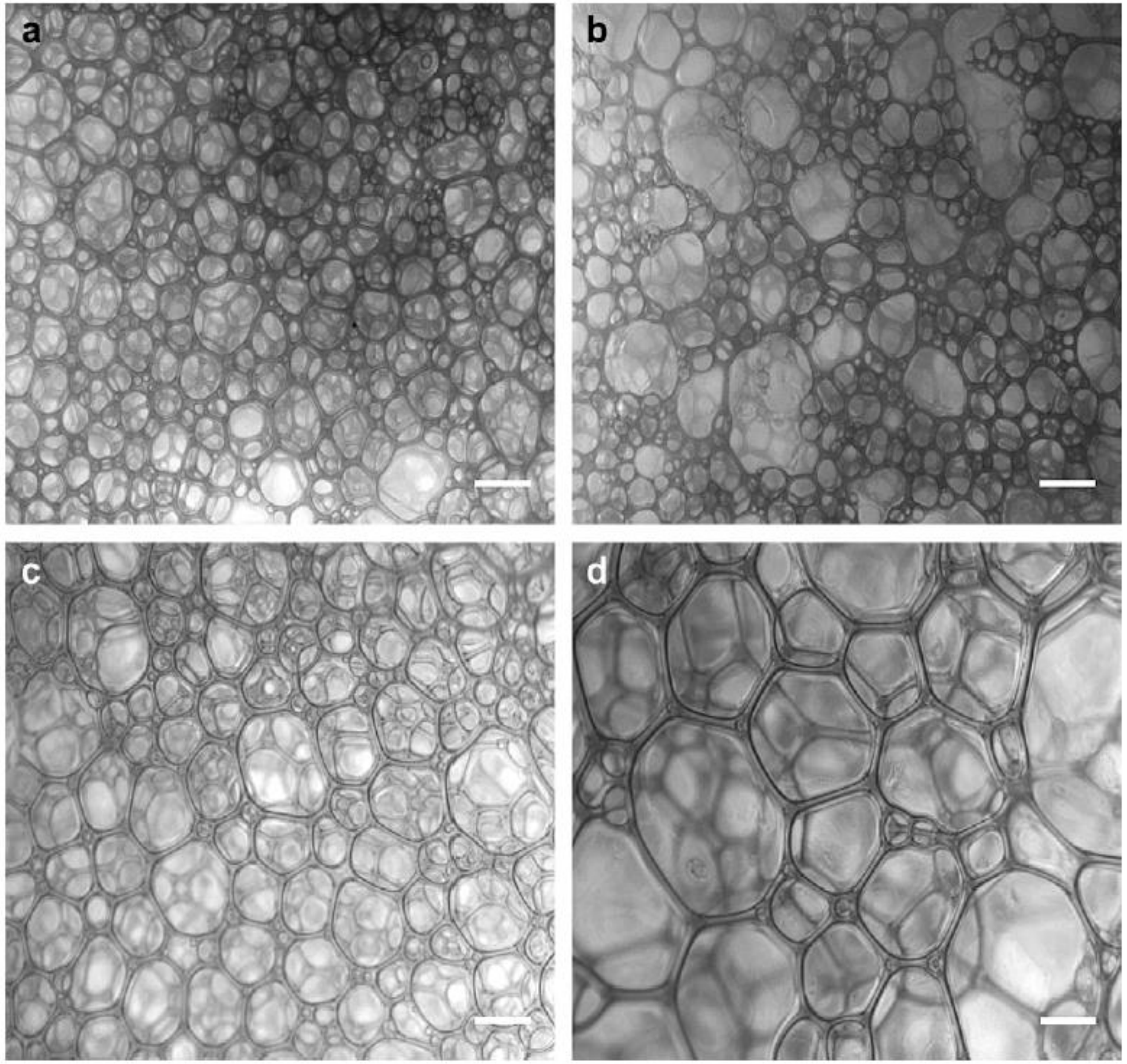
S. Kamath et al. / International Dairy Journal 18 (2008) 994–1002

% OVERRUN

$$\% \text{ overrun} = \frac{\phi_g}{1-\phi_g} 100 = \frac{V_g}{V_L} 100$$

ϕ_g: volume fraction of gas phase in foam
V_g: Volume of gas in foam
V_L: Volume of liquid in foam

WHOLE AND SKIM MILK FOAMS



Images of foam formed at 85° C from

(a) pasteurized homogenized whole milk immediately after foaming

(b) pasteurized homogenized whole milk at half-life

(c) pasteurized skim milk immediately after foaming

(d) pasteurized skim milk at half-life.

Bar: 1000 μm.

S. Kamath et al. / International Dairy Journal 18 (2008) 994–1002

INFLUENCE OF PROCESSING ON FOAMABILITY AND STABILITY

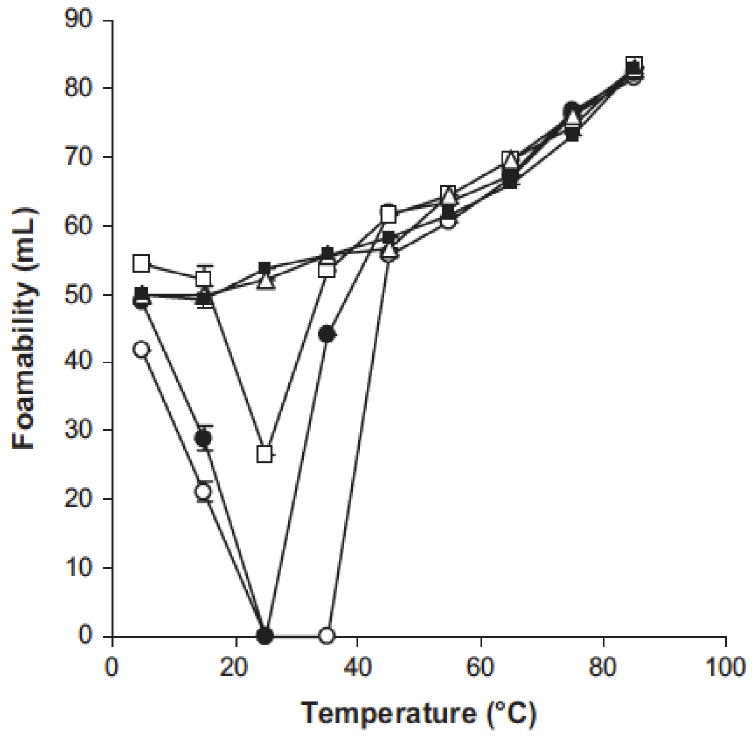


Fig. 2. Average foamability of cows' milk as a function of temperature (5–85 °C): (○) raw whole milk, (●) pasteurized homogenized whole milk, (□) UHT homogenized whole milk, (■) UHT skim milk, (△) pasteurized skim milk. The error bars presented are the pooled standard errors for individual milks. The same standard errors are applied at each data point for a given milk.

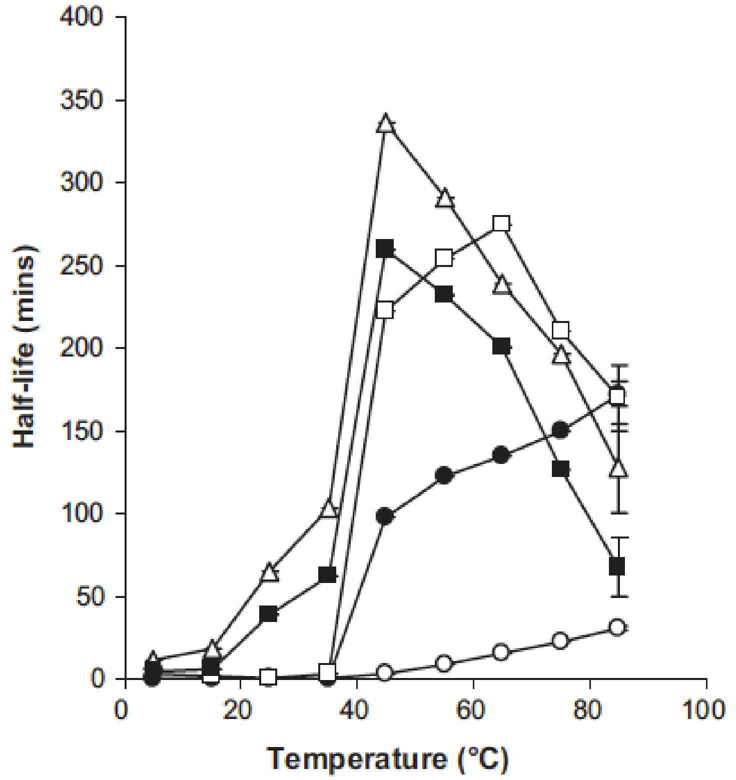
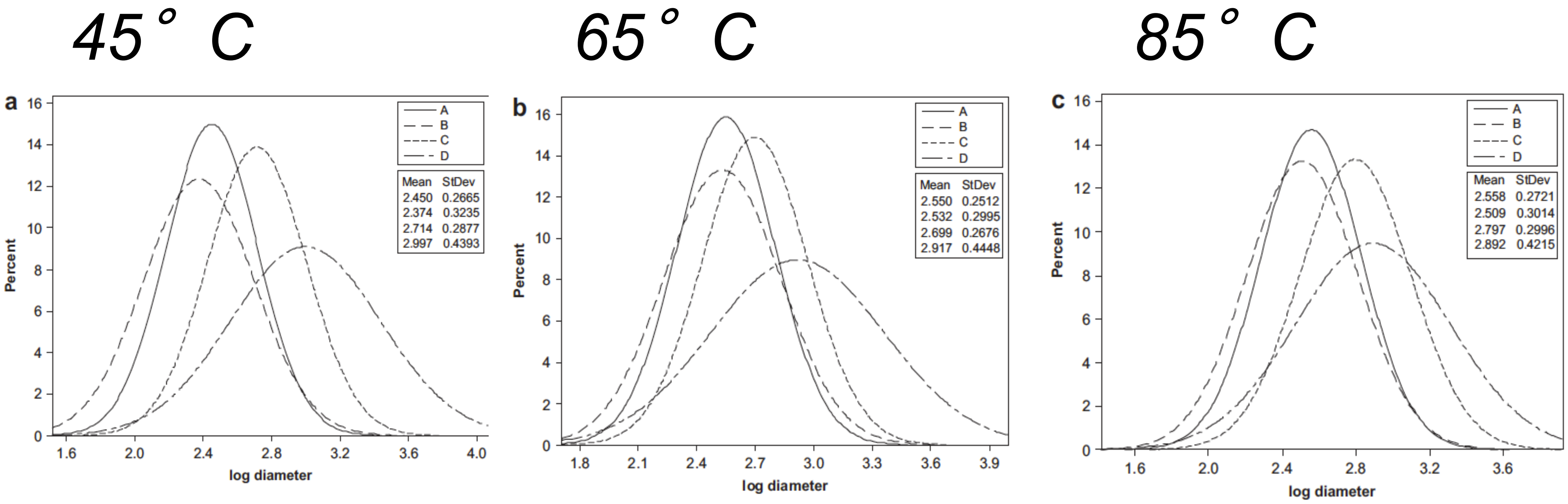


Fig. 3. Average foam stability of cows' milk as a function of temperature (5–85 °C): (○) raw whole milk, (●) pasteurized homogenized whole milk, (□) UHT homogenized whole milk, (■) UHT skim milk, (△) pasteurized skim milk. The error bars presented are the pooled standard errors for individual milks. The same standard errors are applied at each data point for a given milk.

S. Kamath et al. / International Dairy Journal 18 (2008) 994–1002

BUBBLE SIZES OF WHOLE AND SKIM MILK FOAMS

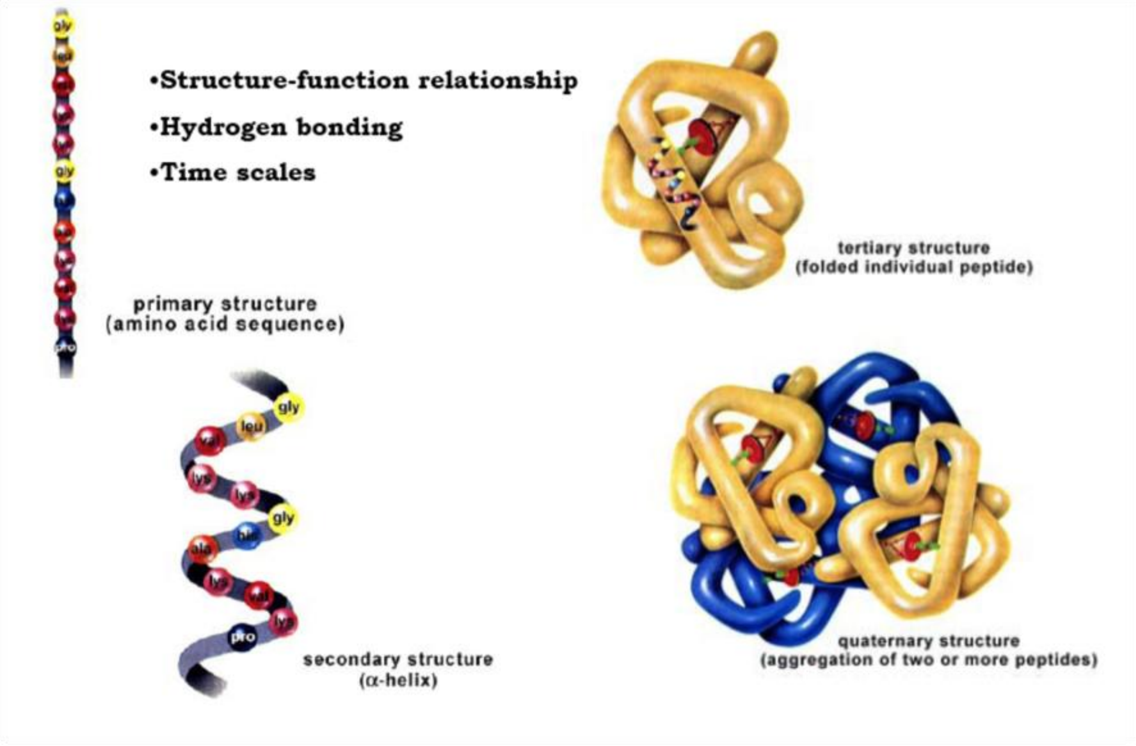


Legend:
A pasteurized homogenized whole milk, fresh foam
B pasteurized homogenized whole milk foam at half-life
C pasteurized skim milk, fresh foam
D pasteurized skim milk foam at half-life.

S. Kamath et al. / International Dairy Journal 18 (2008) 994–1002

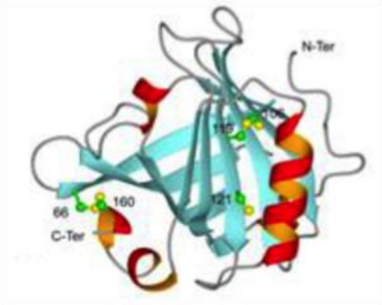
PROTEINS AT INTERFACES

Structure of Proteins is Complex

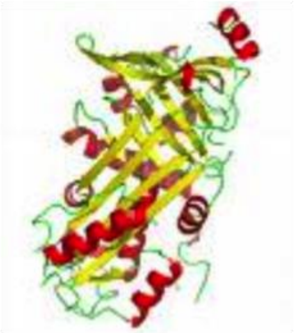


Typical food proteins used to stabilize interfaces:

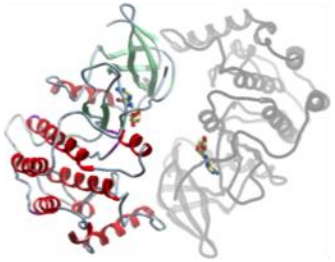
Whey Proteins



Ovalbumin



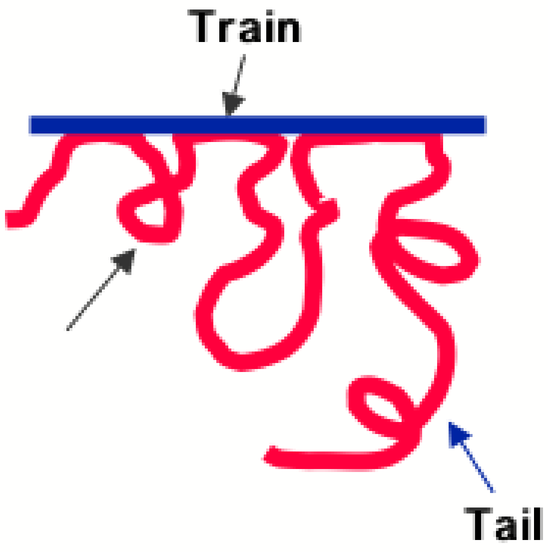
Caseins



MODE OF ADSORPTION OF POLYMERS

Homopolymer

Polysaccharides are predominantly hydrophilic

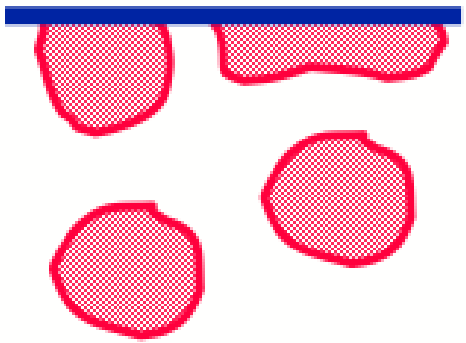


Copolymer

Contain hydro-phobic and hydrophylic sites

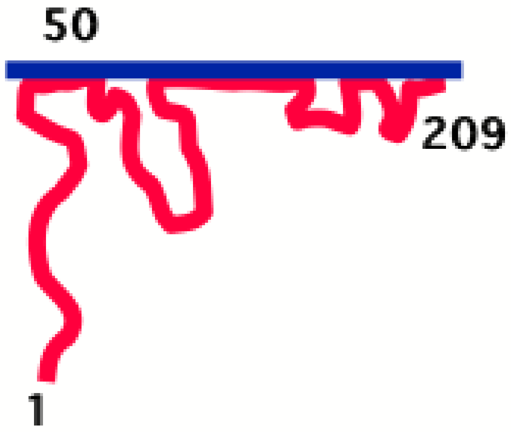
β-Lactoglobulin

Globular protein with very hydrophobic core

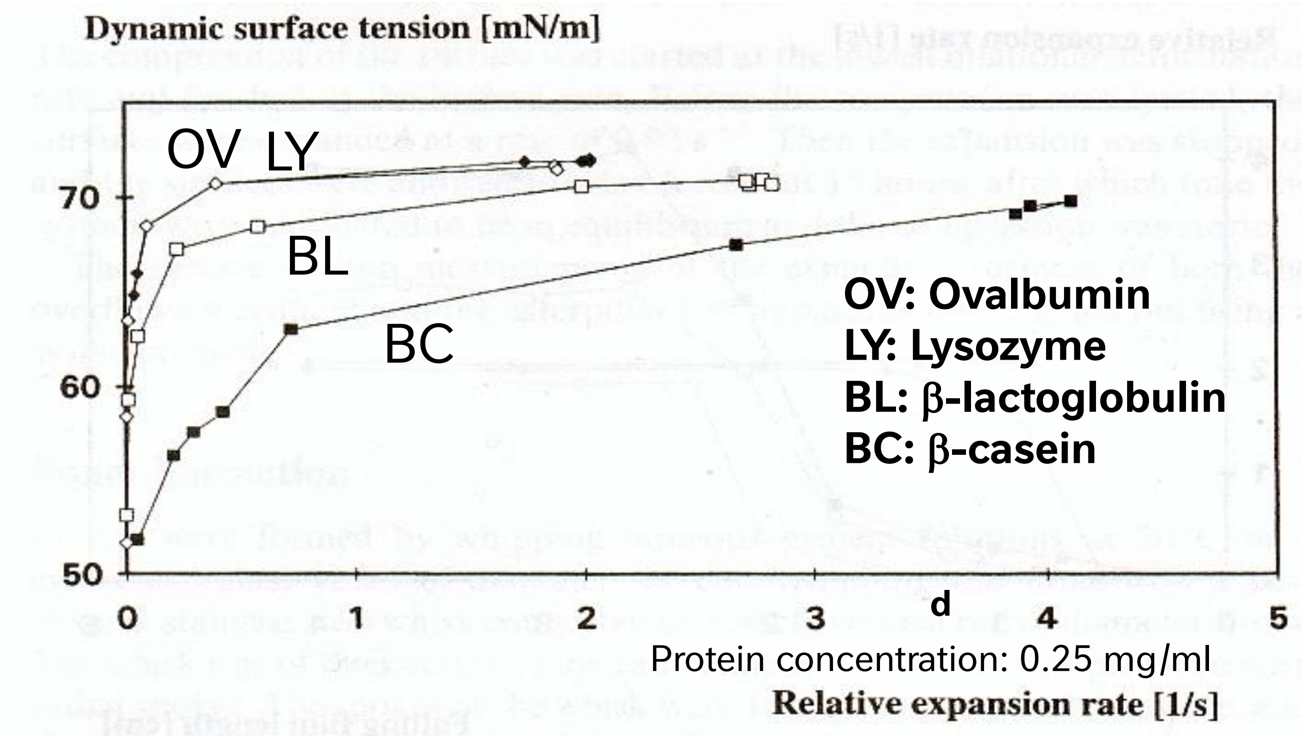


β-Casein

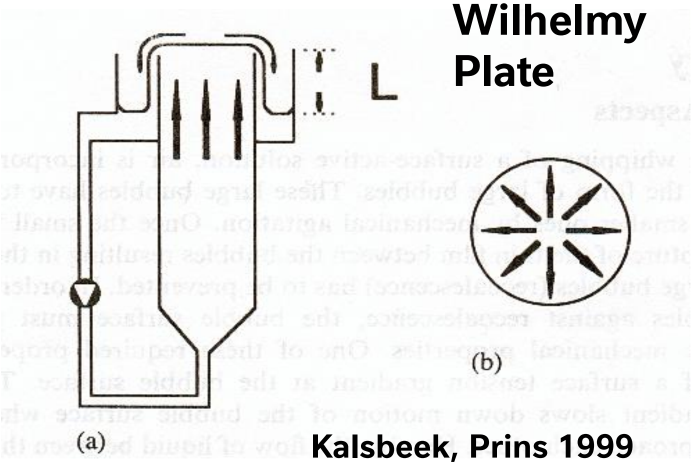
Hydrophilic N-terminal part



DYNAMIC SURFACE TENSION MEASUREMENTS



Overflowing cylinder



Kalsbeek, Prins 1999

<u>Explanation</u>:

Rate of partial unfolding of the protein after adsorption is different and not the rate of protein transport to the surface

<u>Rough estimation of the time scale of unfolding</u>:

100s for LY; 0.25s for BL; 0.1s BC

DILATIONAL SURFACE ELASTICITY AND VISCOSITY FOR DIFFERENT PROTEINS

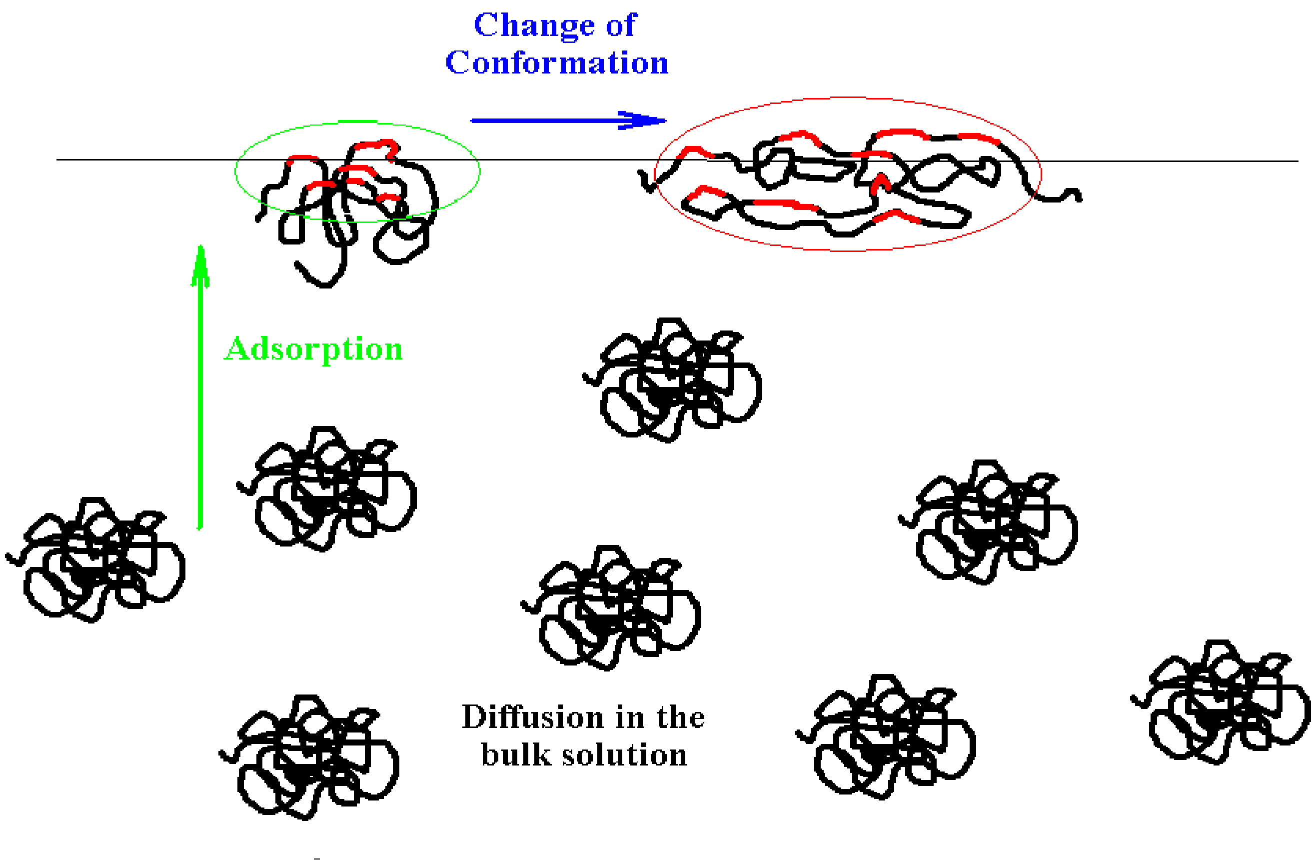
Air/water interface

	β-casein	BLG	BSA	Ovalbumin
Molecular weight (Dalton)	24.000	18.000	69.000	45.000
α-helix (%) β-sheet (%)	1-10 13-16	10 50	55 16	30 27
cystein/mol S-S bridges/mol		5	35 17	4 1
structure of molecule	Random coil	Rigid globular	Less rigid	Compact globular
Modulus at 10 mN/m at 20 mN/m Viscous phase angle at 10 mN/m at 20 mN/m	15 55 4 20	60 90 7 11	60 75 6 11	70 80 5 6

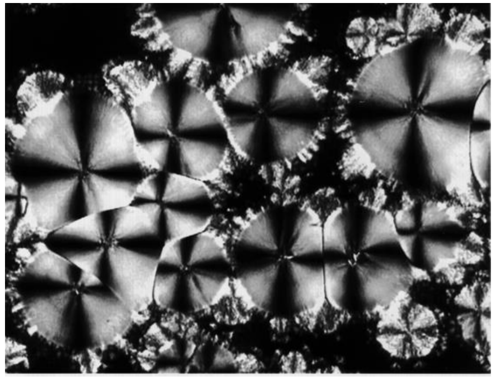
Frequency: 0.1 Hz

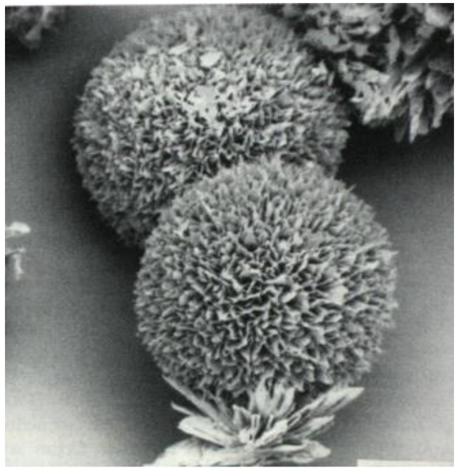
Globular compact proteins show a higher modulus than flexible random coil polymers

STRUCTURAL CHANGES AT INTERFACE

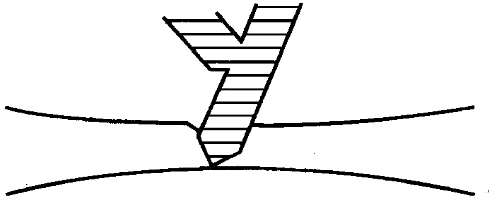


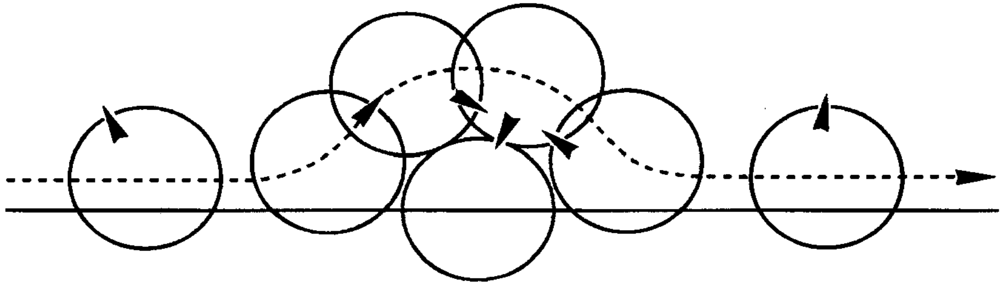
WHIPPING CREAM - PARTIAL COALESCENCE





J. M. deMan et al., 1985





From P. Walsta 'Physical Chemistry of Foods'

Partial Coalescence differs from true coalescence

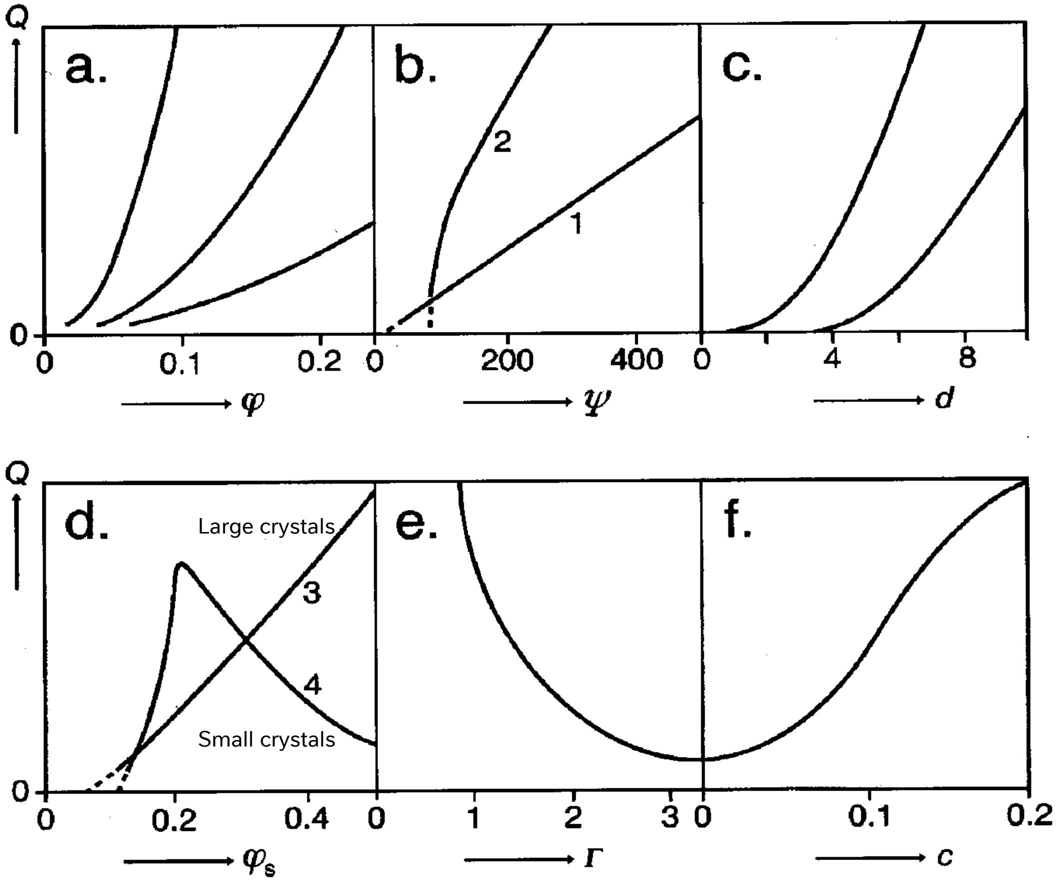
Process is much faster than true coalescence, especially if emulsion is agitated

Since irregular aggregates or clumps are formed the effective volume fraction of the disperse phase increases, resulting in an increase in viscosity

Typical example is butter making upon churning of cream

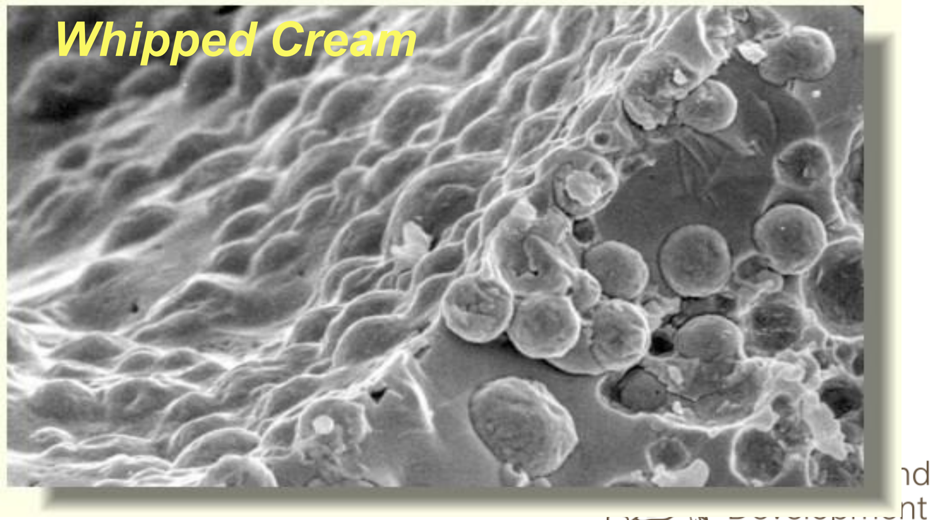
Research and Development

FACTORS AFFECTING PARTIAL COALESCENCE



Effect on rate of partial coalescence (Q) in protein stabilised o/w emulsion

a) Volume fraction (φ)
b) Shear rate (Ψ)
c) Globule diameter (d) in μm
d) Fraction of fat being solid (φ_s)
e) Protein surface load (mg/m^{-2})
f) Concentration c of small molecule surfactant added



STABILITY – COALESCENCE OF BUBBLES

Coalescence is promoted by:
Mechanical disturbances
Reorientation of structures
Absence of disjoining pressure (no repulsion)
Elevated storage temperatures

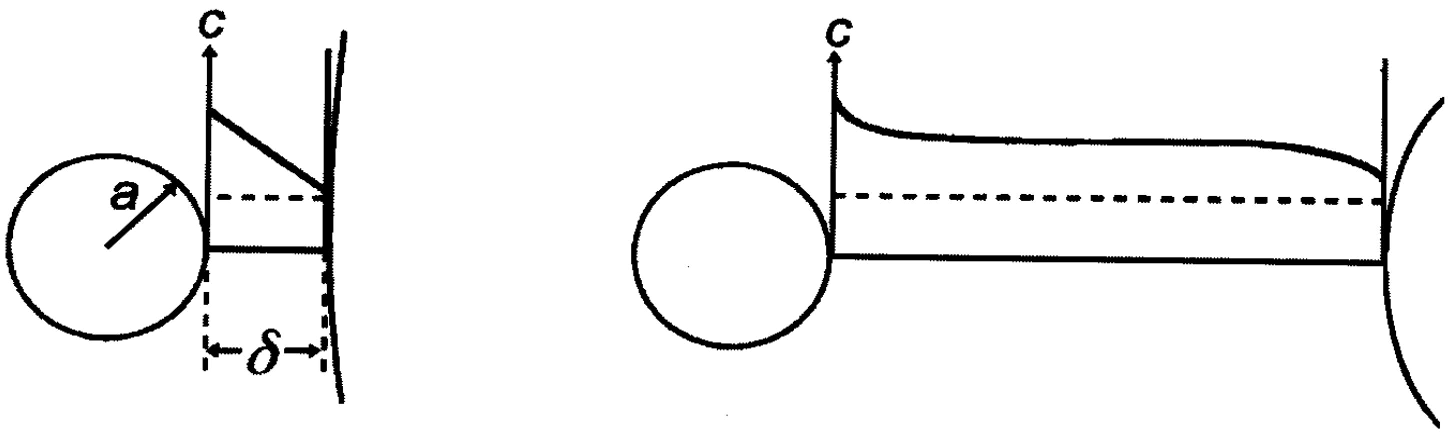
Coalescence is prevented by:
High bulk viscosity
Large surface dilational modulus
High disjoining pressure (repulsion forces between bubbles)
Small particles (thin film between bubbles are smaller)

STABILITY - OSTWALD RIPENING

Particle shrinkage
(De Vries Theory)

$$a^2(t) = a_o^2 - \frac{RTDs_{\infty}\gamma}{p\delta}t$$

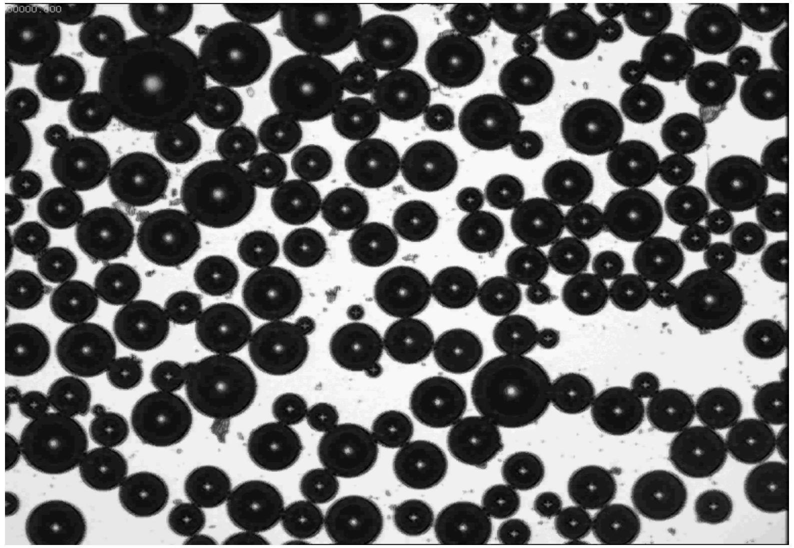
- t = Time
- D = Diffusion coefficient ($1.5\ 10^{-9}\ m^2s^{-1}$)
- δ = Film thickness
- p = Atmospheric pressure (10^5 Pa)
- R = Gas constant
- T = Temperature
- s_∞ = gas solubility
- a_0 = initial radius
- γ = surface tension



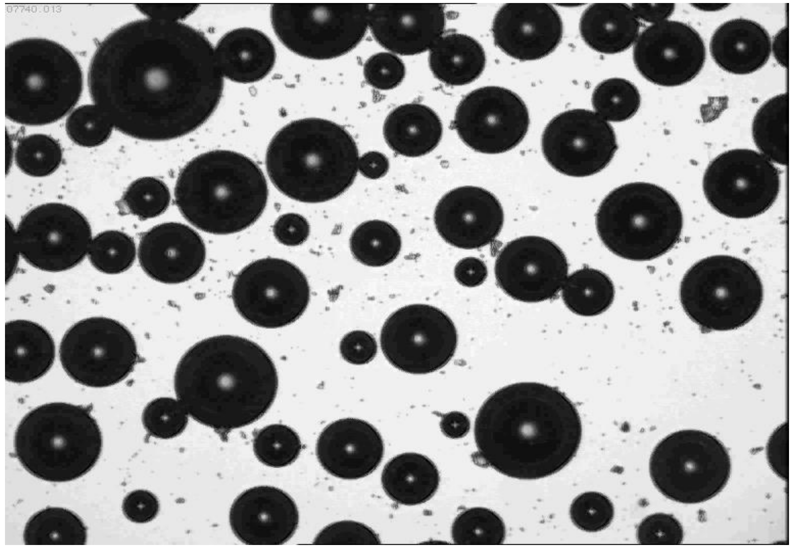
putting $a^2(t) = 0$, t equals the lifetime of a bubble

HOW TO DIMINISH OSTWALD RIPENING

- Choice of gas with low solubility
- Provide elasticity in surface layer - proteins better than low molecular weight surfactants
- Pickering stabilisation - Explore partial coalescence mechanism
- Give the continuous phase a yield stress



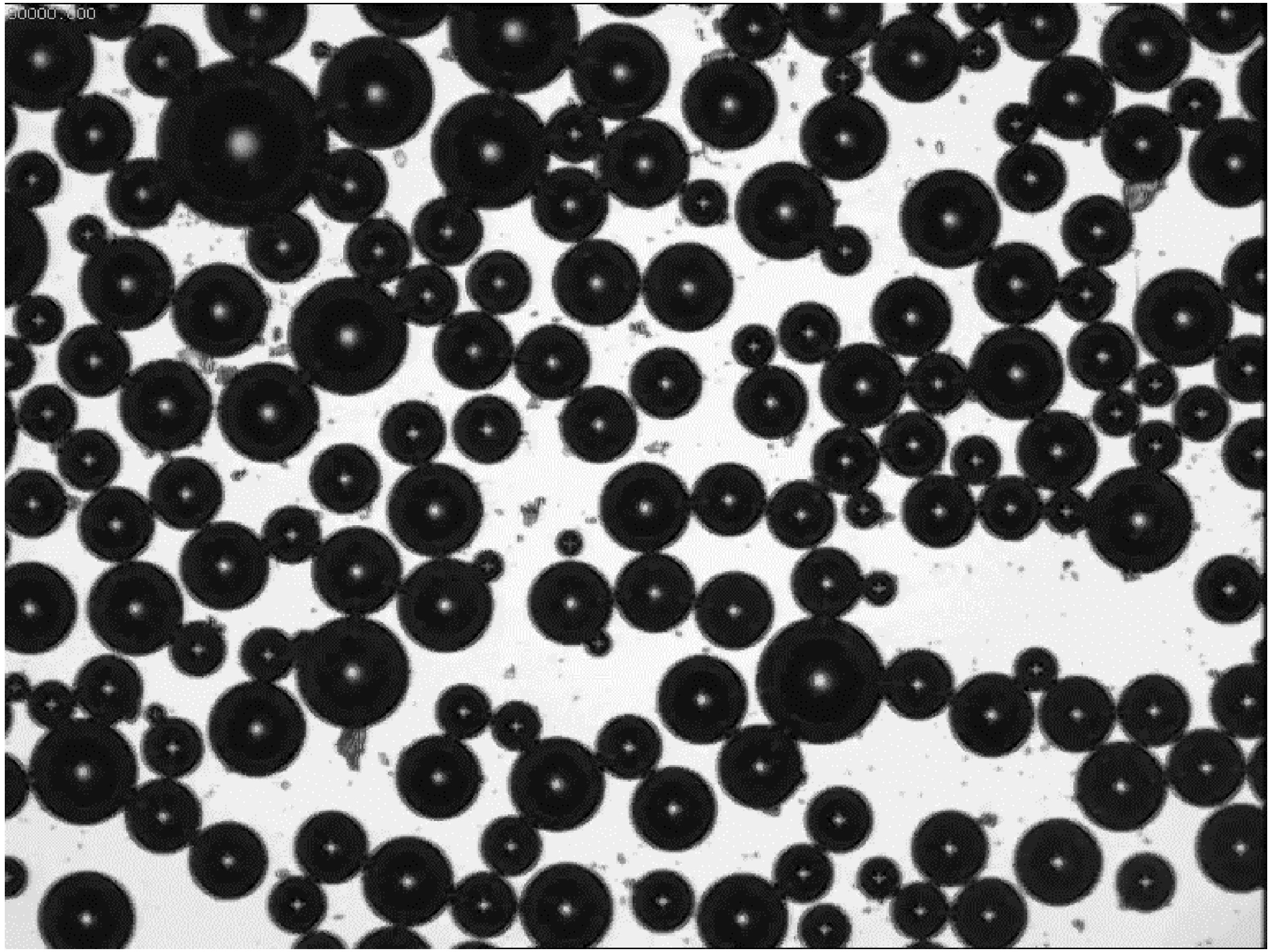
Bubble size at time 0



Bubble size after 2 hours

Research and Development

OSTWALD RIPENING



FOAM DESTABILIZATION MECHANISMS IN COMPARISON

- Creaming is extremely fast in foams created from low viscous liquid phases
- Drainage rate is high just after foam (layer) formation (wet foam). It decreases rapidly in low viscous foams and becomes negligible after 10-20 minutes.
- Disproportionation and coalescence become thereafter the most significant destabilisation phenoma (dry foam).

GELS - CHILLED DAIRY PRODUCTS

Highly attractive sensory properties & health benefits

Consumers demand premium sensory properties and product stability and seek nutritional balance without compromising texture

Dairy products are of complex colloidal and bio-polymeric nature

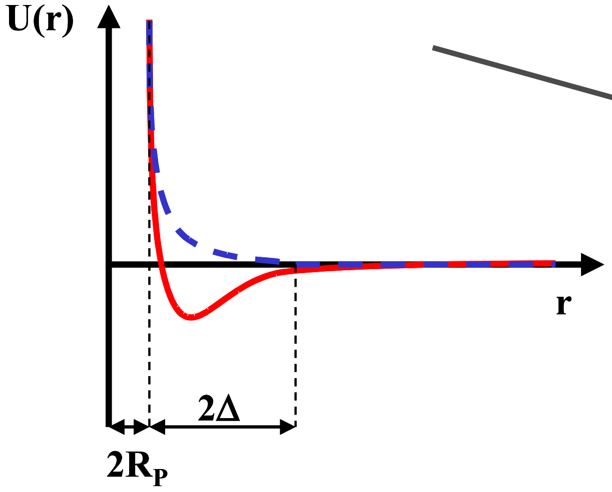
Polysaccharides are frequently used to enhance and maintain textural and visual product properties

Polysaccharide functionality is not well understood and protein-polysaccharide interactions often ignored

SOL-GEL TRANSITIONS

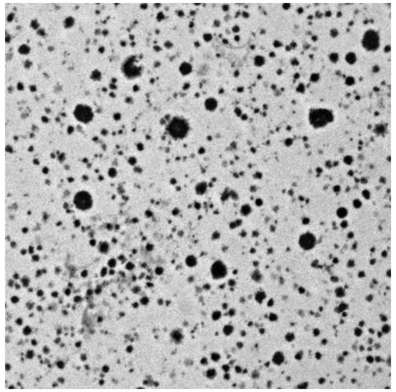
Intrinsic Parameters

Hydrophobic, electrostatic, London & Van der Waals interactions
Interaction potentials, e.g. depletion interactions

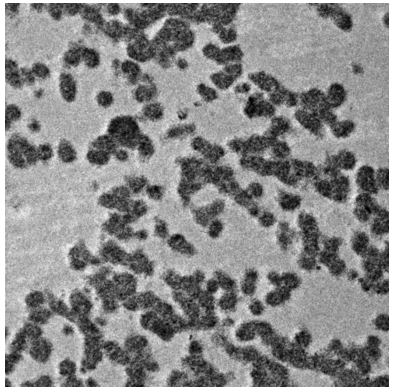


System

Sol-Gel Transition

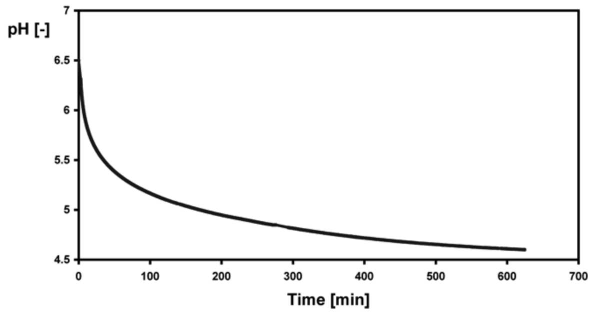


Destabilisation by acidification



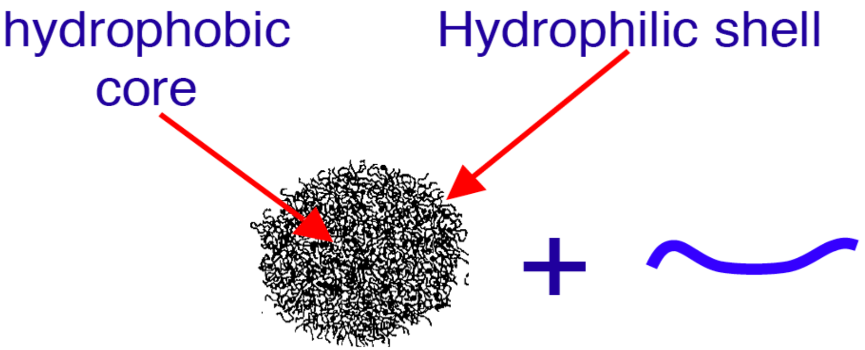
Control Parameters

Concentration, thermodynamic conditions (e.g. temperature, pressure, co-solutes)
transport condition (e.g. diffusion)
Particle size and distribution
Ionic strength
Acidification kinetics



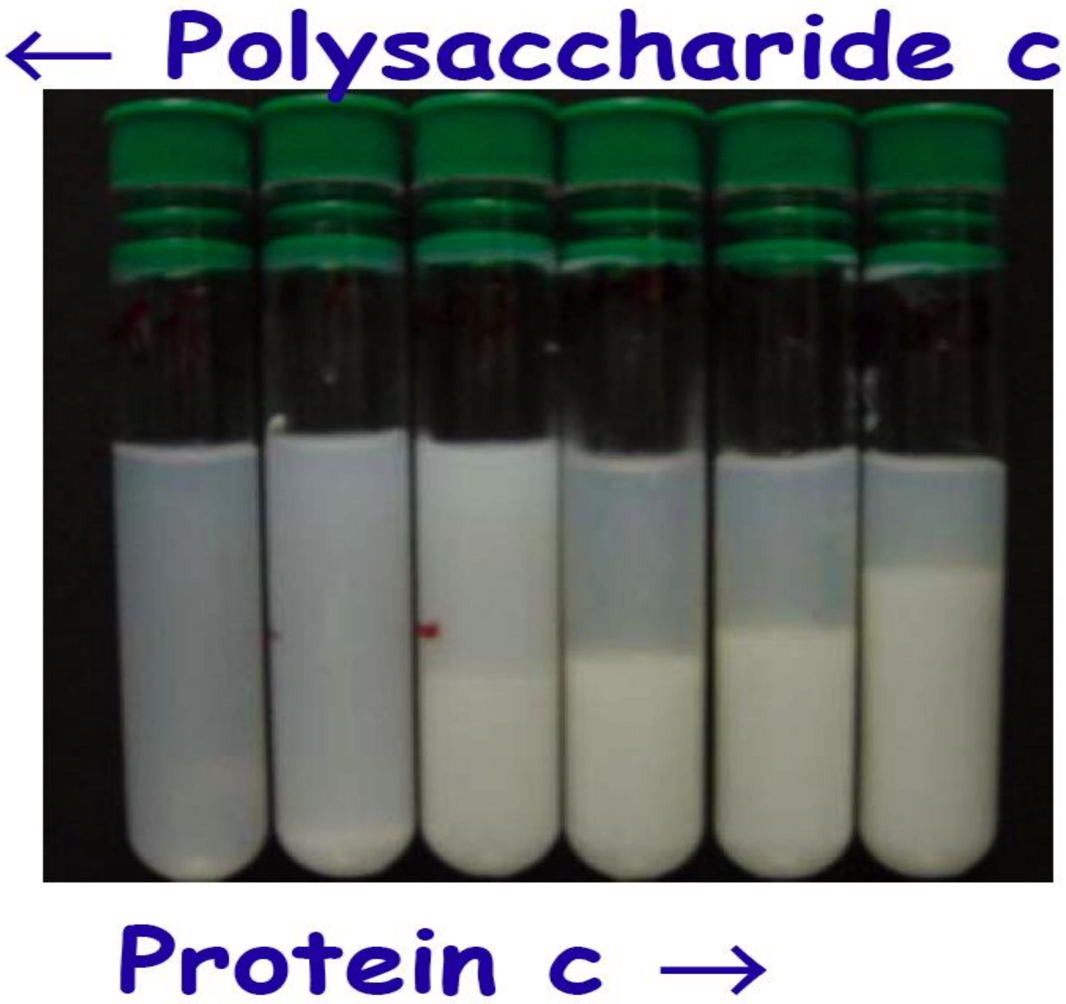
Ph.D. Thesis, P. Aichinger, NRC Lausanne

SKIM MILK AND XANTHAN AS MODEL SYSTEM



Casein Micelles
- R ~ 100 nm
- Hard spheres
- Negatively charged above isoelectric point

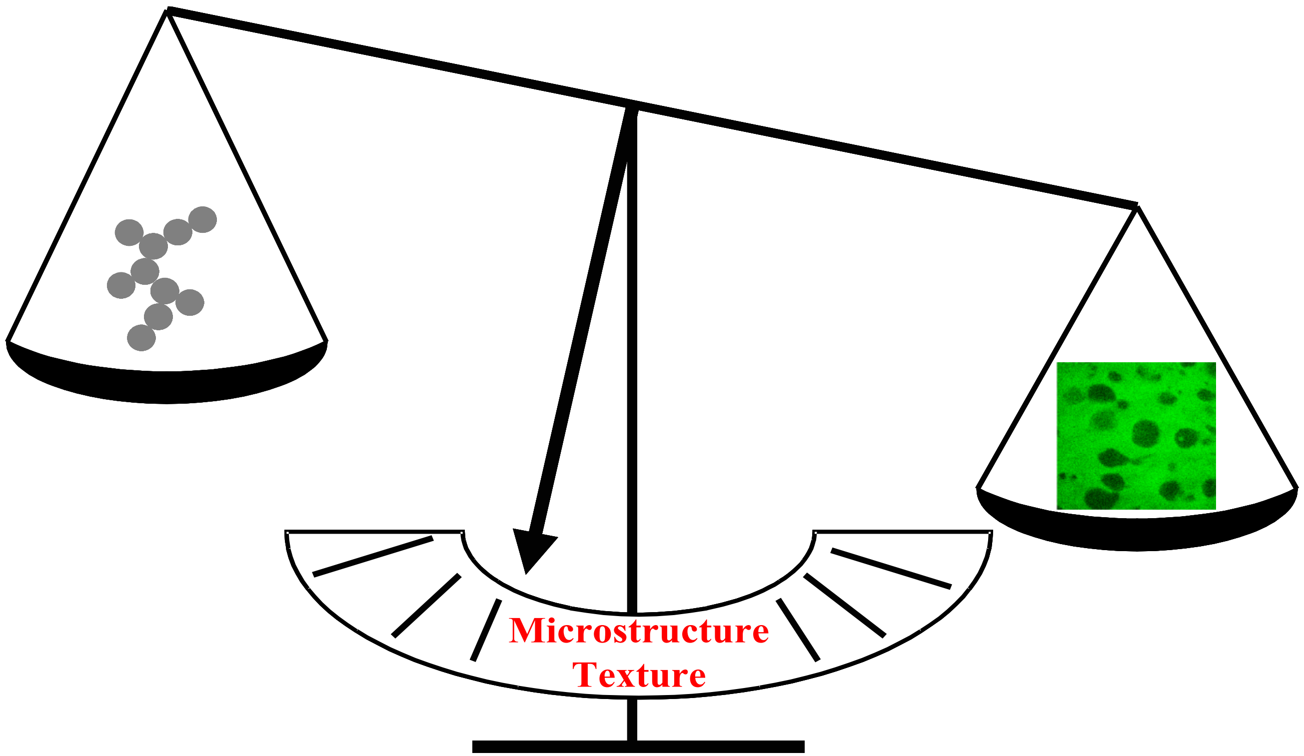
Xanthan
- Rg ~ 230 nm
- Rod like
- M_w ~ 10^6g/mol
- c* ~ 0.028 wt%
- Negatively charged



Ph.D. Thesis, P. Aichinger, NRC Lausanne

DESIGNING GEL TEXTURES

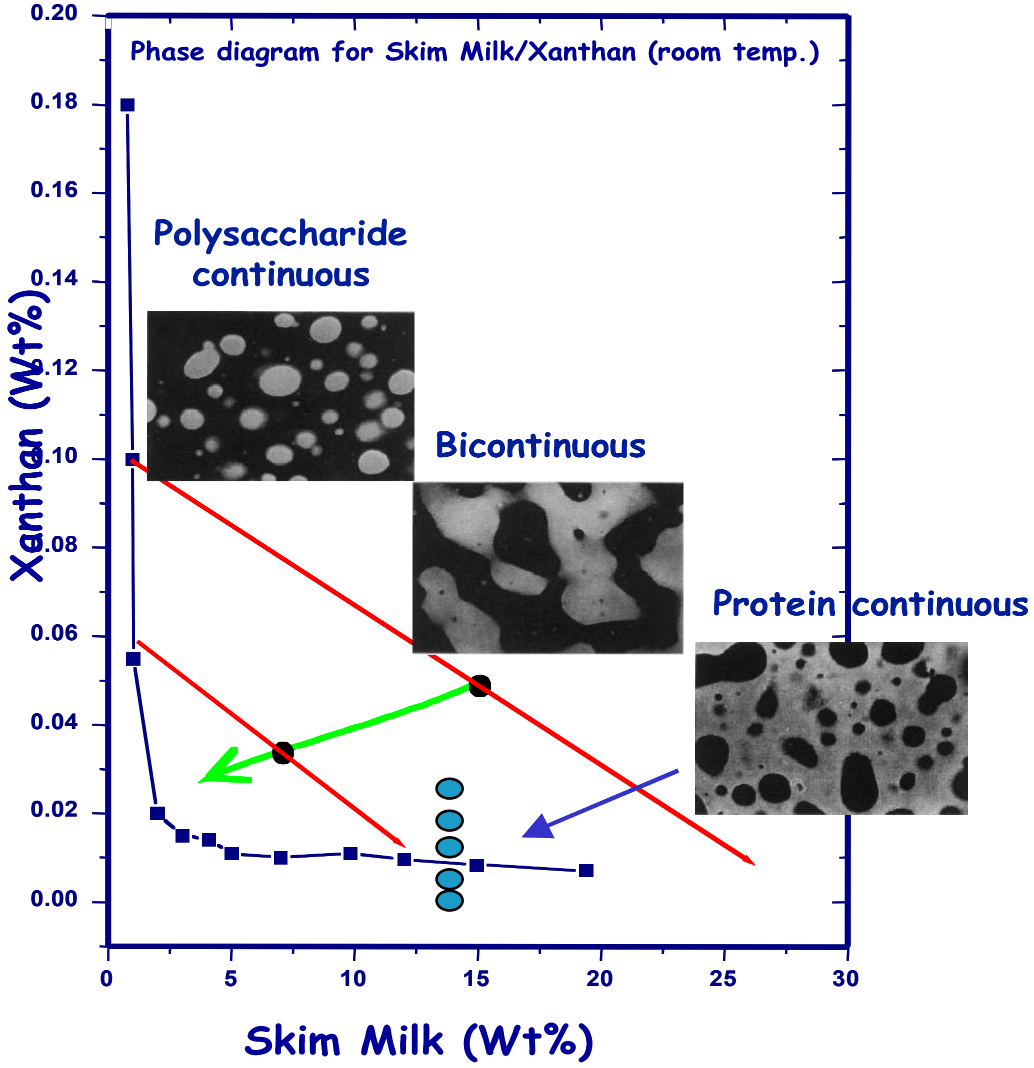
Aggregation kinetics **versus** ***Phase separation kinetics***

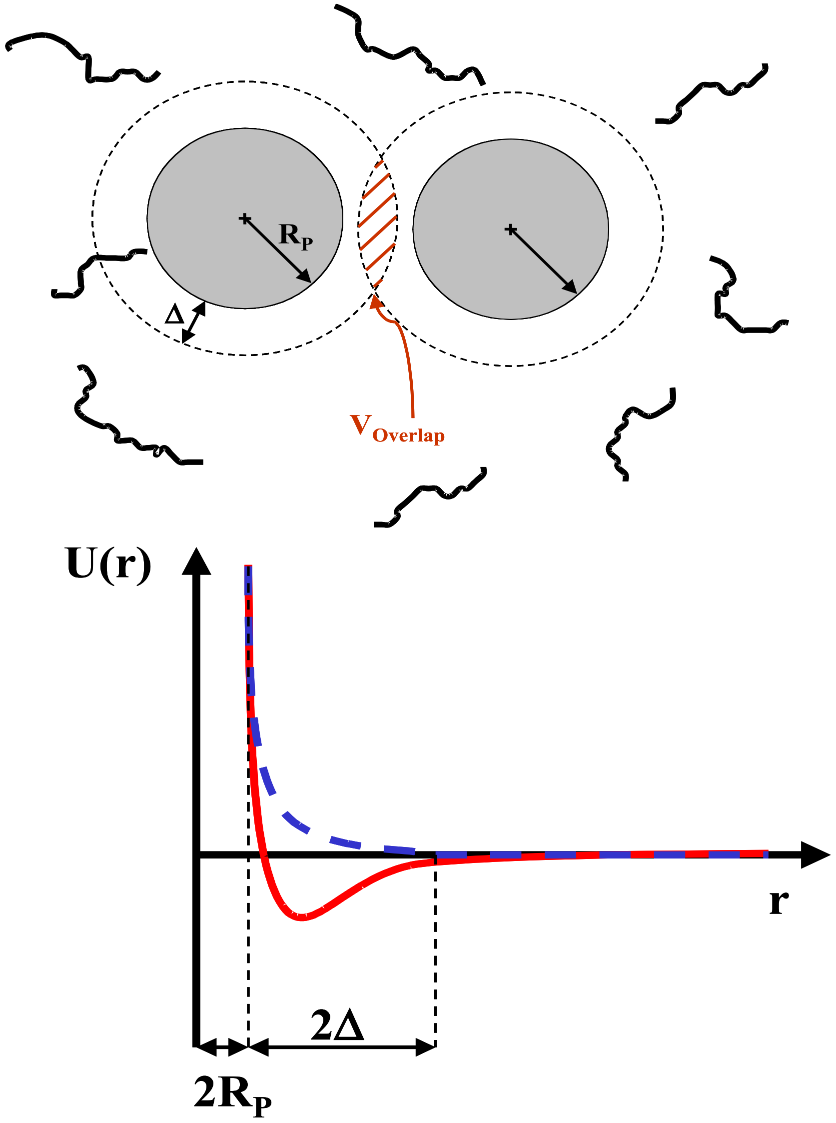


Tunable microstructure & mechanical properties?

Ph.D. Thesis, P. Aichinger, NRC Lausanne

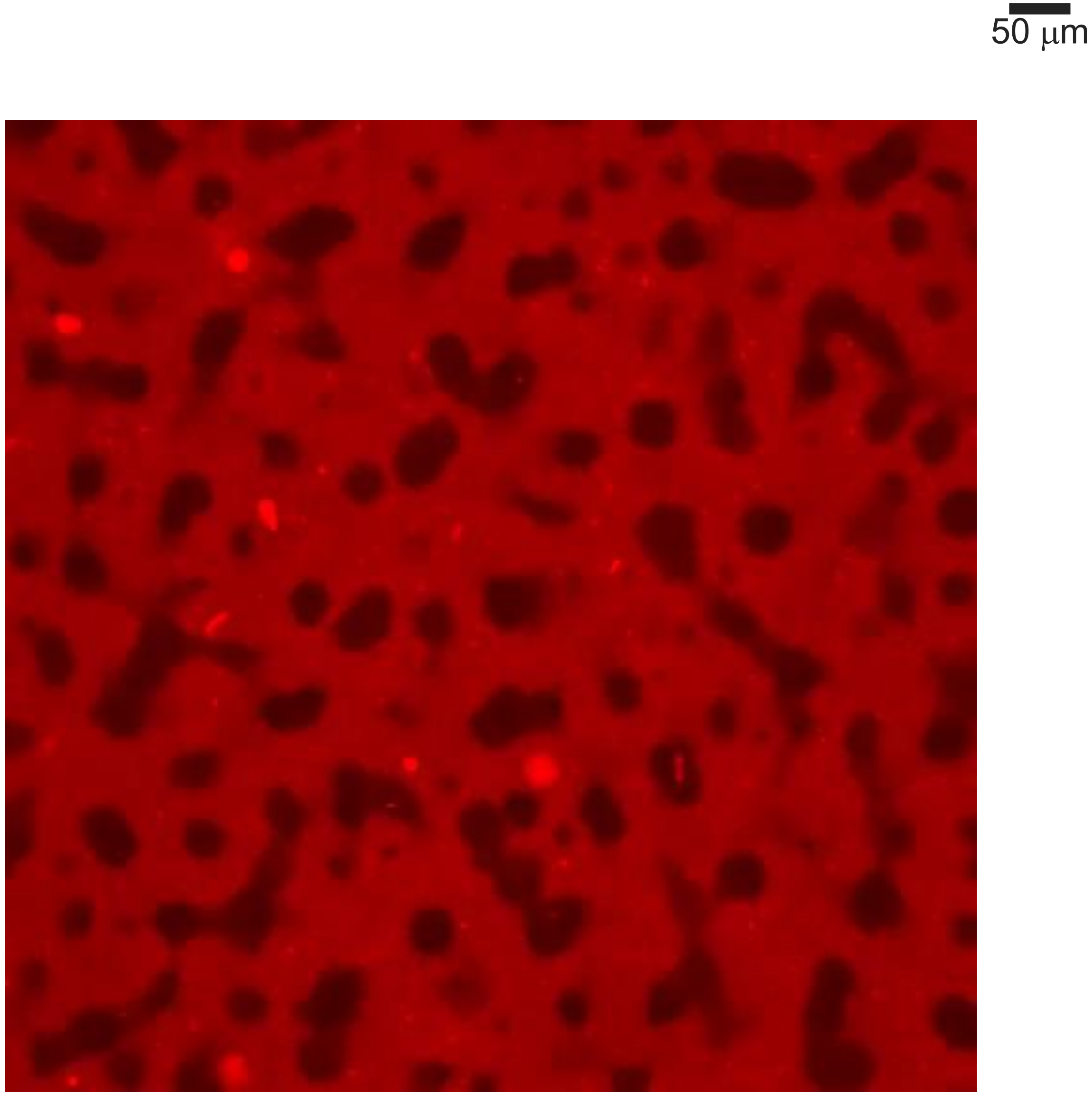
DEPLETION INDUCED PHASE SEPARATION

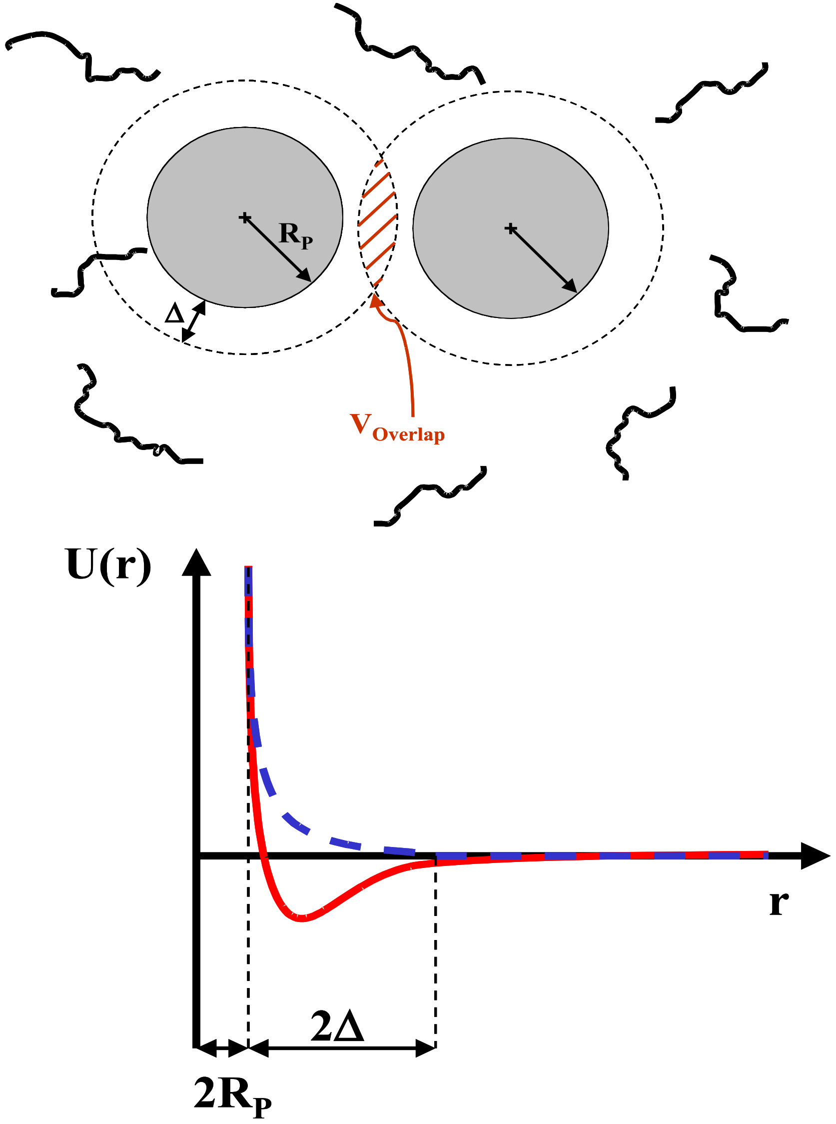




Suresh Bhat (Univ. de Fribourg)

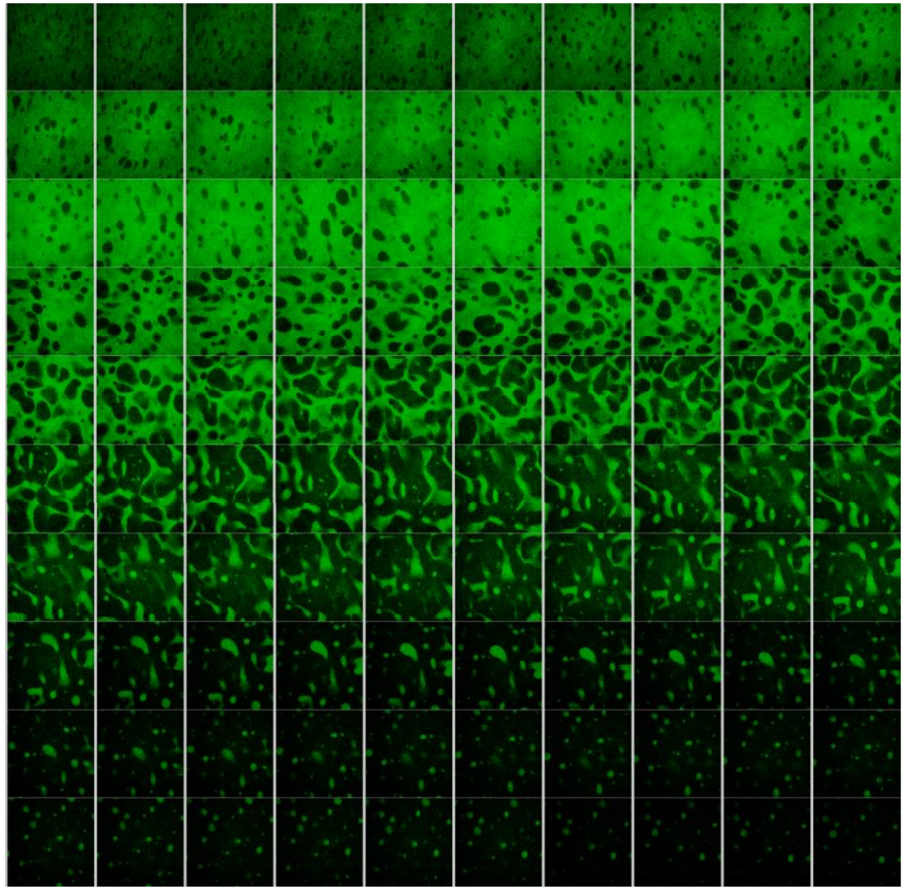
FIRST STRUCTURE FORMATION PROCESS: PHASE SEPARATION



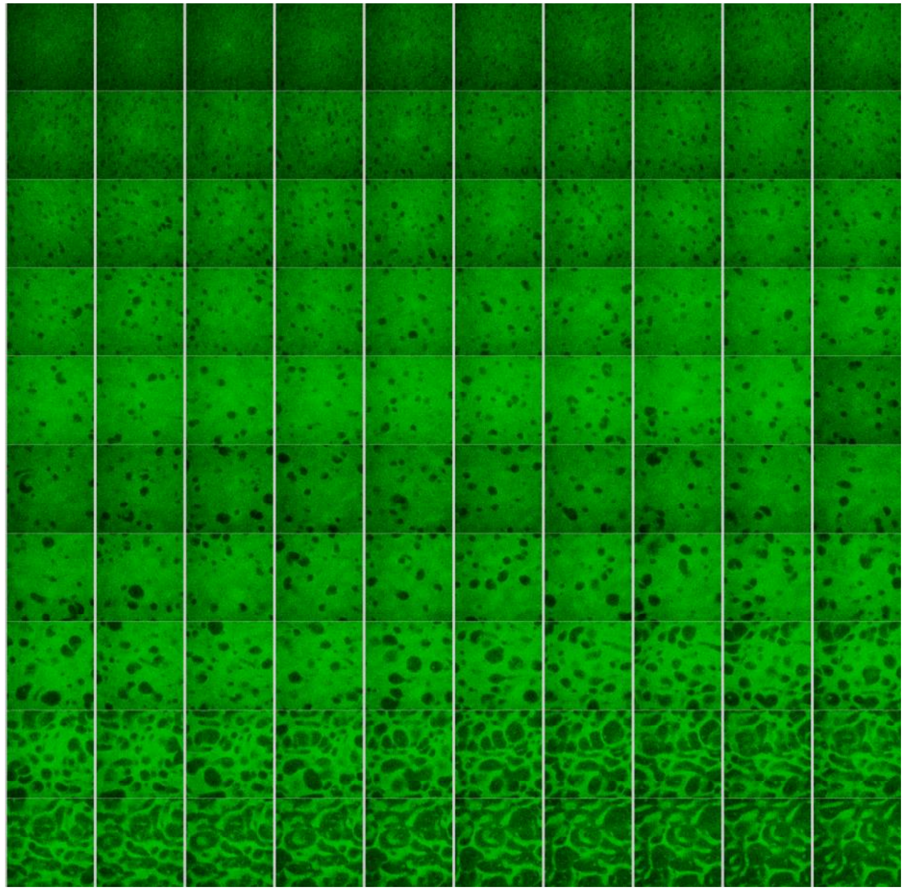


Ph.D. Thesis, P. Aichinger, NRC Lausanne

FIRST STRUCTURE FORMATION PROCESS: COMPARISON OF PHASE SEPARATION AT 30 AND 40° C



30° C, unheated skim milk (14%), 0.02% XG (pH 6.5)

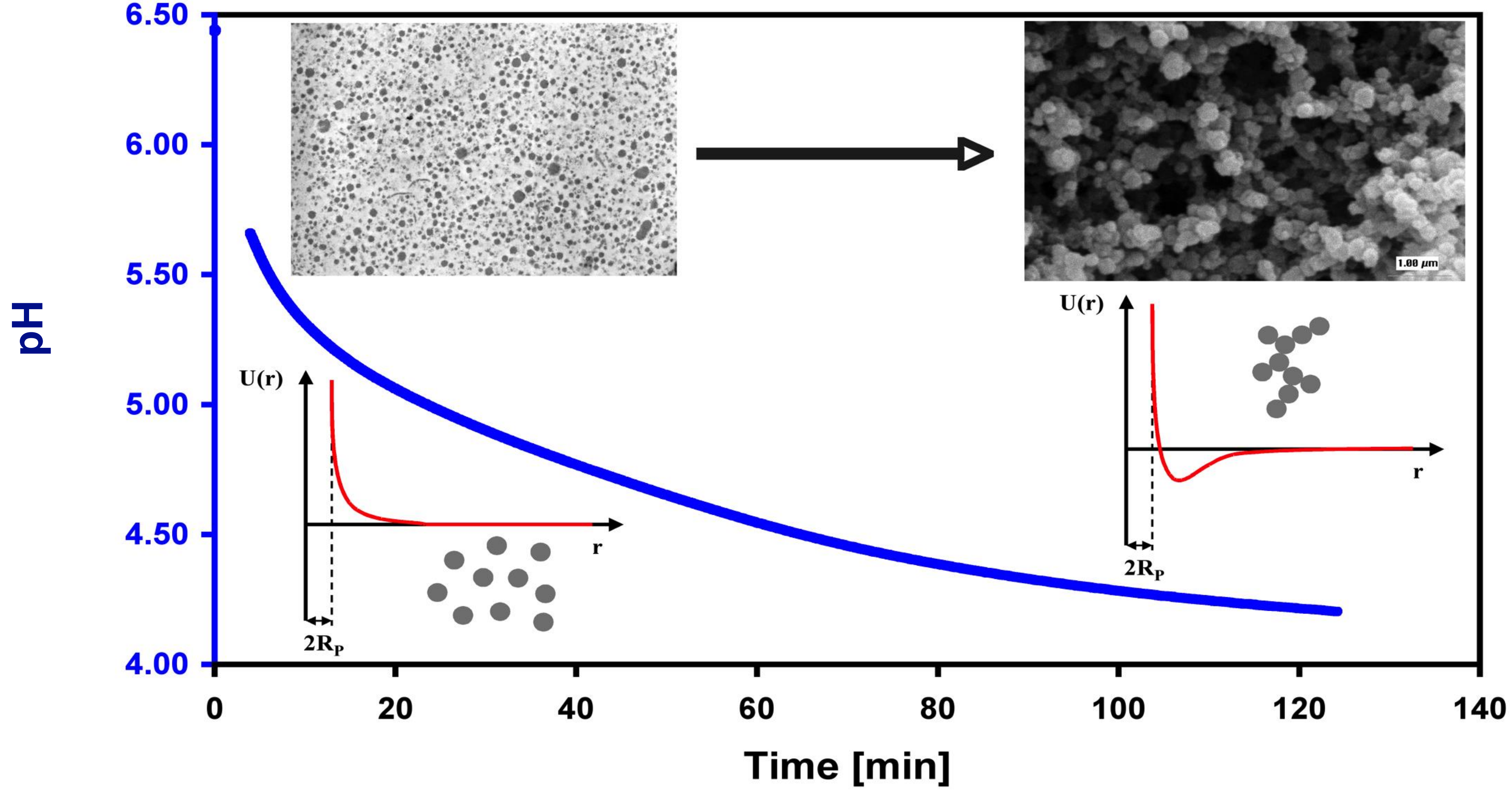


40° C, unheated skim milk (14%), 0.02% XG (pH 6.5)

125 μm

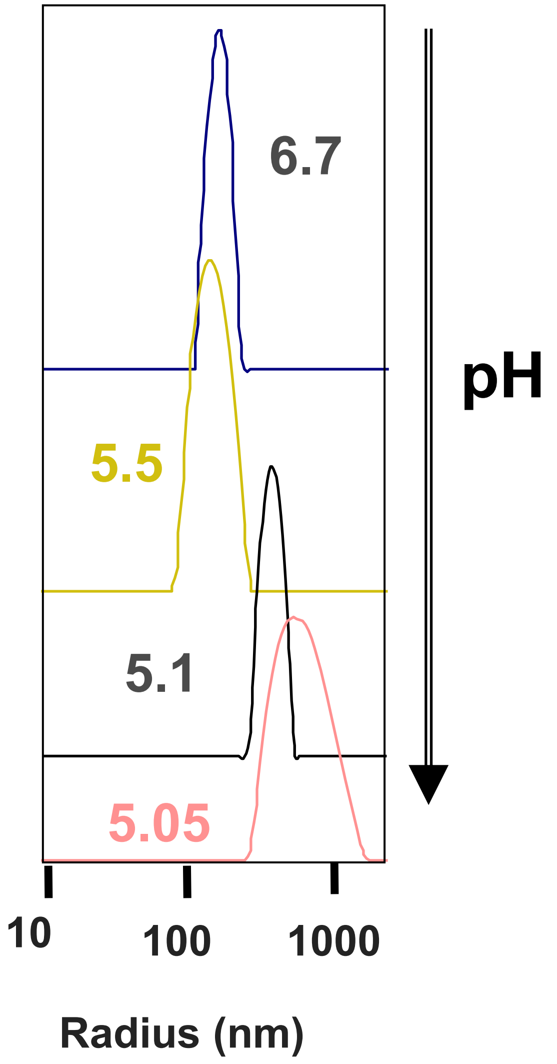
Ph.D. Thesis, P. Aichinger, NRC Lausanne

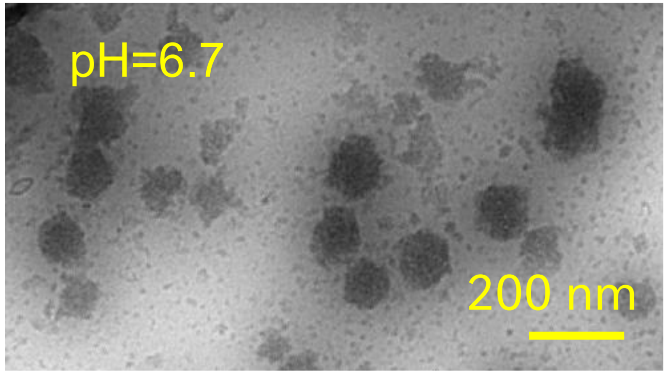
SECOND STRUCTURE FORMATION PROCESS: ACID-INDUCED CASEIN MICELLE AGGREGATION



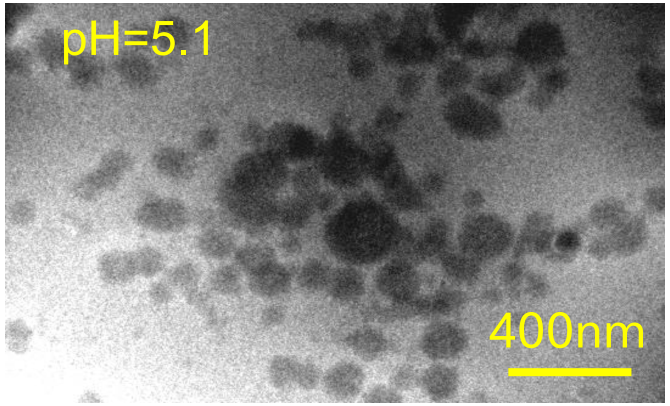
Ph.D. Thesis, P. Aichinger, NRC Lausanne

AGGREGATE FORMATION IN MILK





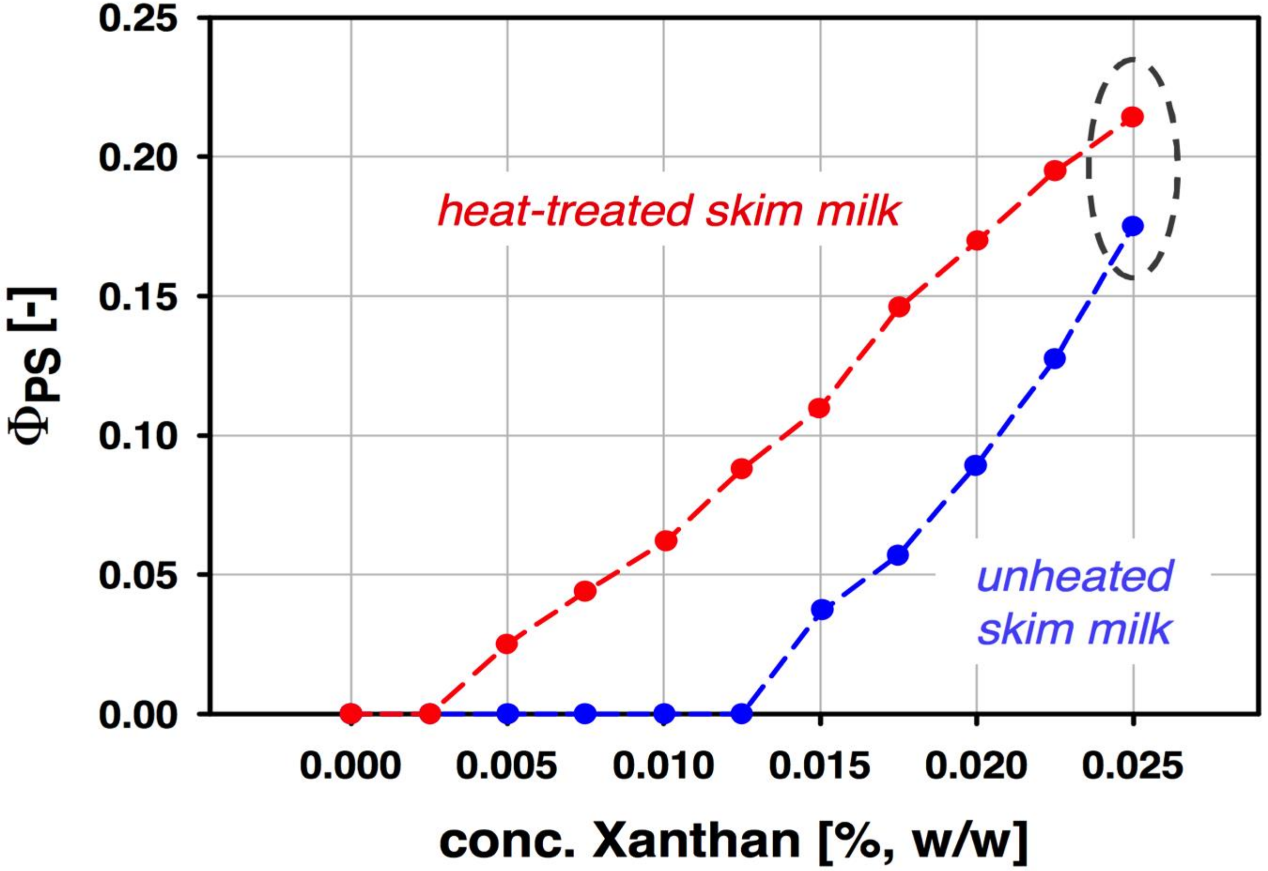
At physiological pH of 6.7 the casein micelles are sterically stabilized by the charges of the kappa-caseins



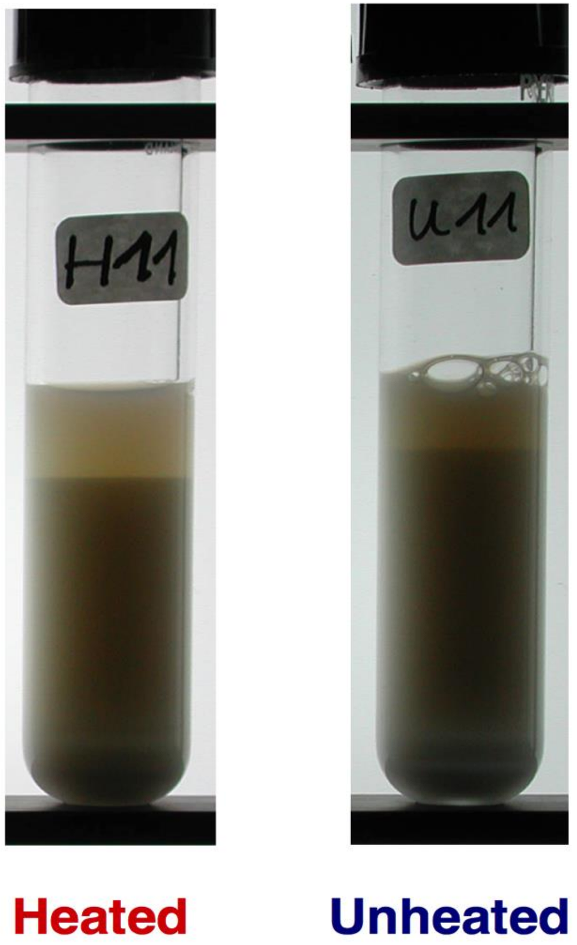
At the isoelectric point we have no repulsion any more and clusters are formed which further aggregate and form a gel network

Laurent Sagalowicz, NRC Lausanne

INFLUENCE OF MILK PROCESSING



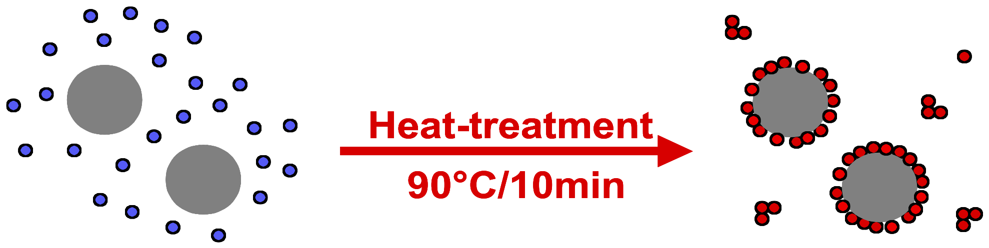
Visual inspection of tubes and photographs taken after incubation at 40°C for two days (pH 6.5)

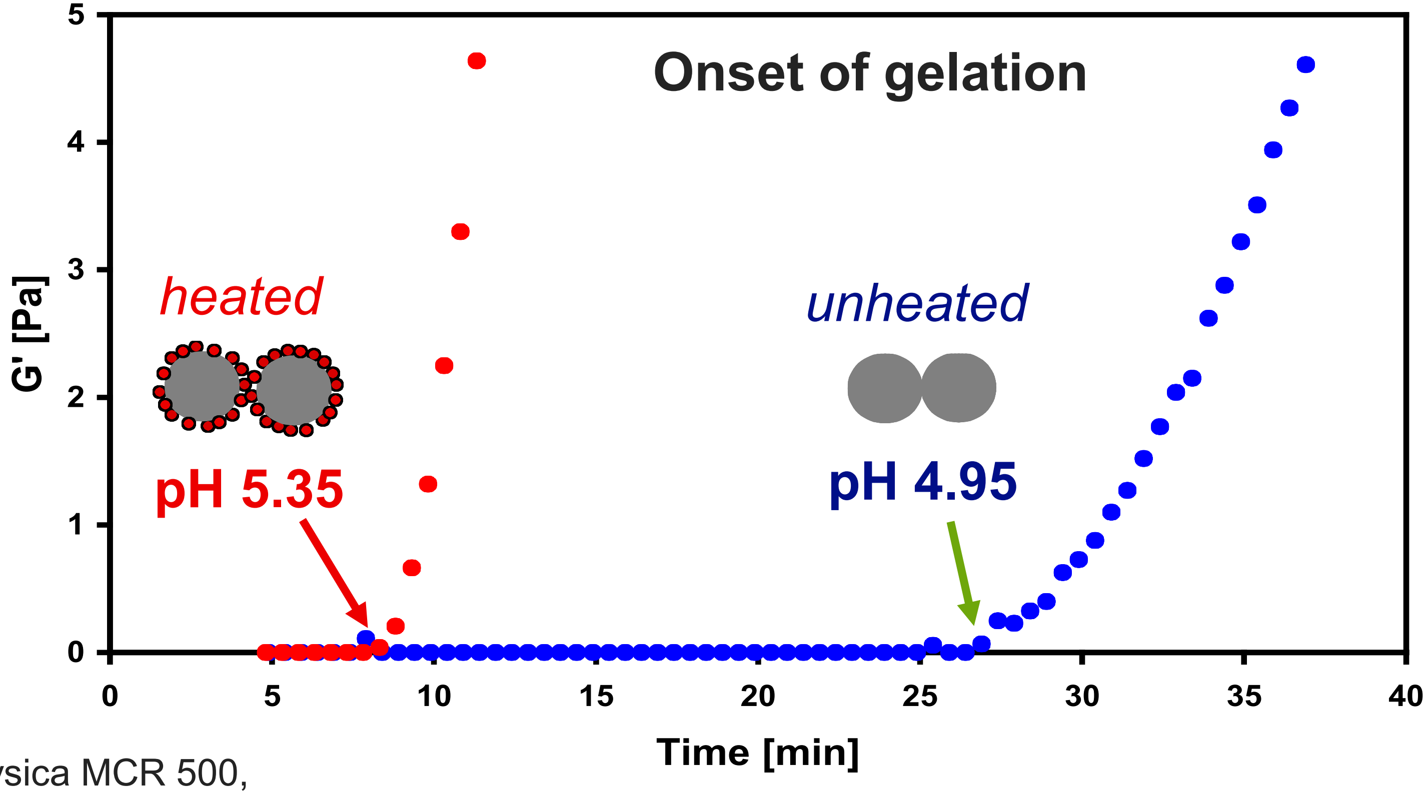


Skim milk (14% SMP) + 0.025% XG

Ph.D. Thesis, P. Aichinger, NRC Lausanne

INFLUENCE OF MILK PROCESSING



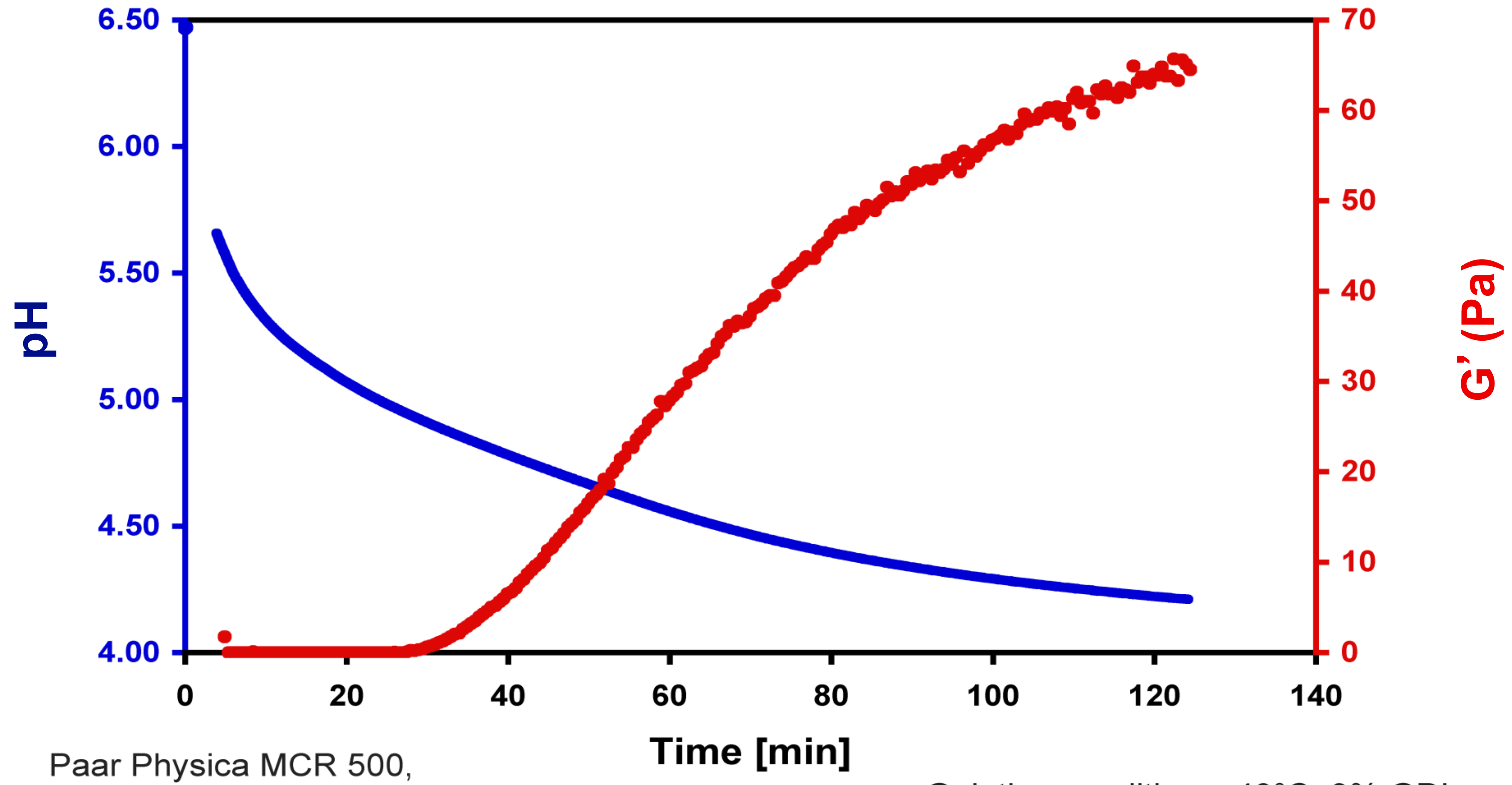


Paar Physica MCR 500,
CC27, 0.1Hz, 0.04% strain

Gelation conditions: 40° C, 3% Glucurono Delta Lactone (GDL)

GEL FORMATION INVESTIGATED BY RHEOMETRY

unheated skim milk (14%SMP)

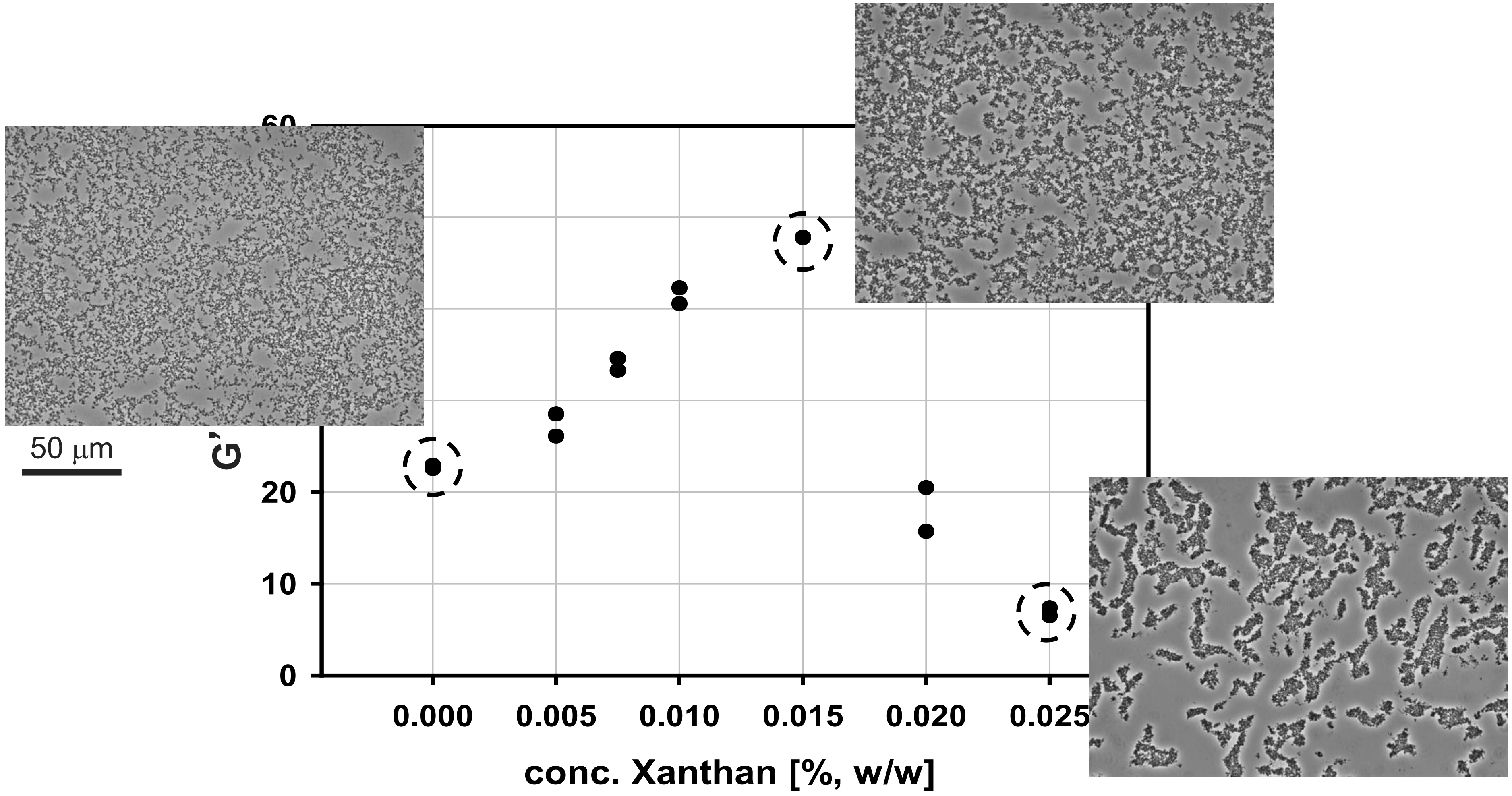


Paar Physica MCR 500,
CC27, 0.1Hz, 0.04% strain

Gelation conditions: 40°C, 3% GDL

Ph.D. Thesis, P. Aichinger, NRC Lausanne

GEL STRENGTH AT pH 4.60 – UNHEATED SKIM MILK

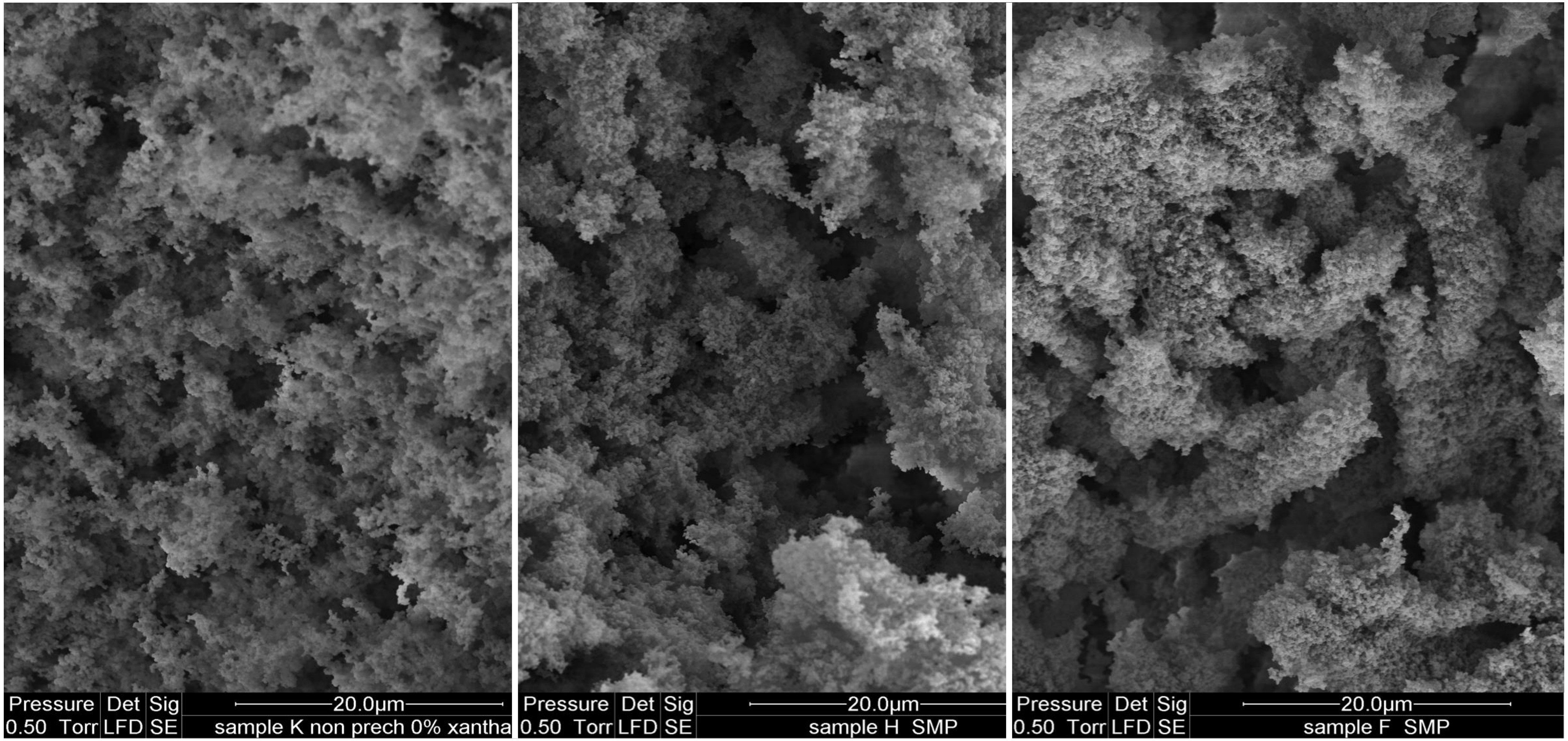


Paar Physica MCR 500,
CC27, 0.1Hz, 0.04% strain

Gelation conditions: 40° C, 3% GDL

Ph.D. Thesis, P. Aichinger, NRC Lausanne

SCANNING ELECTRON MICROSCOPY (SEM)

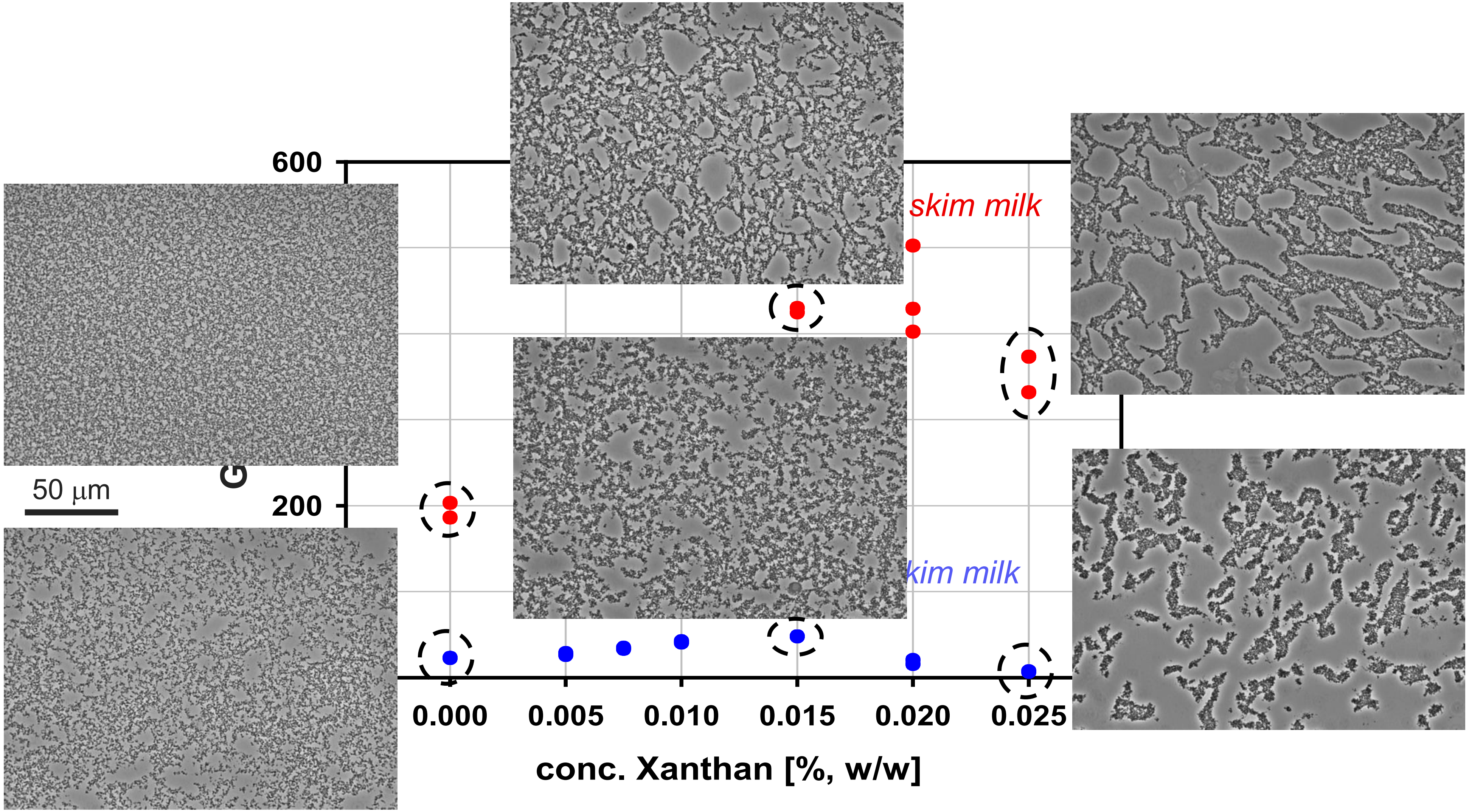


0 XG **0.015% XG** **0.025% XG**

conc. Xanthan

Ph.D. Thesis, P. Aichinger, NRC Lausanne

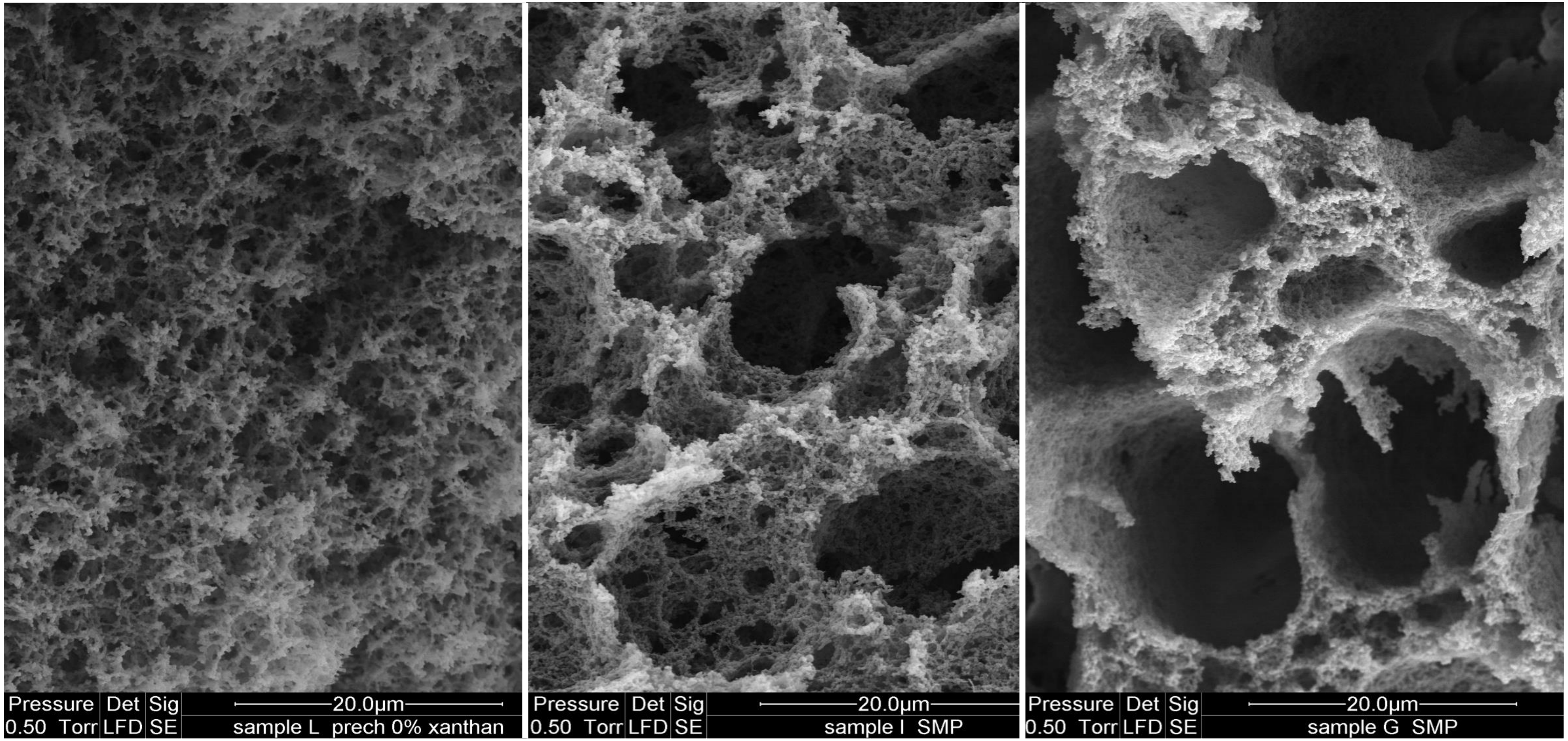
GEL STRENGTH AT PH 4.60 – HEAT-TREATED SKIM MILK



Paar Physica MCR 500,
CC27, 0.1Hz, 0.04% strain

Gelation conditions: 40° C, 3% GDL

SCANNING ELECTRON MICROSCOPY (SEM)

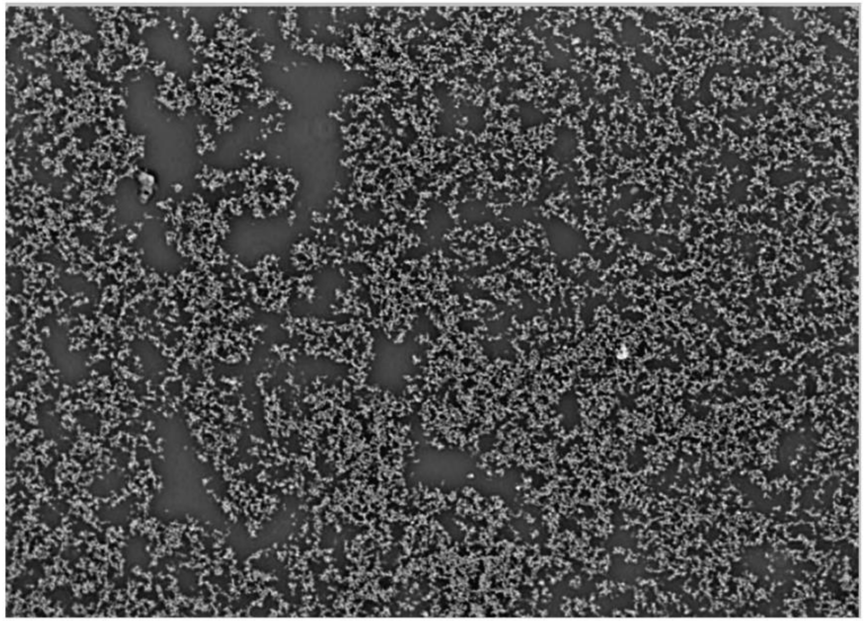


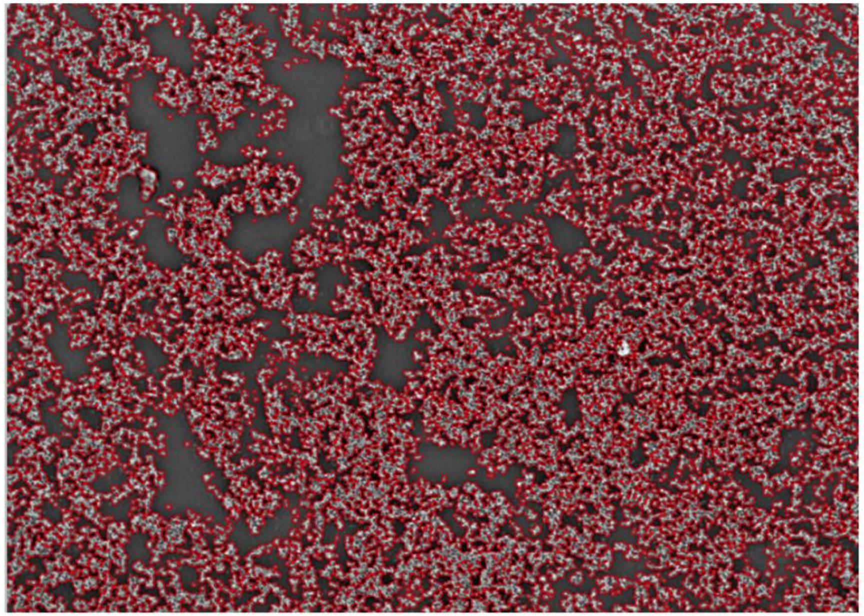
0 XG **0.015% XG** **0.025% XG**

conc. Xanthan

NEEDS FOR QUANTITATIVE NUMBERS

1. **Segmentation:**

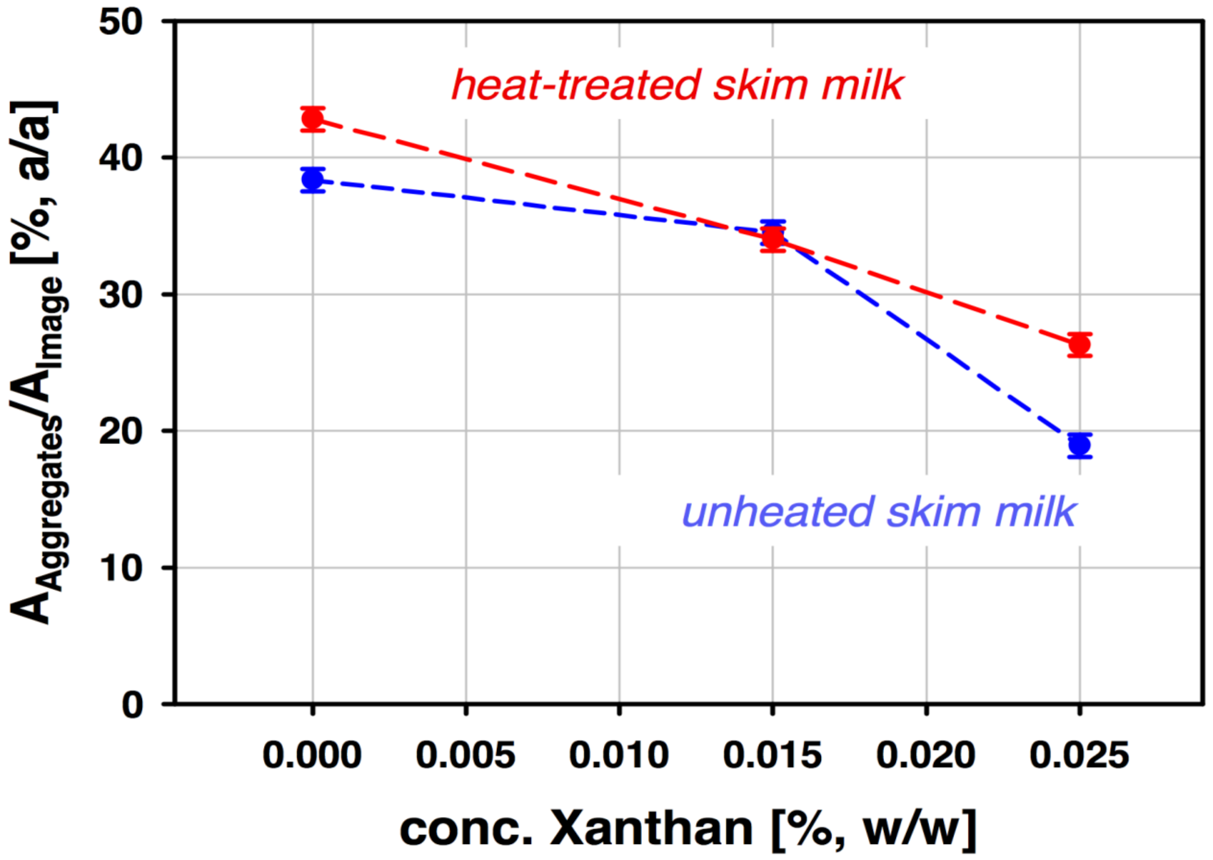




2. Calculation of image surface area ratio:

$$\frac{A_{Aggregates}}{A_{Image}} \sim \text{Volume fraction occupied by network}$$

VOLUME FRACTION OCCUPIED BY PROTEIN



Mean values calculated from 25 – 30 PCLM images analysed per gel sample

Error bars: LSD (least significant difference)

Ph.D. Thesis, P. Aichinger, NRC Lausanne

CONCLUSIONS

- Many food products are complex heterogeneous multiphase systems formed by interactions between molecules, particles, drops and bubbles
- The continuous as well as dispersed phases can have different state of matter, complex shapes and different length scales
- Large interface areas are common in food systems
- Food are in most cases in a non-equilibrium state
- Interaction forces on a molecular as well as colloidal scale are driving the formation and stability of foods
- Model systems help to reduce the complexity and understand the underlying structuring principles under well defined conditions
- Real food systems can be approached by increasing the complexity in simple model systems

Martin Michel
Pierre Aichinger
Marie-lise Dillman
Martine Rouvet
Marie-France Clerc
Eric Kolodziejick
Carla Costa-Liz
Martin Leser
Laurent Sagalowicz
Heribert Watzke
Reinhard Miller
Vincent Meunier
Alessandro Marabi
Giles Vuataz
Guy Mayor
All links and materials obtained from internet

Backup

Maillard reaction – Hodge scheme

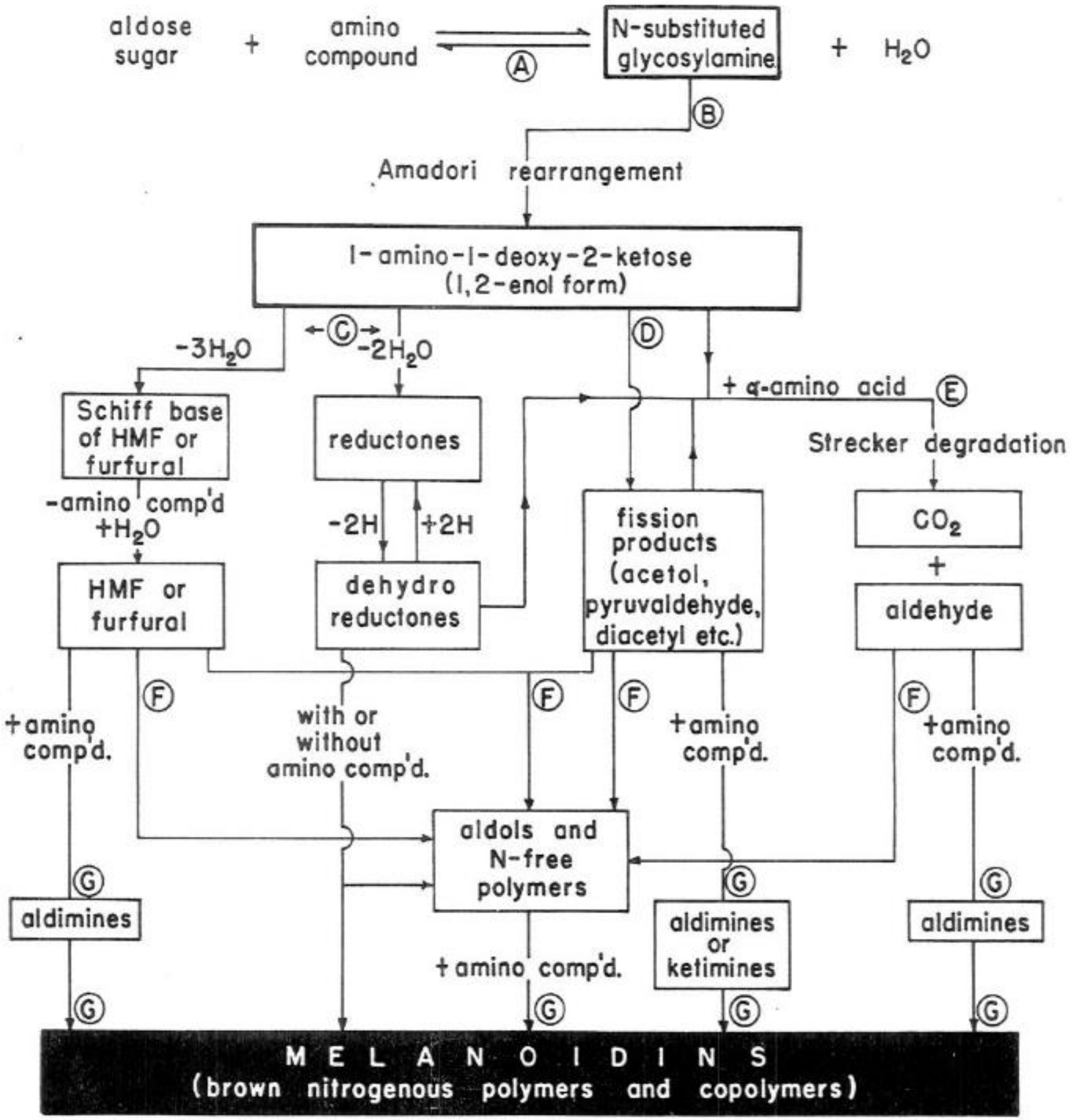


Figure I. Amadori rearrangement in integration of known reactions leading to browning in sugar-amine systems

Reducing sugar + amino group → Schiff base

↓ Rearrange

Amadori (or Heyns) compound

↓ Enolization and degradation

Reactive intermediates like deoxyosones and reductones

↓

α-Dicarbonyls + amino acids → aldehydes and other volatile compounds (= aroma)

↓ Aldol and Michael-type reactions

High molecular weight melanoidins (brown pigments = color)

John E. Hodge (1953: Chemistry of browning reactions in model systems. *Agricultural and Food Chemistry,* p. 928-943.