Crystallization of fat and oils

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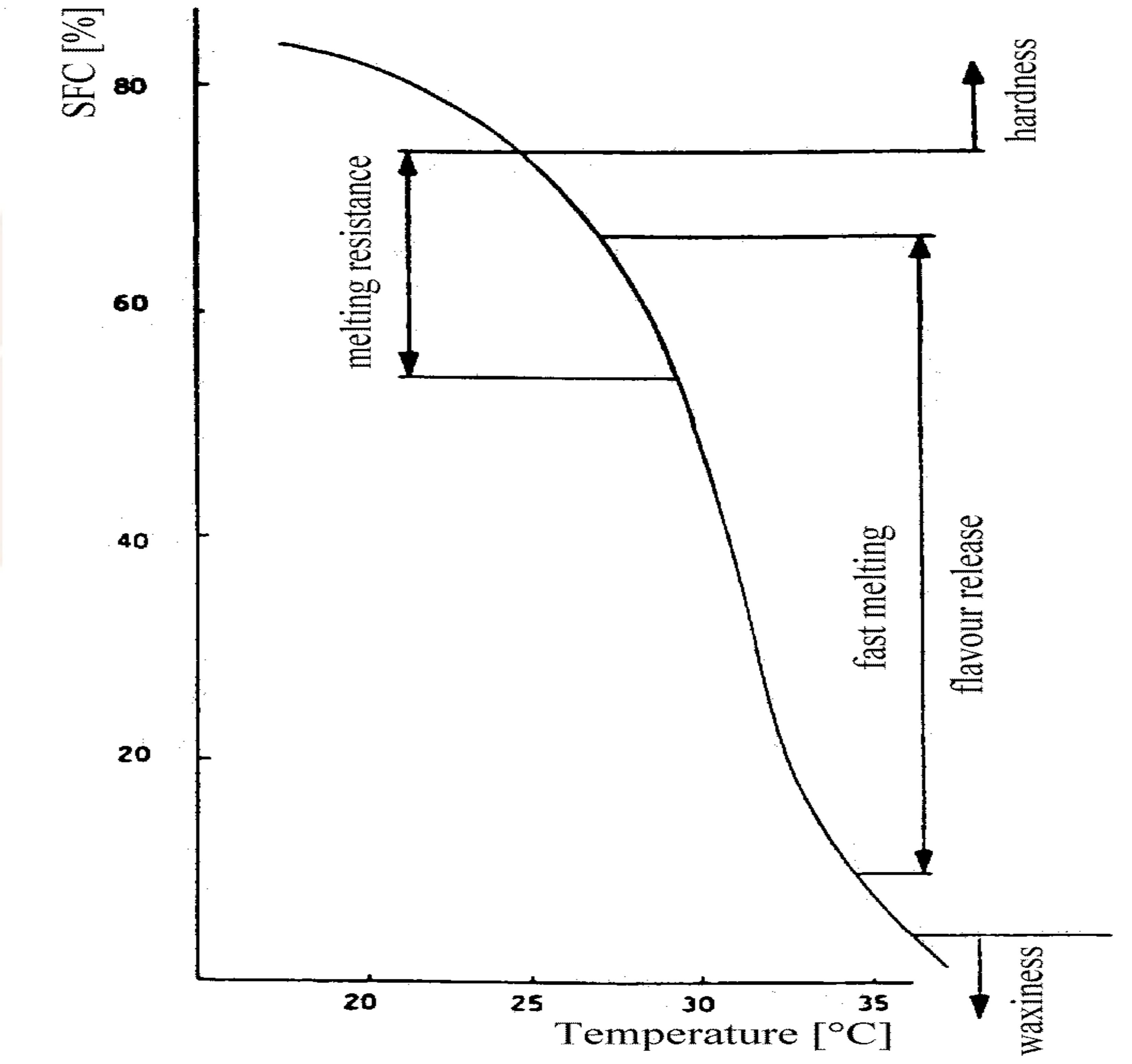
Crystallization → Melting behaviour = demands for a good chocolate



Crystallization → Melting behaviour = demands for a good chocolate

- ❖ Enough solid fat at 20°C :

  → **good 'snap' upon fracture**

- ❖ Enough solid fat between 20-25°C:

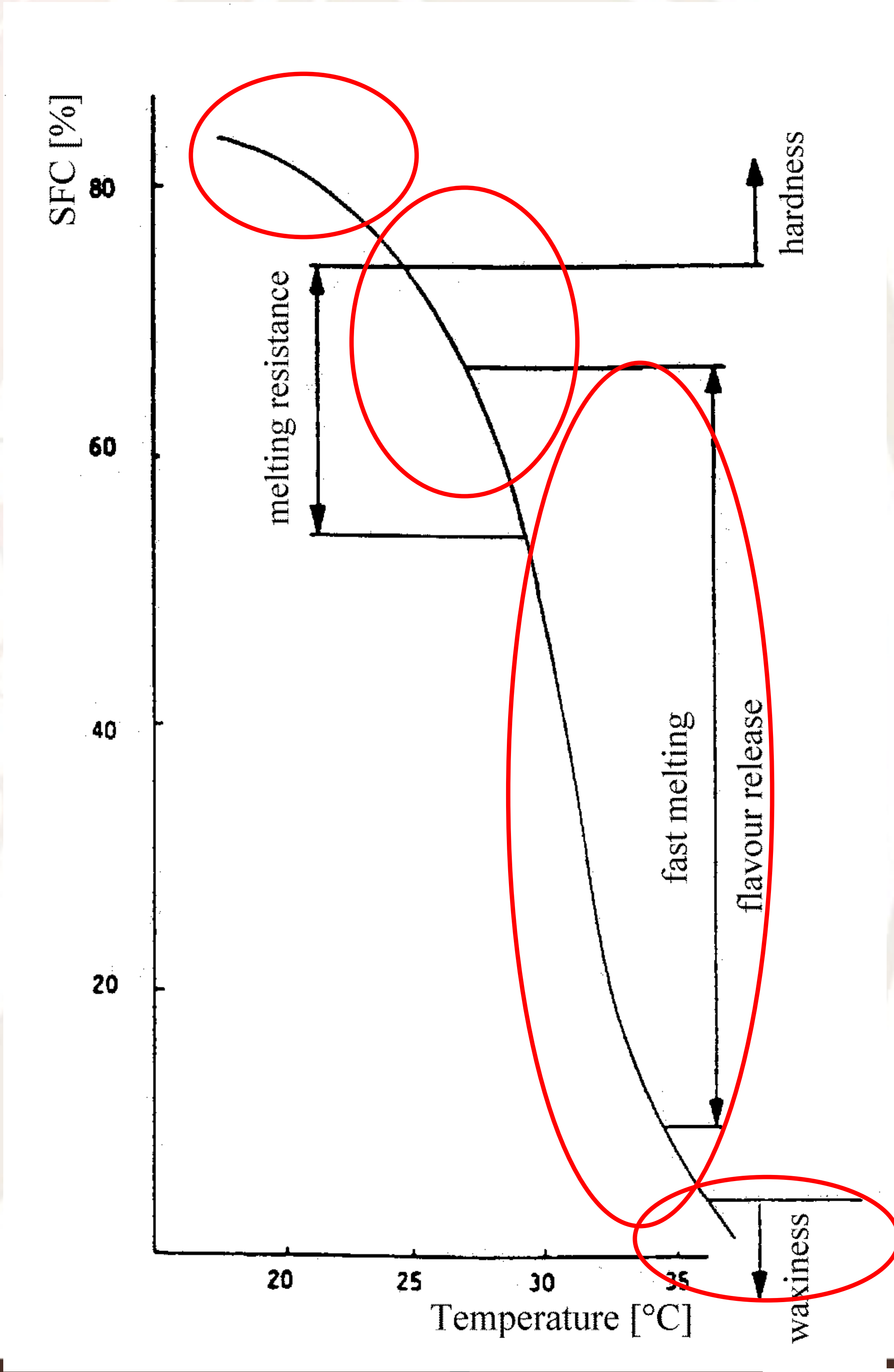
  → **preventing stickiness at consumption**

- ❖ Sharp melting profile between 25-30°C:

  → **mouthfeel, flavour release and cold sensation**

- ❖ Melted at body temperature:

  → **preventing 'waxy feeling'**



Outline

- Fats and oil: chemistry
- Importance of fat crystallization
- Structural levels in fat crystallization
  - Primary crystallization
    - Thermodynamic driving force, nucleation, crystal growth, polymorphism
  - Microstructural development
  - Macroscopic properties
- How to measure?
- Case study cocoa butter

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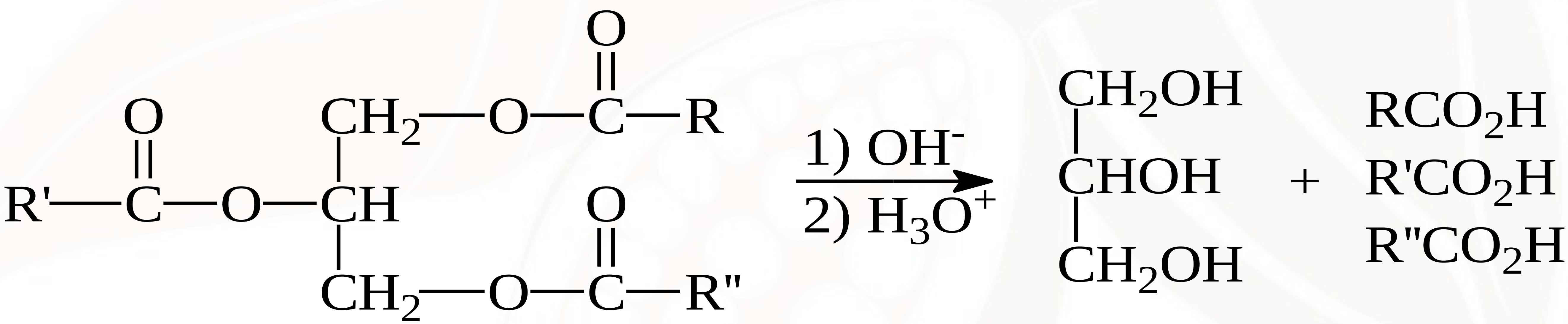
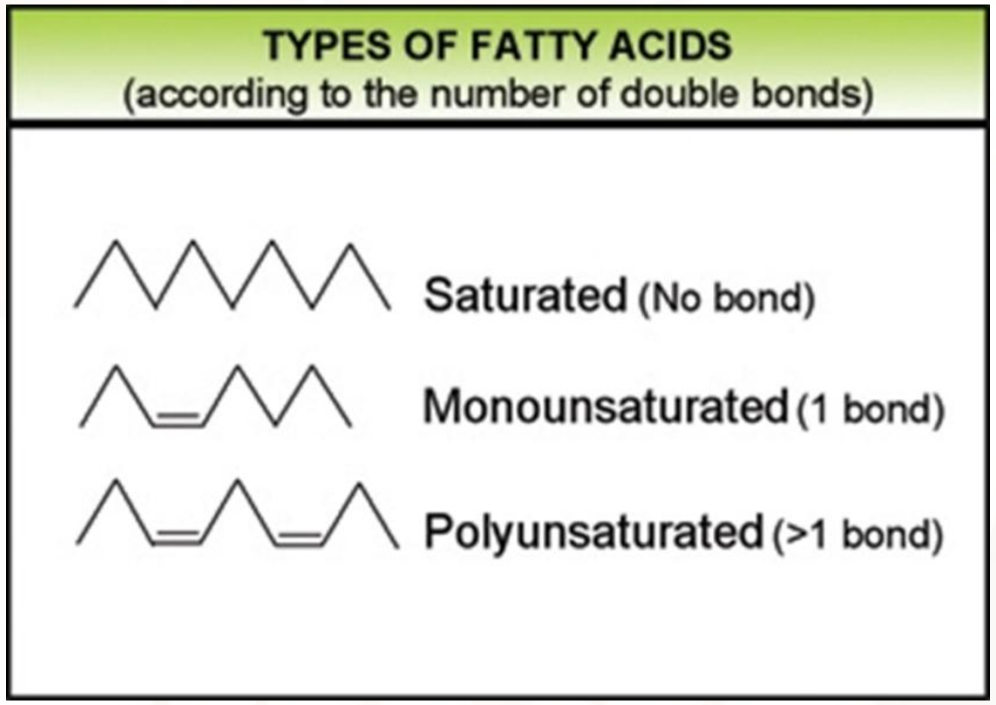
Fats and oils

- Oil/fat = mixture of triacylglyceorls
- Animal or vegetable origin
- Triacylglycerols



Fatty acids

- Aliphatic carboxylic acids with 4 or more carbon atoms
- Even number of carbon atoms
- 3 different types of fatty acids



- Short (4 - 6 C-atoms), medium (8 - 14 C-atoms) and long chain (≥ 16 C-atoms) fatty acids

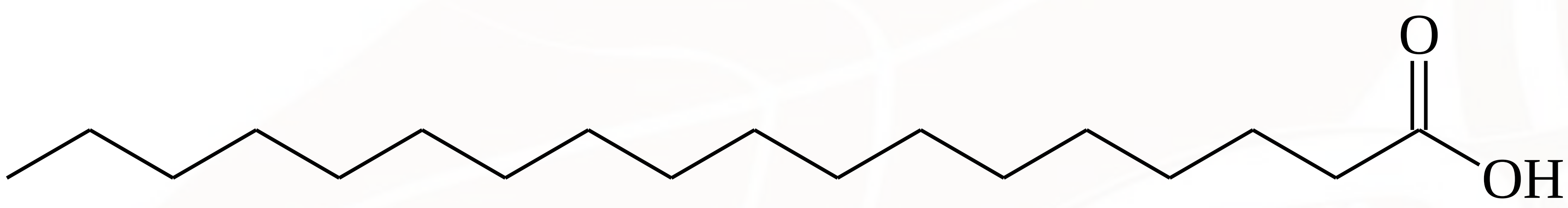
Fatty acids

- Systematic and trivial names of frequently occurring saturated and unsaturated fatty acids

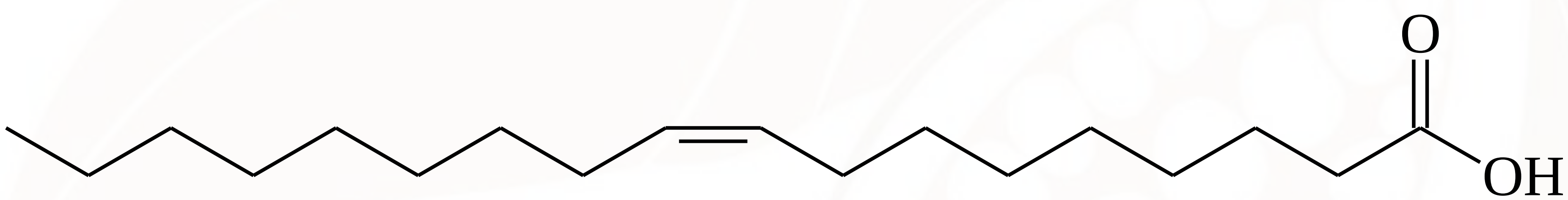
Systematic name (acid)	Trivial name	Chain Length (ω-notation)	m.p. (°C)
Decanoic	Capric	10:0	31.6
Dodecanoic	Lauric	12:0	44.4
Tetradecanoic	Myristic	14:0	54.3
Hexadecanoic	Palmitic	16:0	62.9
Octadecanoic	Stearic	18:0	70.0
9-Octadecanoic	Oleic	18:1ω9	13.0
9-*trans*-Octadecanoic	Elaidic	18:1ω9	36.0
13-Docosenoic	Erucic	22:1ω9	33.5
9,12-Octadecadienoic	Linoleic	18:2ω6	-3.0
9,12,15-Octadecatrienoic	α-Linolenic	18:3ω3	-11.9
5,8,11,14-Eicosatetraenoic	Arachidonic	20:4ω6	
5,8,11,14,17-eicosapentanoic	EPA	20:5ω3	-11.9
4,7,10,13,16,19-Docosahexaenoic	DHA	22:6ω3	

Fatty Acids

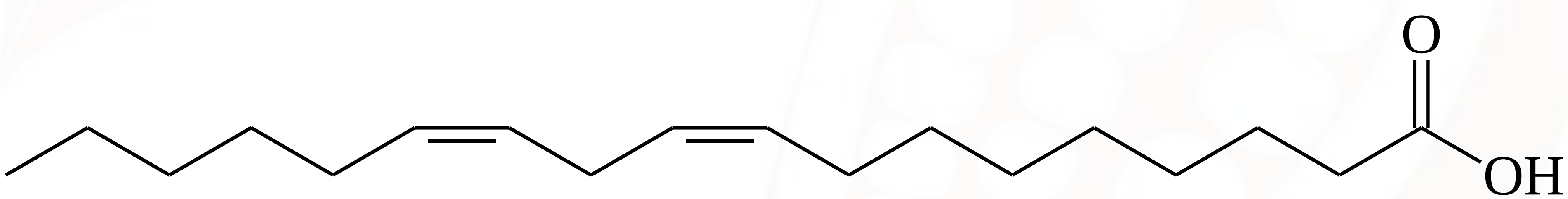
- *cis* isomer predominates in unsaturated fatty acids
- more unsaturation ⇒ lower melting point



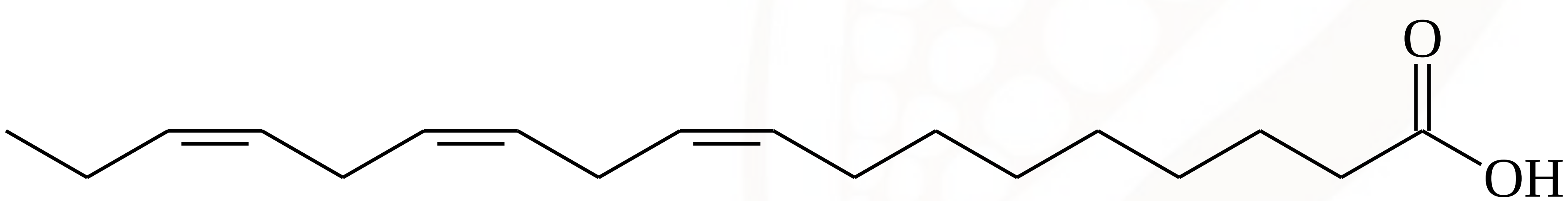
stearic acid (18:0)
m.p. 70ºC



oleic acid (9-18:1)
an ω-9 fatty acid
m.p. 16ºC



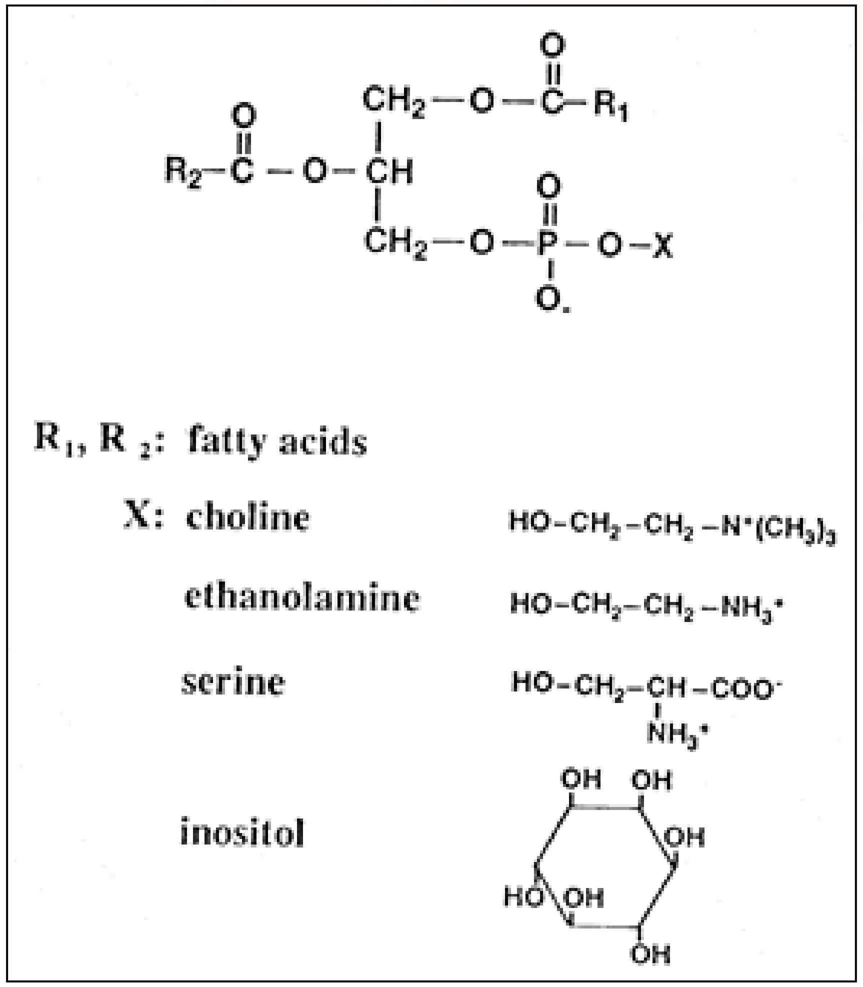
linoleic acid (9,12-18:2)
an ω-6 fatty acid
m.p. -5ºC

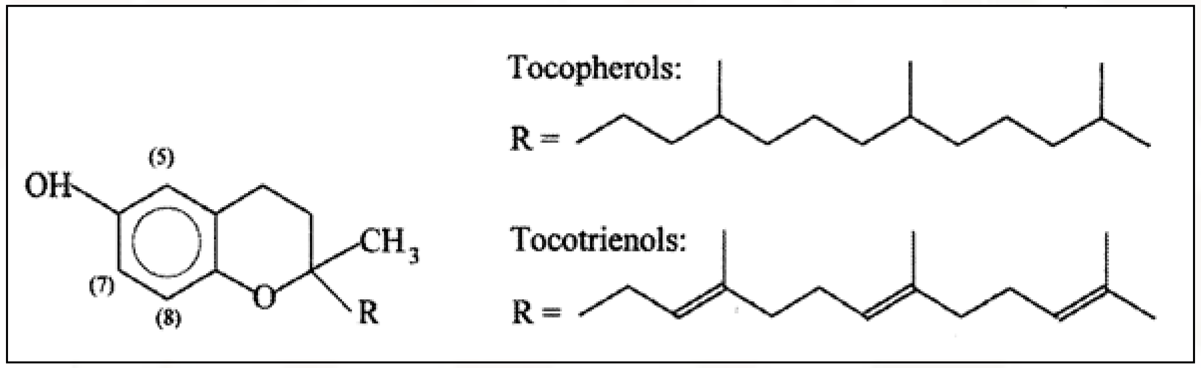


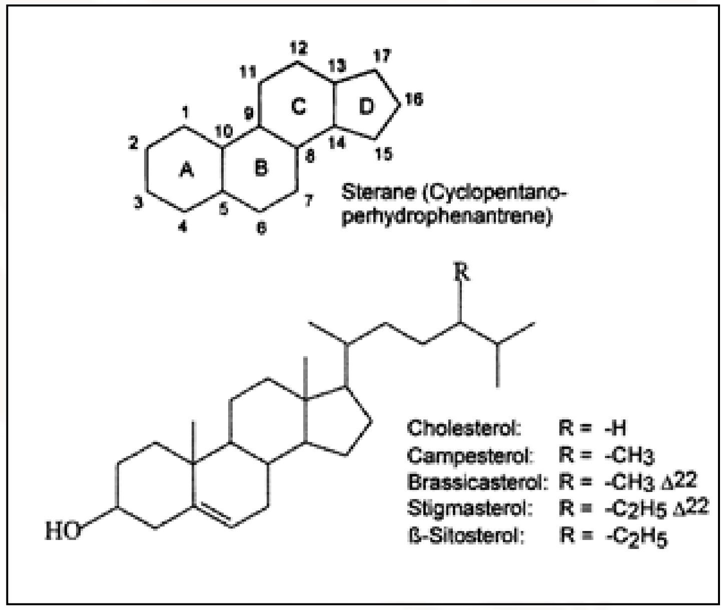
linolenic acid (9,12,15-18:3)
an ω-3 fatty acid
m.p. -11ºC

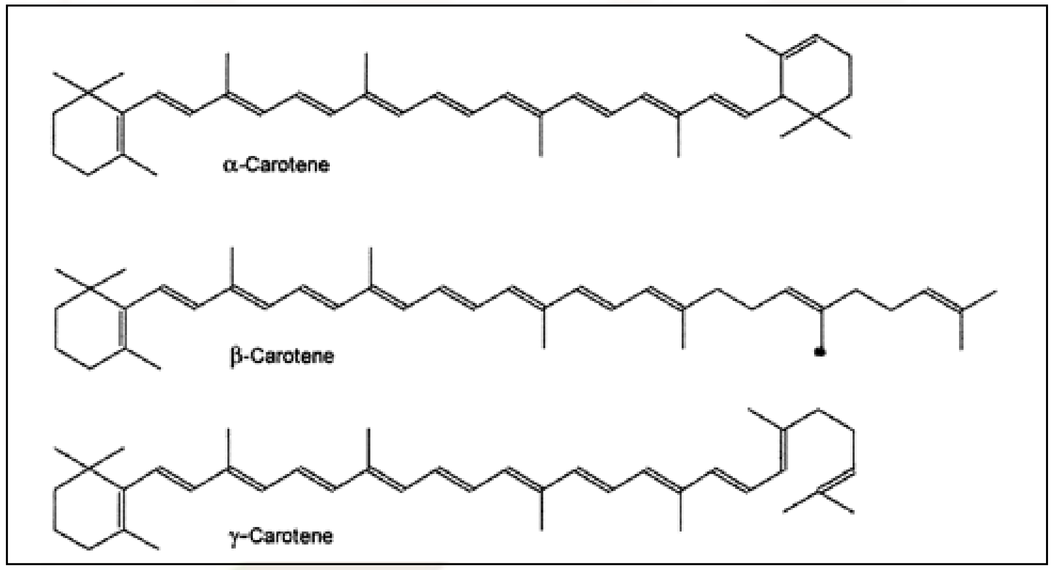
Fats and oils: minor compents

- Minor components:
  - free fatty acids, monoacylglycerols, diacyglycerols
  - phospholipids
  - unsaponifiable matter: sterols, tocopherols, wax esters, hydrocarbons, fat soluble vitamins









Cocoa butter = fat

Fatty acid (1)

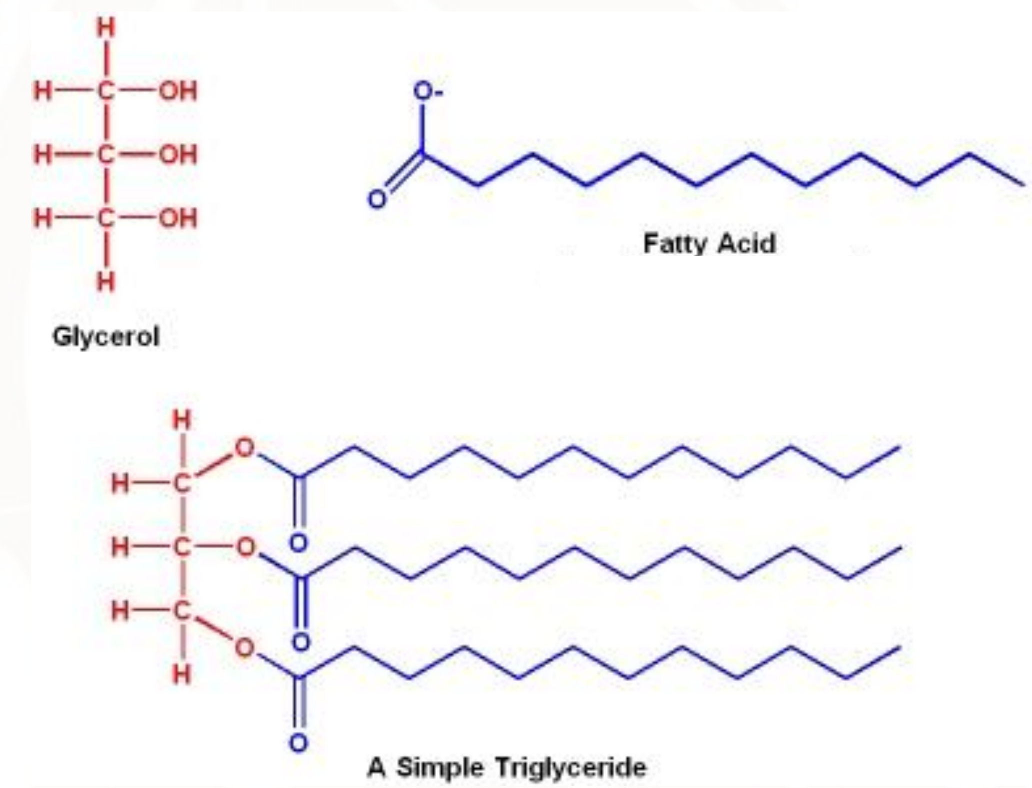
Fatty acid (2)

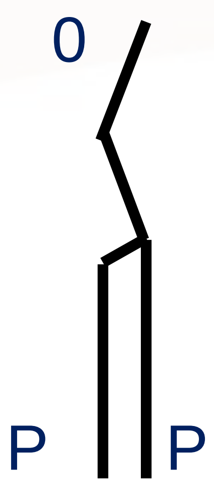
Fatty acid (3)

<u>Cocoa butter</u>

(1) & (3) = Palmitic acid (P) (± 26%) and/or Stearic Acid (St) (± 36%)

(2) = Oleic acid (O) (± 33%)





P	P	St
0	0	0
P	St	St
16,5%-19%	38,5%-40%	23%-26%

Typical chemical composition= **Unique physical properties**

→ Depending on the origin

Outline

- Fats and oil: chemistry
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  - Microstructural development
  - Macroscopic properties
- How to measure?
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- Importance of fat crystallization

Many fat-rich products with a substantial amount present in the crystallized form

→ Affects product structure and texture

→ Determines product quality

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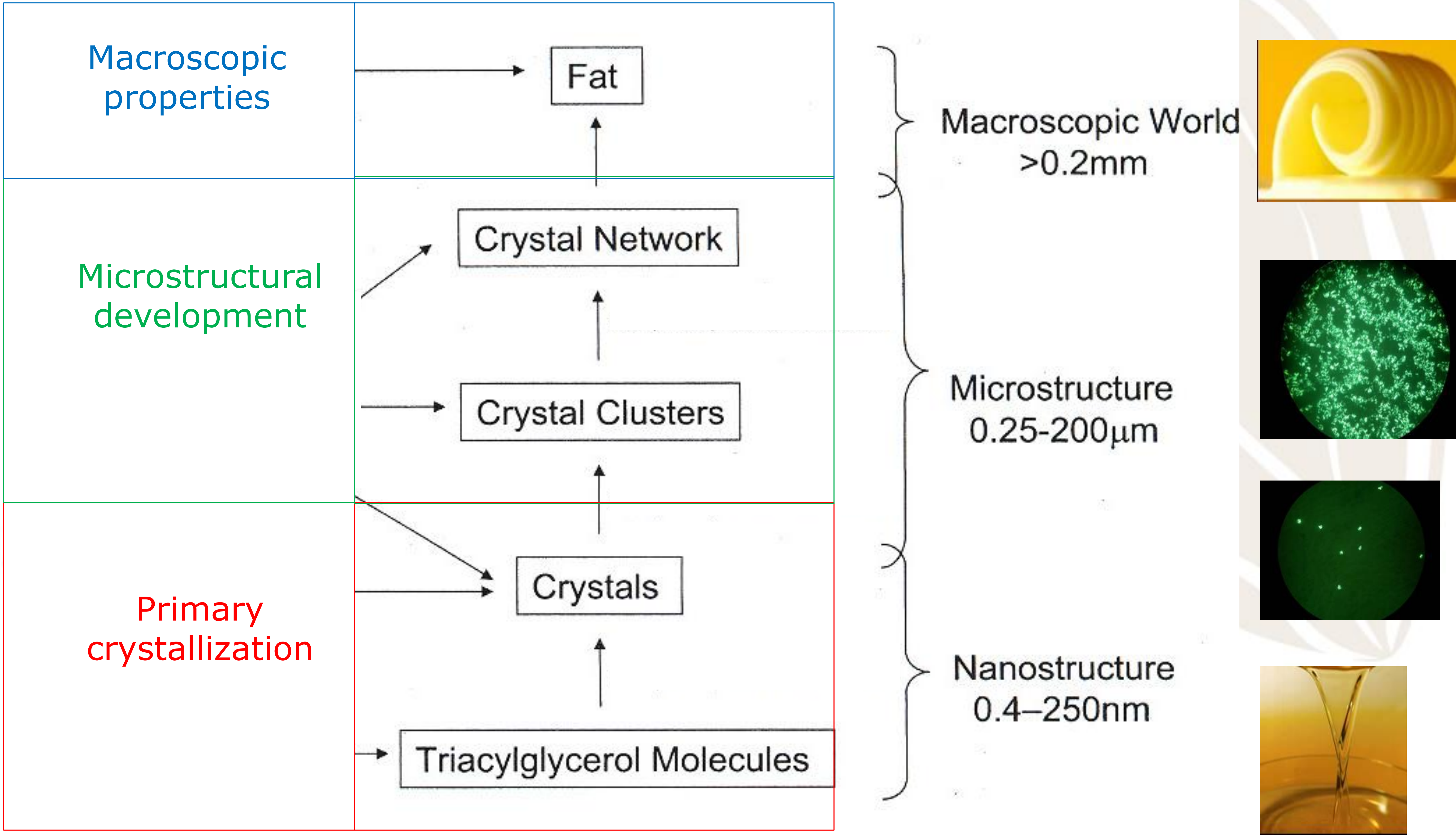
Structural levels in fat crystallization



Primary crystallization: driving force

- Driving force

  = difference in chemical potential $\Delta\mu$ between liquid and solid

1. Crystallization from solution

Supersaturation needed

- = concentration C (m^{-3}) > concentration at saturation C_s (m^{-3})

$$\Delta\mu = R_g \times T_k \times \ln\left(\frac{C}{C_s}\right)$$

R_g = universal gas constant (8.314 J mol^{-1} K^{-1})

T_K = absolute temperature (K)

(C/C_s) : supersaturation ratio= σ (-)

Primary crystallization: driving force

2. Crystallization from the melt:

Supercooling needed

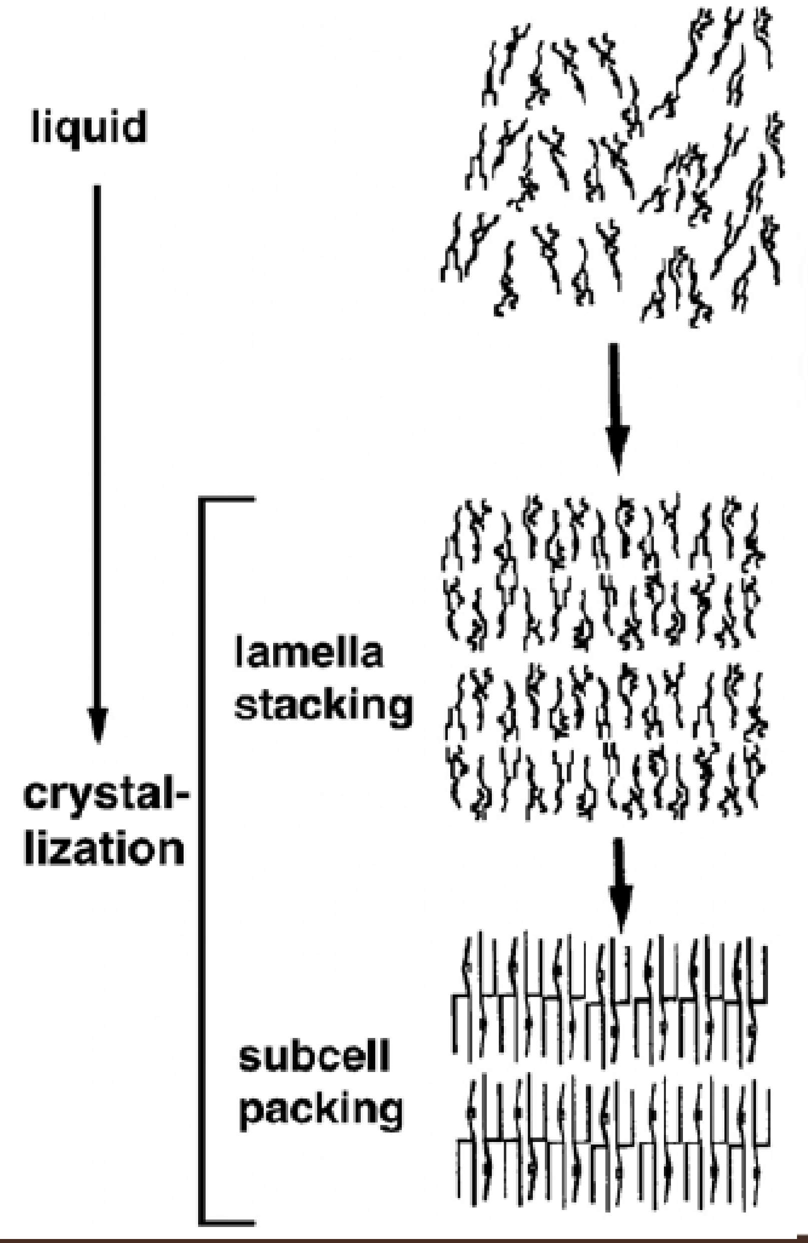
- = temperature (T_K) (K) < melting temperature (T_{Km}) (K)

$$\Delta\mu = \Delta H_m \times \frac{T_{km} - T}{T_{km}} = \Delta H_m \times \frac{\Delta T}{T_{km}}$$

T_{Km}-T_K = ΔT = supercooling (K)

ΔH_m: molar melting heat (J/mol)

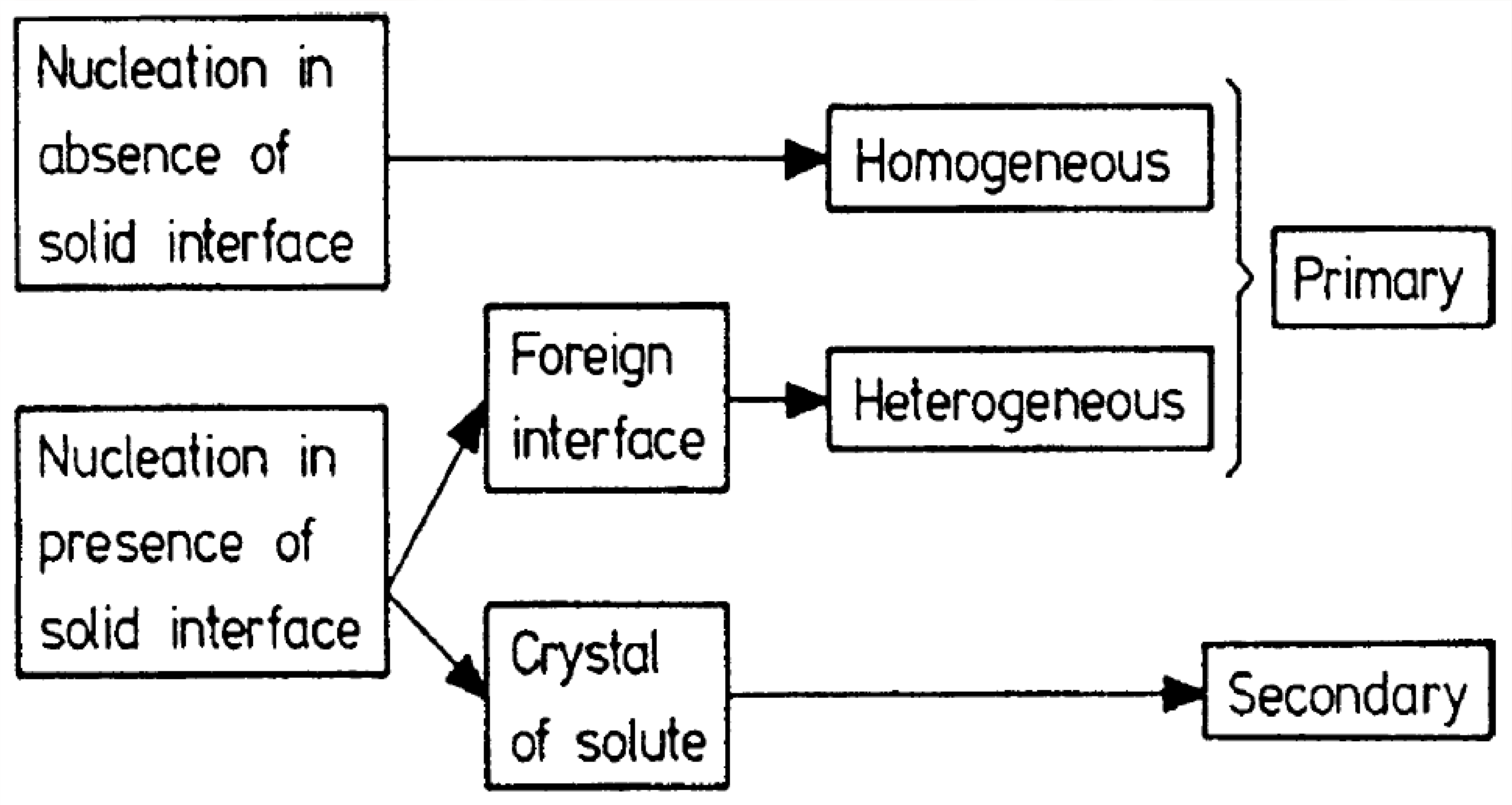
(ΔT/T_{km}) = σ_r (-): relative supercooling



Primary crystallization: nucleation

Nucleation = generation of a crystal nucleus by assembling growth units

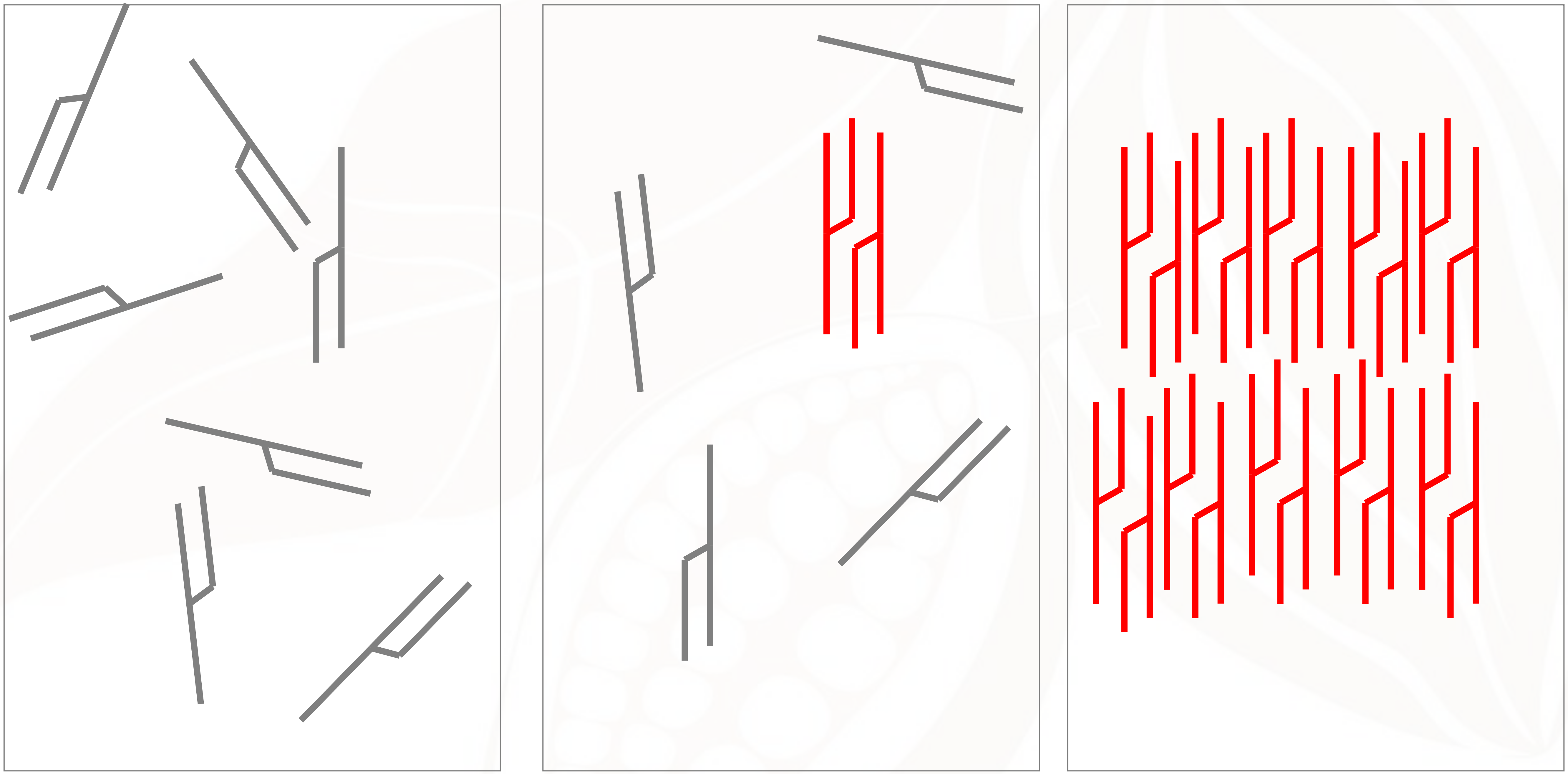
⇒ critical activation-energy needed!!!



Primary crystallization: nucleation

1. Primary homogeneous nucleation
   - = not catalyzed by foreign surfaces or existing fat crystals
   - Up to 30K supercooling needed

Homogeneous Nucleation



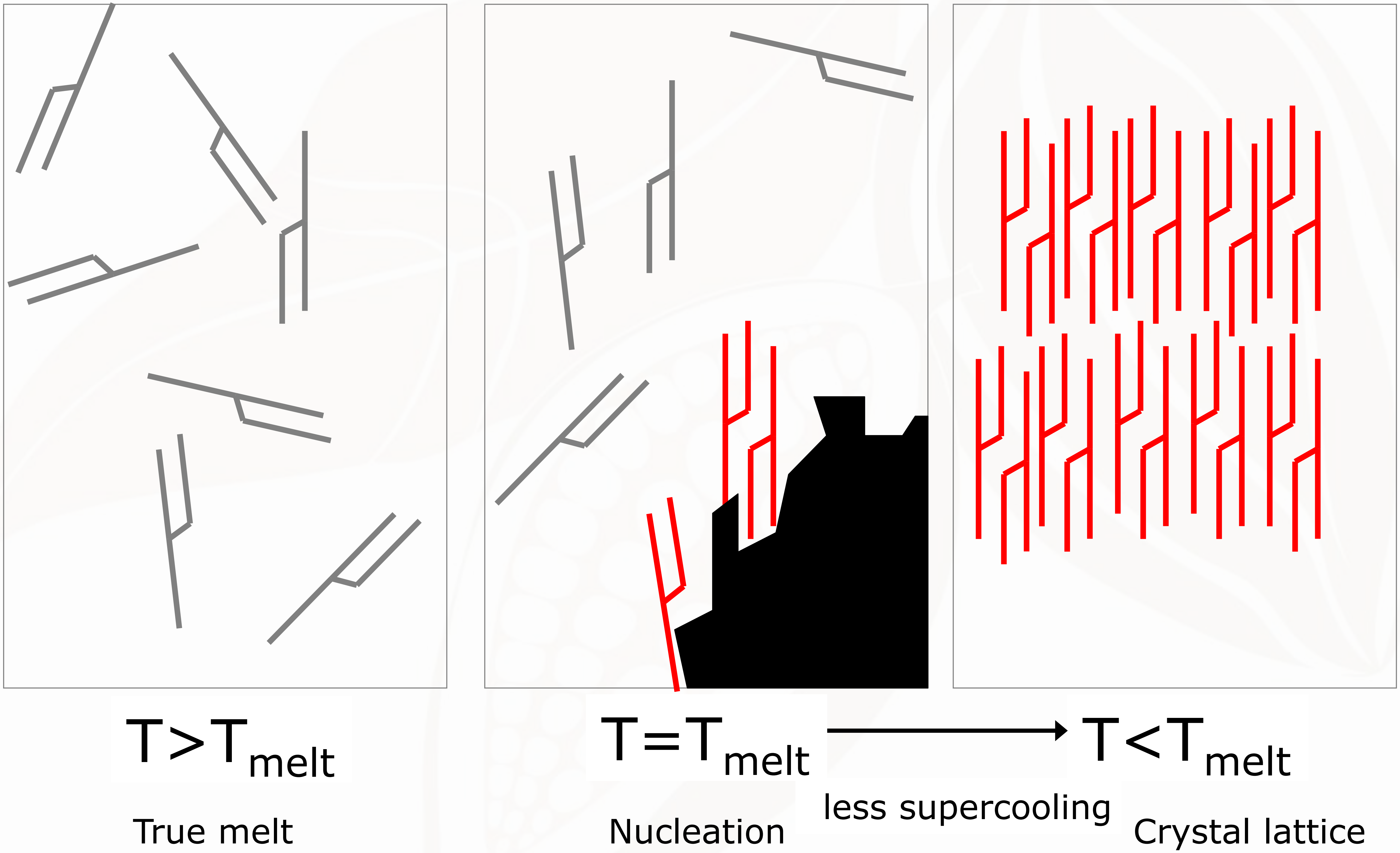
$T > T_{melt}$ $T = T_{melt}$ —supercooling→ $T << T_{melt}$

True melt   Crystal embryos   Crystal lattice

Primary crystallization: nucleation

1. Primary homogeneous nucleation
   - = not catalyzed by foreign surfaces or existing fat crystals
   - Up to 30K supercooling needed
2. Primary heterogeneous nucleation
   - = catalyzed by foreign surfaces (e.g. impurities, impeller blades etc.)
   - Most frequent in natural fats and oils, enough impurities present

Heterogeneous Nucleation

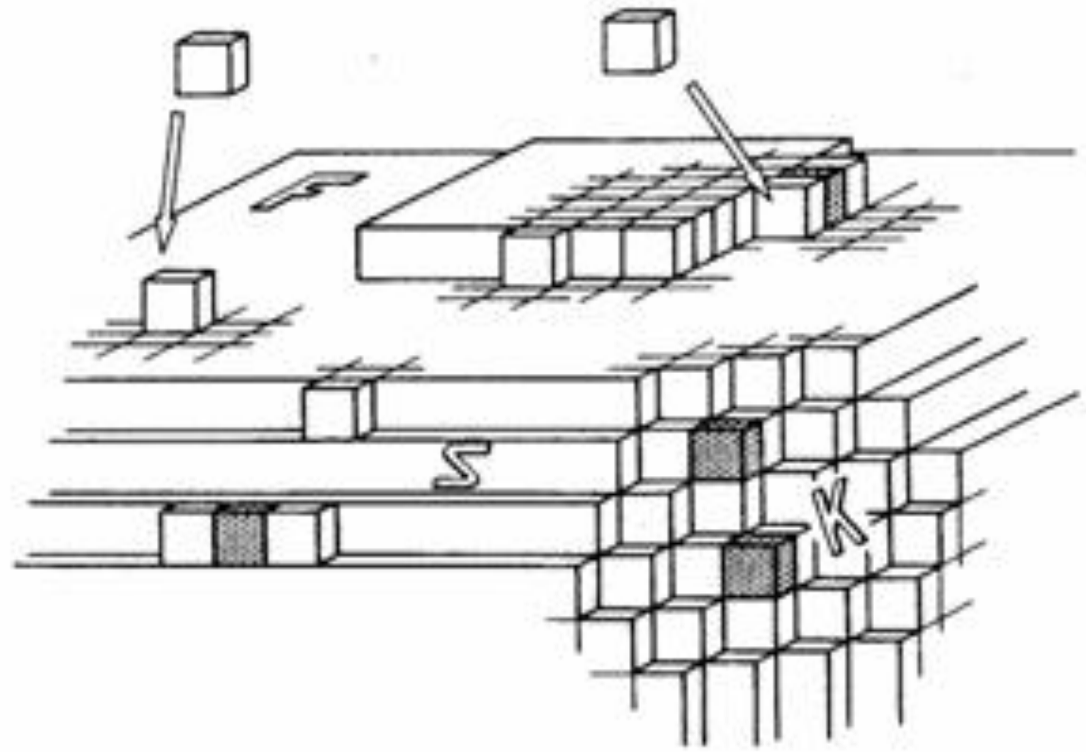


Primary crystallization: nucleation

1. Primary homogeneous nucleation
   - = not catalyzed by foreign surfaces or existing fat crystals
   - Up to 30K supercooling needed
2. Primary heterogeneous nucleation
   - = catalyzed by foreign surfaces (e.g. impurities, impeller blades etc.)
   - Most frequent in natural fats and oils, enough impurities present
3. Secondary nucleation
   - = catalyzed by crystals of the crystallizing material ⇒ secondary nuclei
   - Very frequent in crystallization from solution and in industrial crystallizers

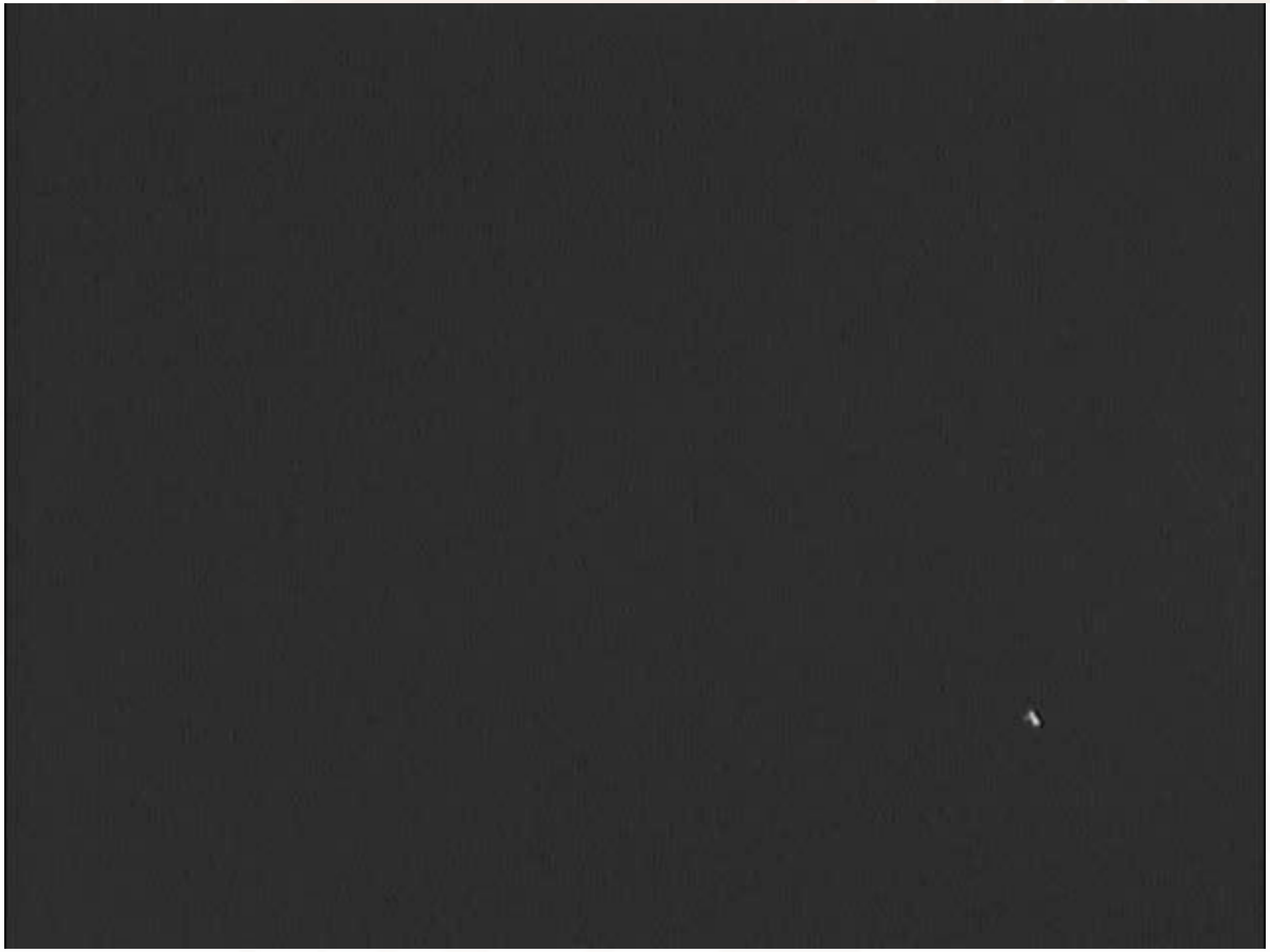
Primary crystallization: crystal growth

- Depends on
  - **external factors**:
    - Supersaturation, supercooling, solvent, temperature, presence of impurities, …
  - **internal factors**:
    - Structure, bonds, crystal defects, …
- **Mechanism** of crystal growth depends on the type of interface:
  - flat (F), kinked (K), stepped (S)



Schematic representation of three types of growth sites. Each cube depicts a growth unit

Primary crystallization: crystal growth



- Palm stearin crystallizing at 30°C after cooling down from 80°C at 10°C/min
- Real time duration of the movie: 5min, 2.5 min to volume filling

Polymorphism

- Polymorphism

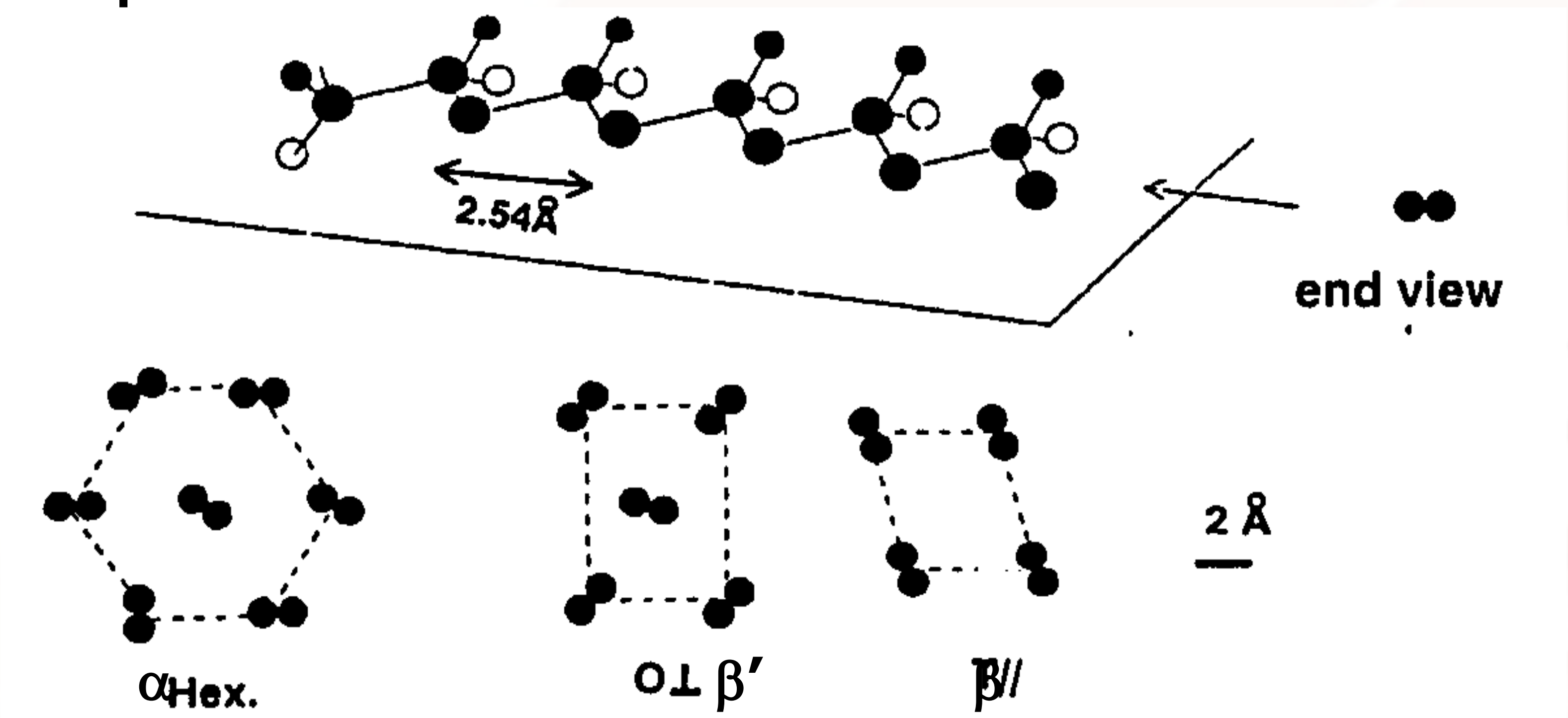
= the existence of several crystalline phases with the same chemical composition that have a different structure, but yield identical liquid phases upon melting.

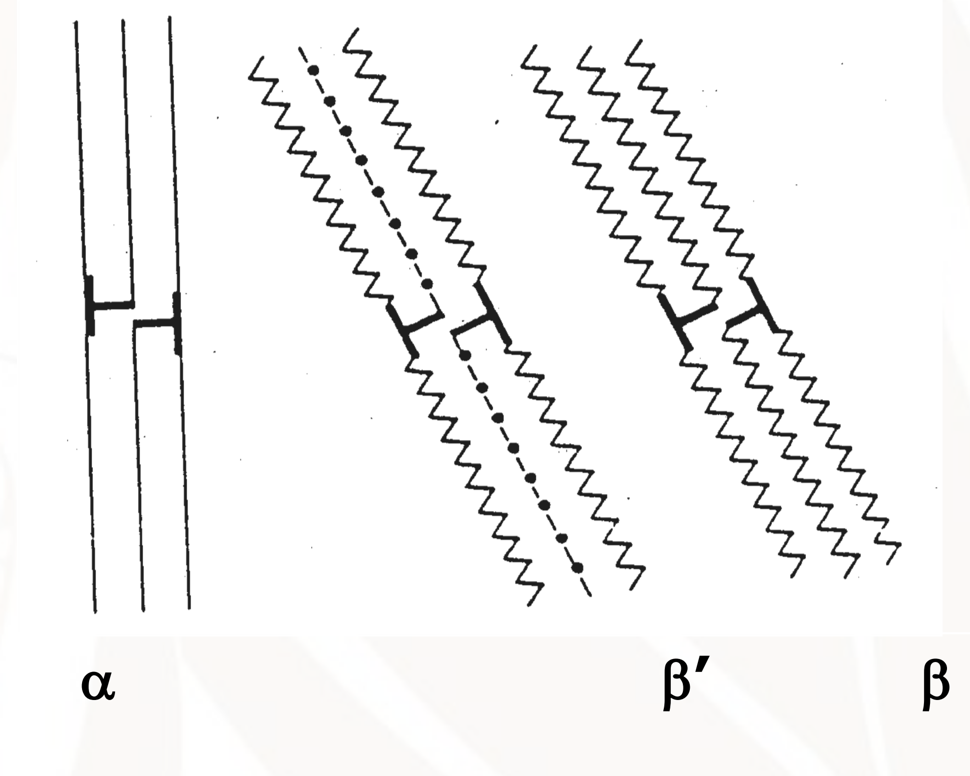
- Polymorphic transition
  - ⇒ less stable to more stable polymorphs
  - ⇒ 'solid-state', 'melt-mediated' or 'solvent mediated'

- *<u>Importance</u>*: obtaining and maintaining (during storage) of specific macroscopic properties
  - E.g. sandiness in margarine and fat bloom on chocolate are caused by a polymorphic transition

Polymorphism

- 3 basic polymorphs (α, β′, β), each with their specific properties





• Subcell packing of the hydrocarbon chains (cross section of the aliphatic chains): hexagonal (α), orthorombic (β’), triclinic (β)

• Different angle with respect to the end methyl group for the different polymorphs

• Zigzag form of one of the 3 chains perpendicular to the other 2 for the β’ form

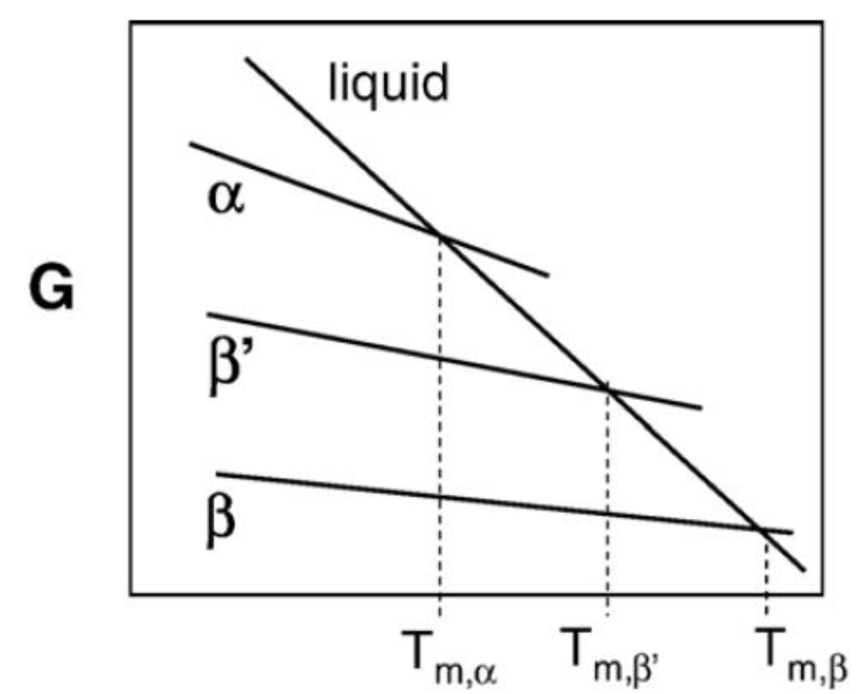
• Zigzag structures of 3 fatty acid chains in the same plane for the β form

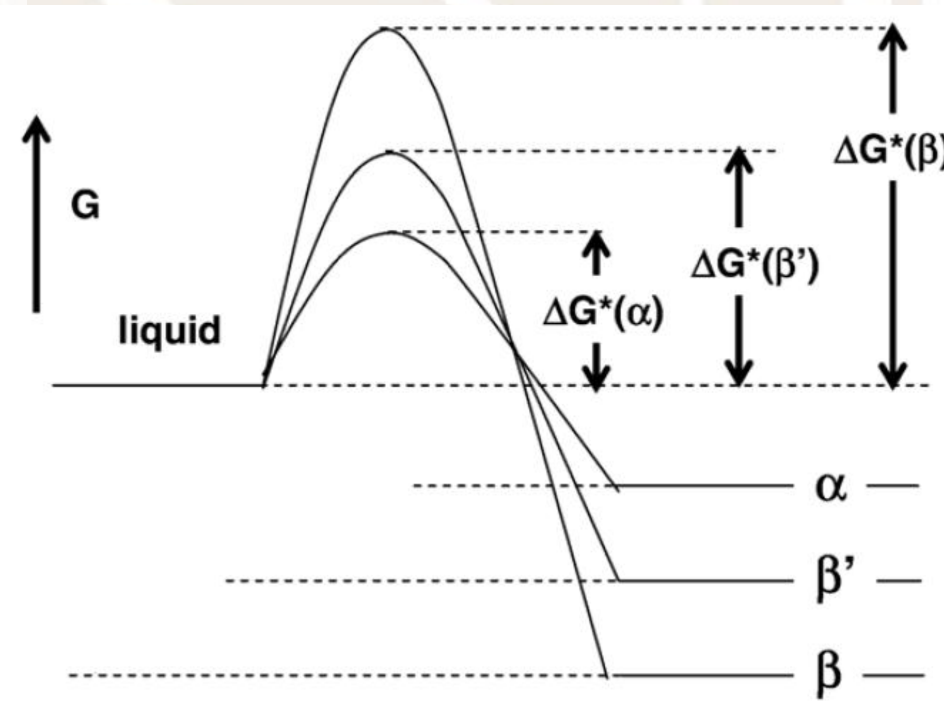
Polymorphism

- 3 basic polymorphs (α, β', β), each with their specific properties
  - Melting range, melting heat: $\alpha < \beta' < \beta$
  - Density : $\alpha < \beta' < \beta$
  - Stability: $\alpha < \beta' < \beta$
  - Activation-energy for nucleation: $\alpha < \beta' < \beta$

  ➔ onset of spontaneous nucleation: $\alpha > \beta' > \beta$

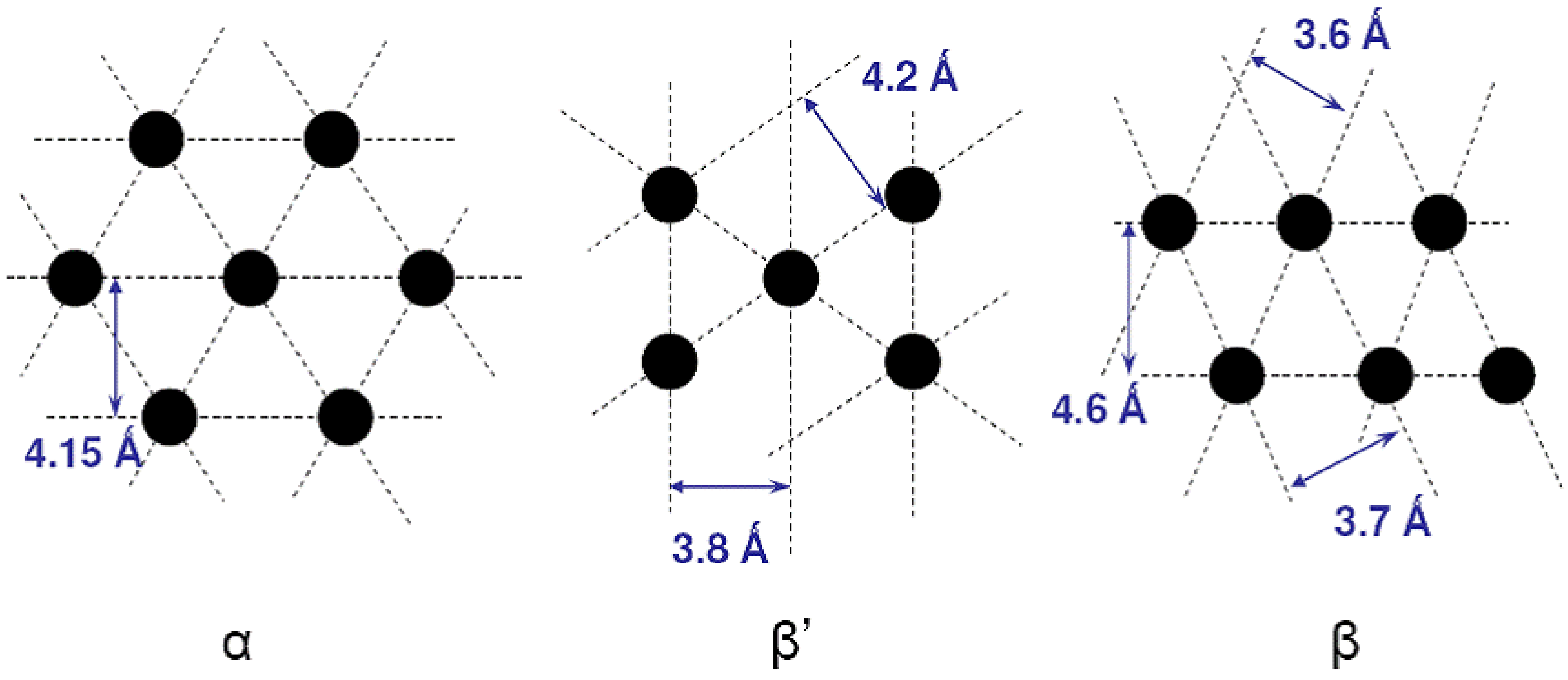
  ➔ the least stable polymorph crystallizes first and will transform to a more stable polymorph as a function of time
- Different submodifications possible depending on the TAG composition
- At low temperatures: γ polymorph = sub α polymorph





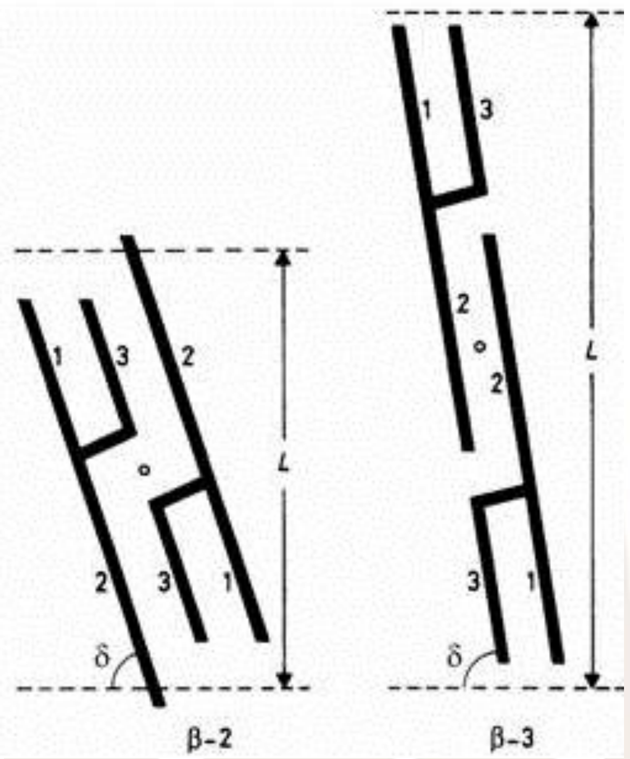
Polymorphism

- Identification of the different polymorphs
  ⇒ XRD diffraction lines: WAXD (wide angle X-ray diffraction) → short spacings

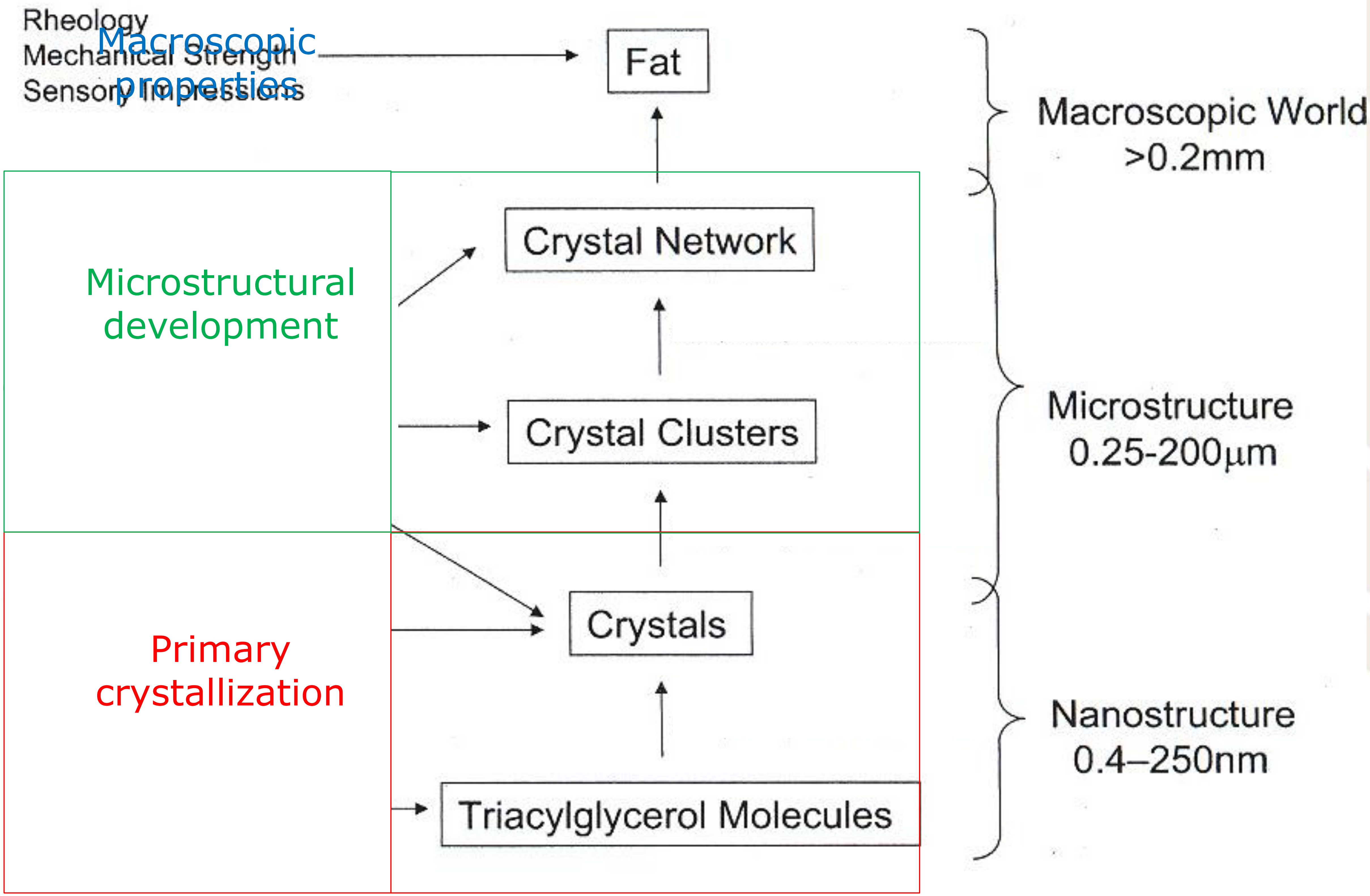


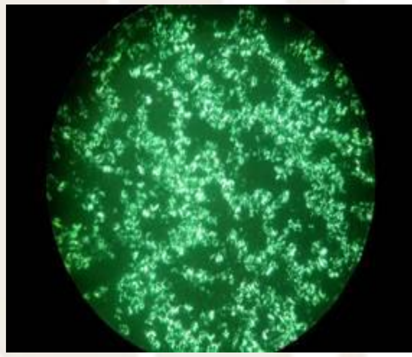
Organization of the TAG molecules

- The TAG molecules form layers in a specific stacking
- Layer thickness ~
  - Chain length
  - Tilt of the end methyl group
  - Type of packing
- Two types of longitudinal packing, resulting in pairs of 2 or 3 fatty acid chains long, 2L and 3L resp.
- Longitudinal packing ~ TAG composition
  - Many mono-unsaturated TAGs (unsaturation on 2-position)
    - ➔ preferentially 3L
    - ➔ fatty acids separated in saturated and unsaturated zone
- Determination by XRD diffraction pattern: SAXS (small angle X-ray scattering) → long spacings



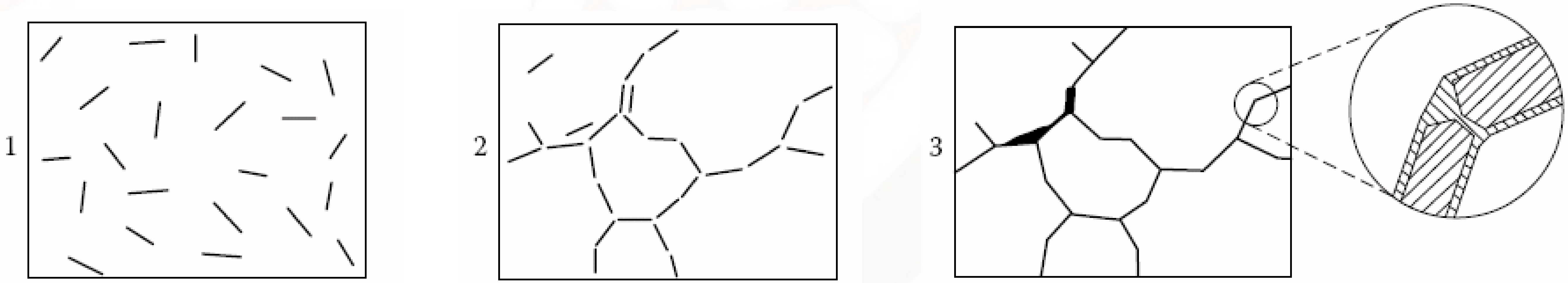
Structural levels in fat crystallization





Microstructural development

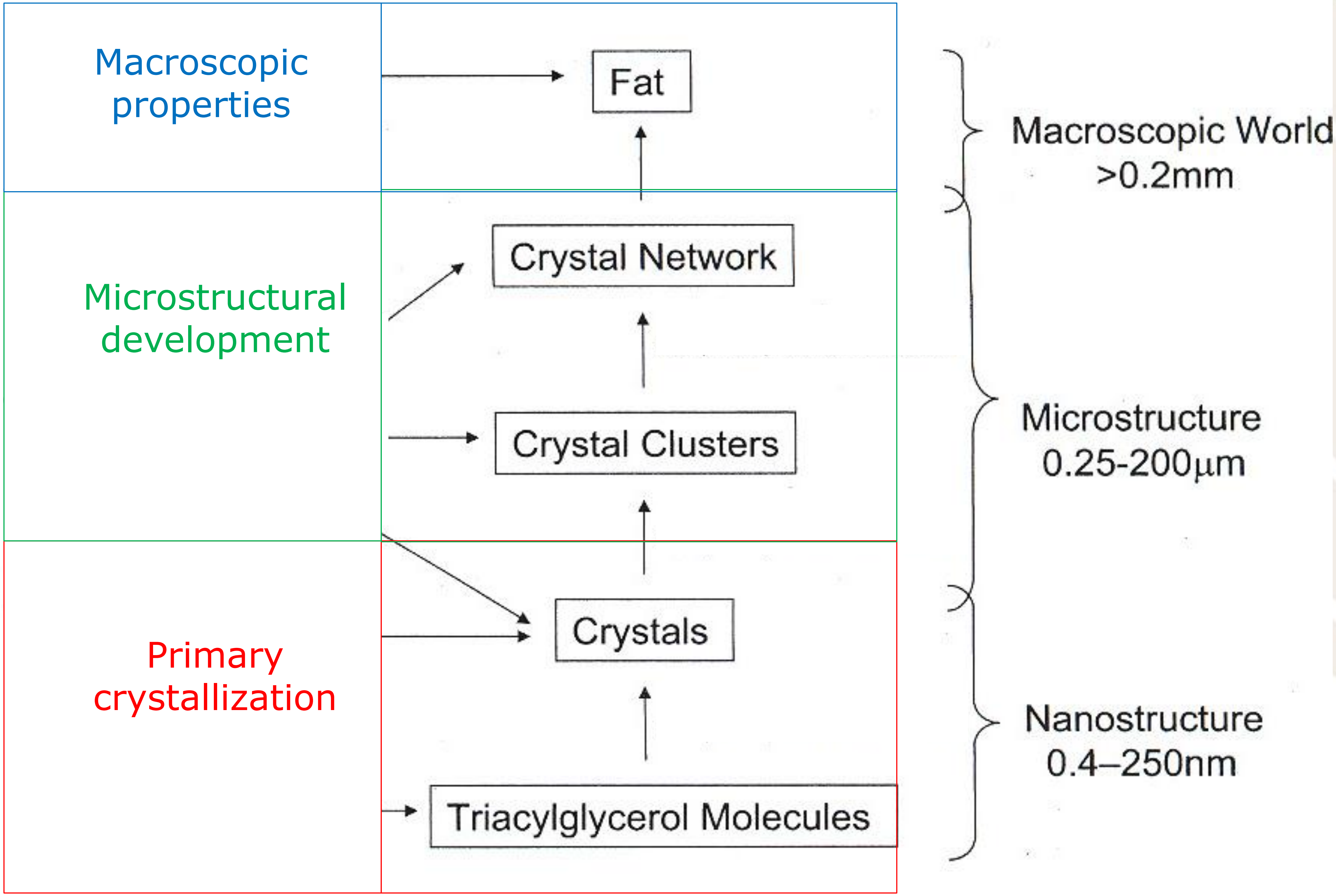
- Schematic presentation of the microstructural development:
  1. aggregation of crystals
  2. network formation
     - Continuous 3D network
     - Liquid fat trapped within the network
  3. sintering

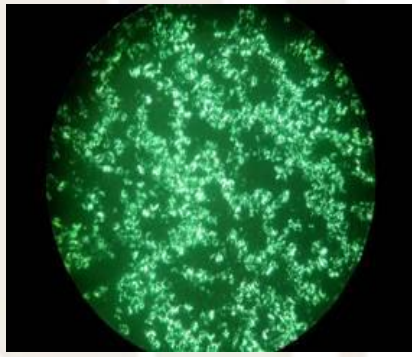


Microstructural development

- Network properties depend on:
  - Number and size of the crystals
  - Interactions between the crystals
  - Presence of other components
- Influencing factors
  - Crystallization temperature
  - Cooling rate
  - Agitation
  - Storage time

Structural levels in fat crystallization





Macroscopic properties

- How does the consumer experience the product?
  - Smell
  - Taste
  - Appearance e.g. Fat bloom
  - Mouth feel (cool sensation, no waxy taste)
  - Melting in the hand, sticking to fingers
  - Snap
  - ...

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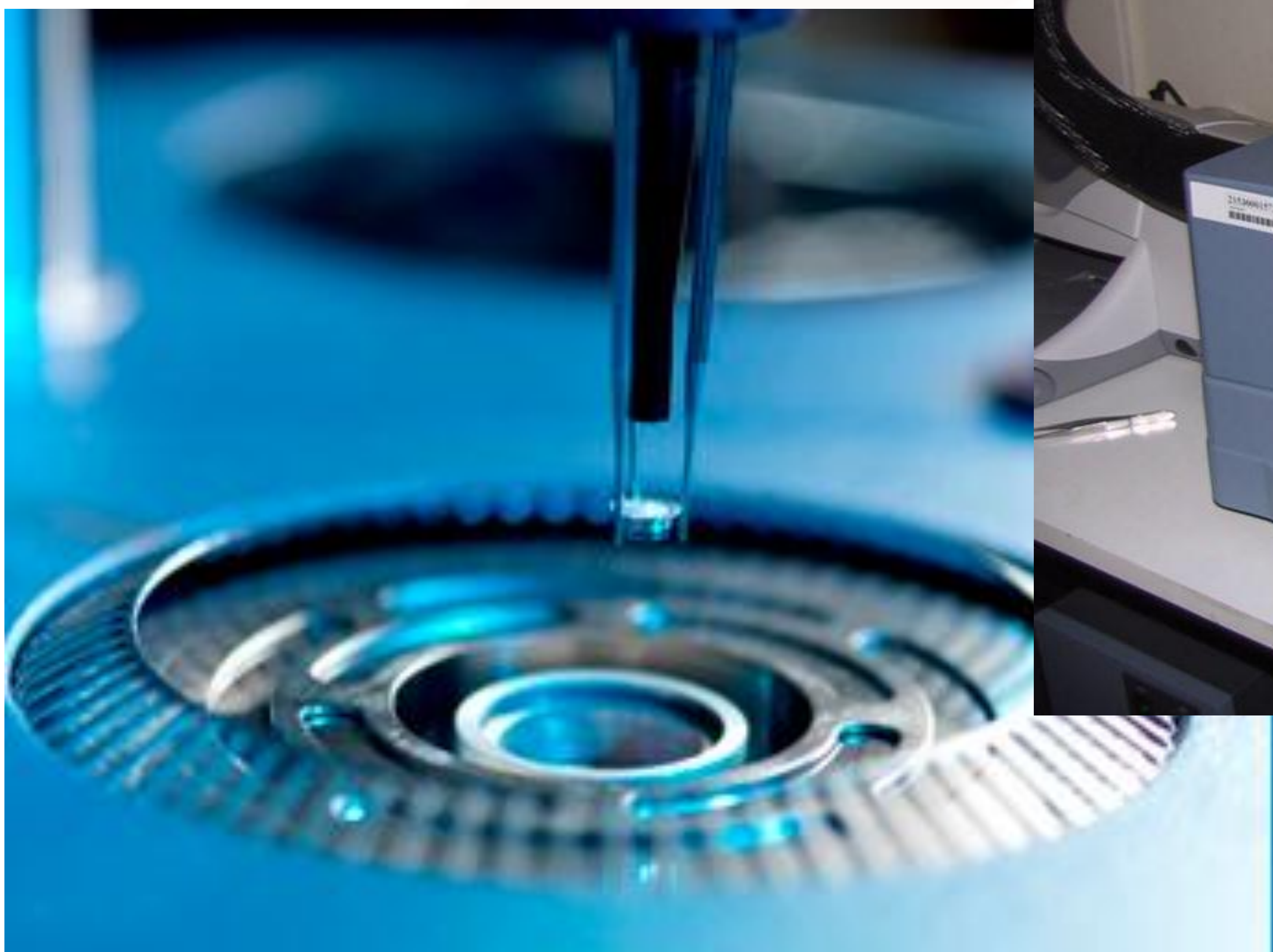
How to measure?

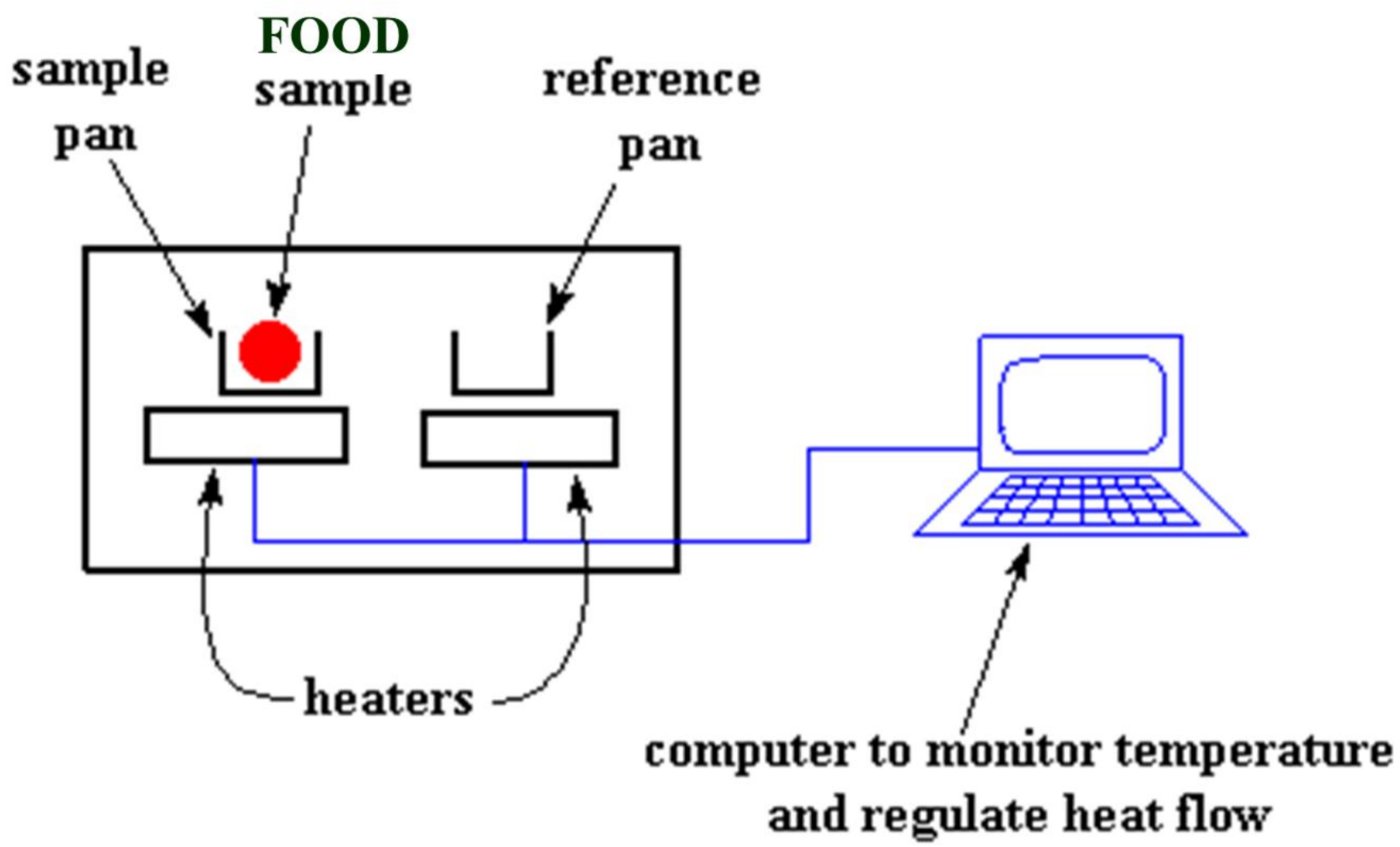
- DSC (Differential Scanning Calorimetry)
- pNMR (pulsed Nuclear Magnetic Resonance)
- XRD (X-ray Diffraction)
- Microscopy
- Rheology
- Texture analysis
- Sensorial analysis

Primary crystallization: How to measure?

- DSC

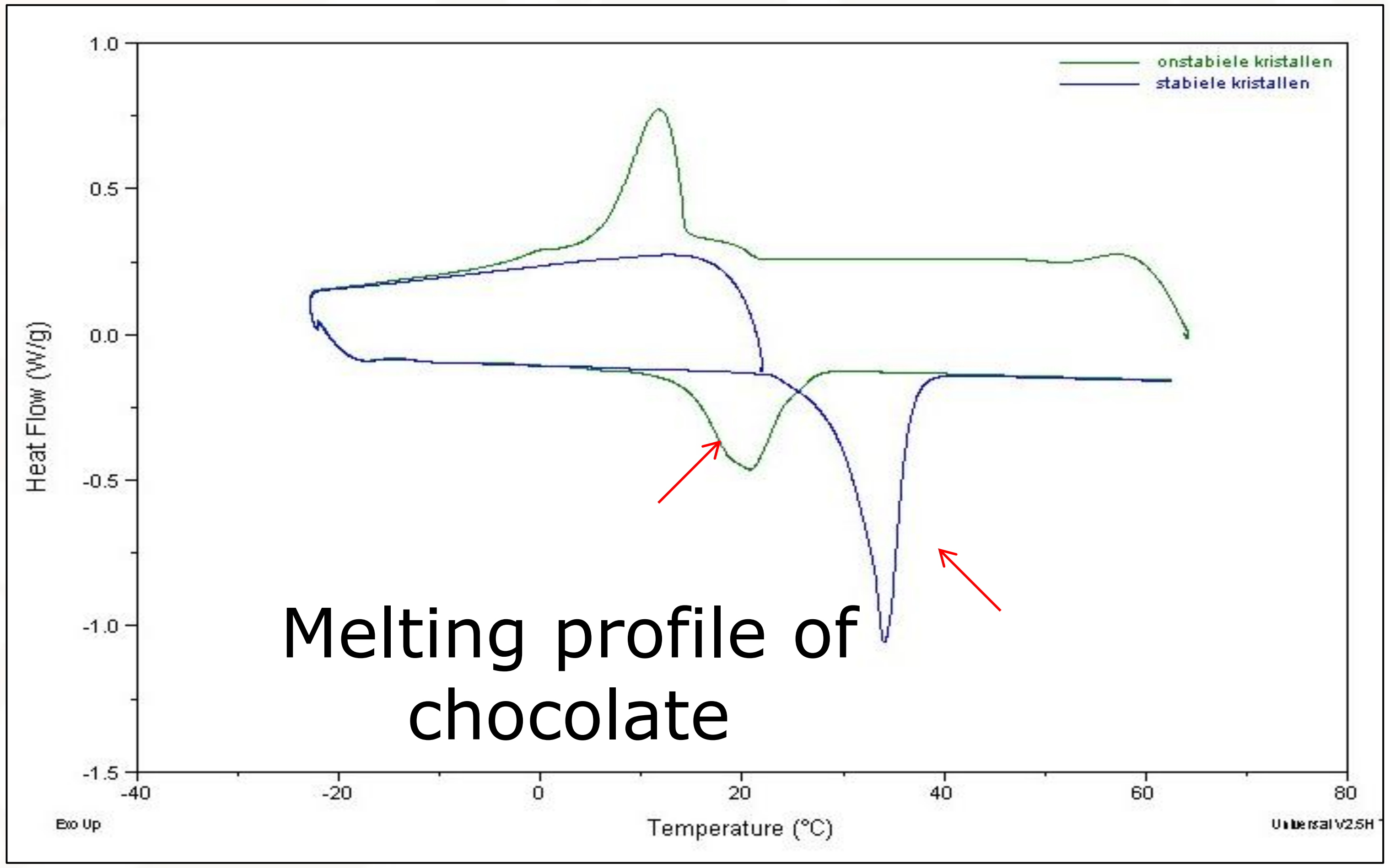


- DSC (Differential Scanning Calorimetry)
  - Measures the difference in heat flow between the sample (=fat) and the reference (=air) while both are subjected to the same temperature-time protocol

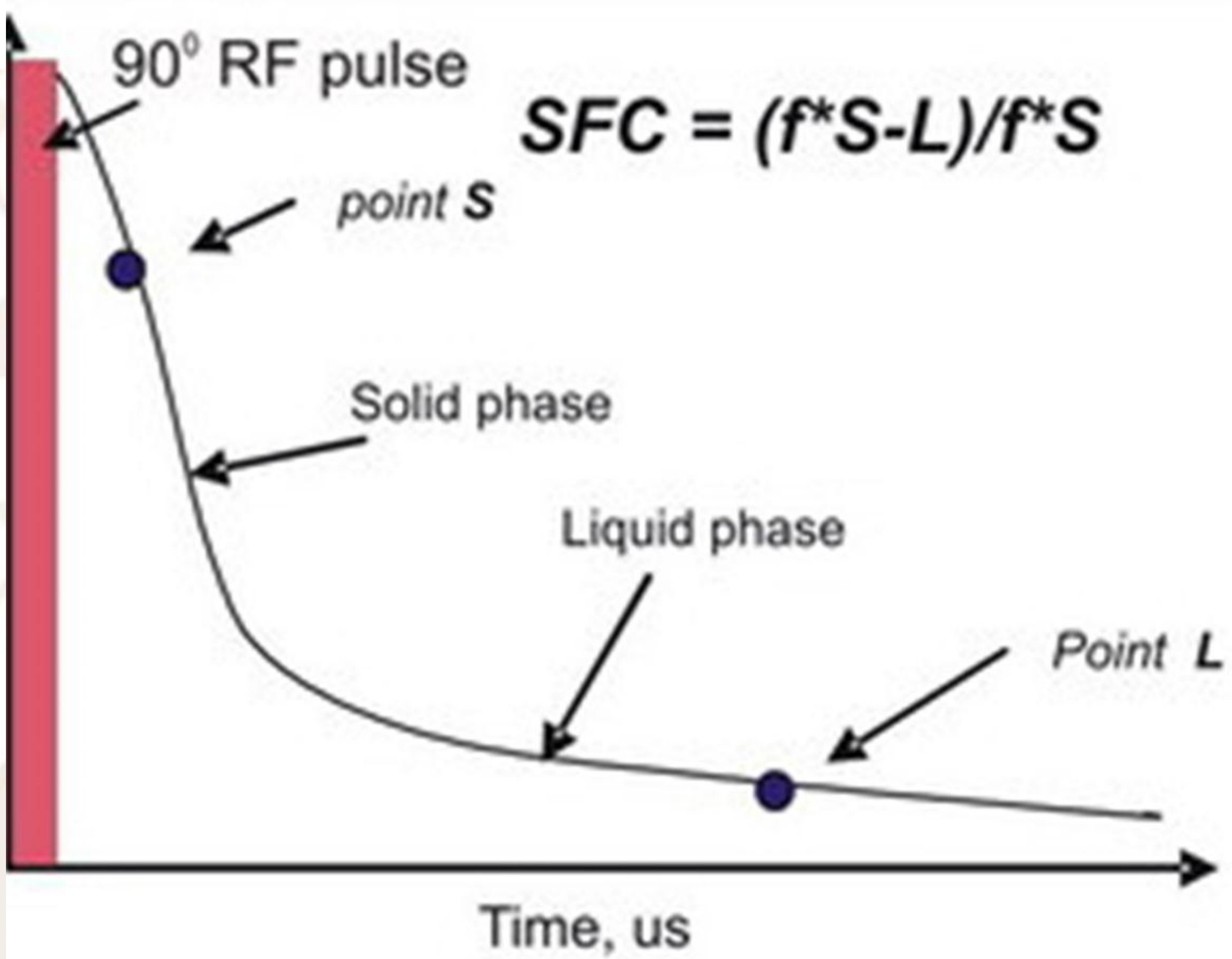


- DSC (Differential Scanning Calorimetry)
  - Provides information on processes that involve heat release (exothermic processes, e.g. crystallization) or heat absorption (endothermic processes, e.g. melting)

– Applications
  - Monitoring kinetics of crystallization
  - Recording melting profile → melting point provides an indication of polymorphism

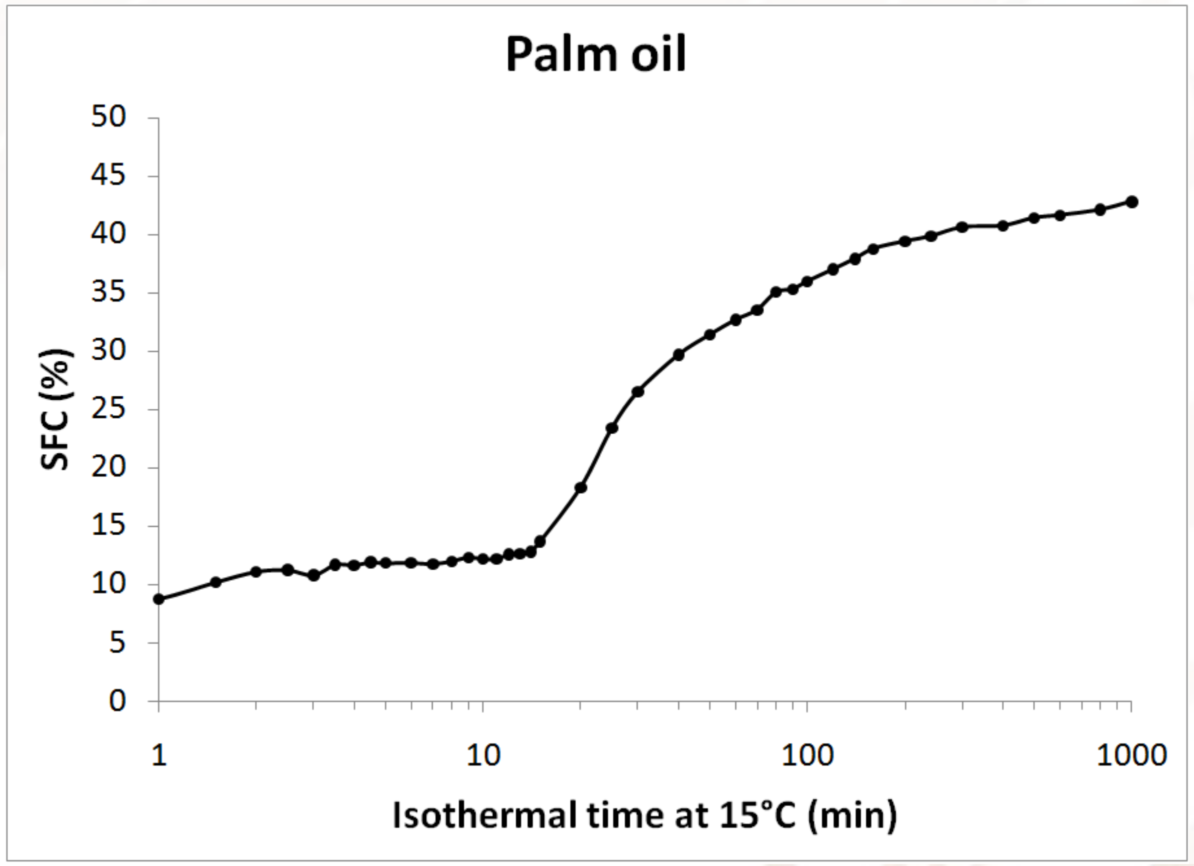


- pNMR (pulsed Nuclear Magnetic Resonance)
  - Electromagnetic pulse absorbed by ^1H-protons
  - Disturbance of the spin of the protons
  - Relaxation to the equilibrium
  - Fast for “solid” protons (crystals)
  - Slow for “liquid” protons

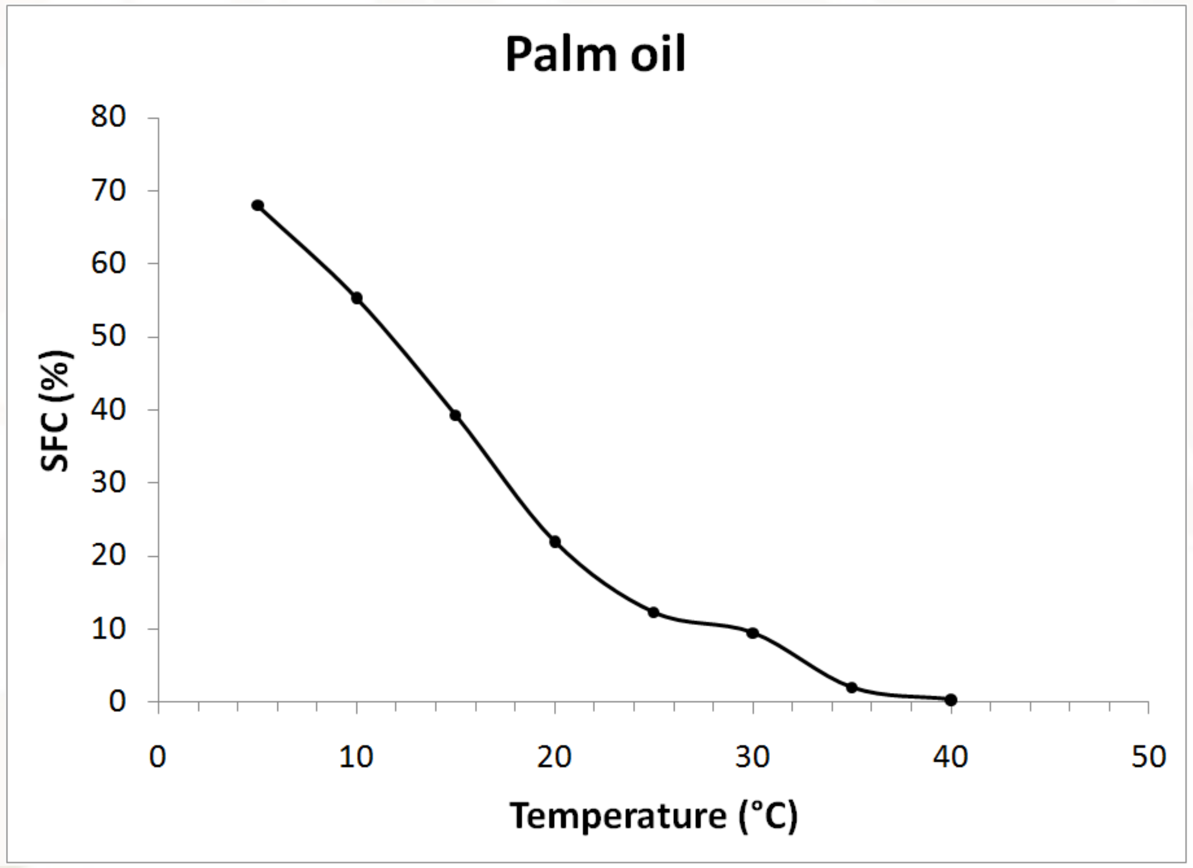


- pNMR (pulsed Nuclear Magnetic Resonance)
  - Solid fat content as a function of time (isothermal) or temperature (non-isothermal)
  - SFC as a function of temperature:
    - Equilibrium situation at each T, no information on kinetics

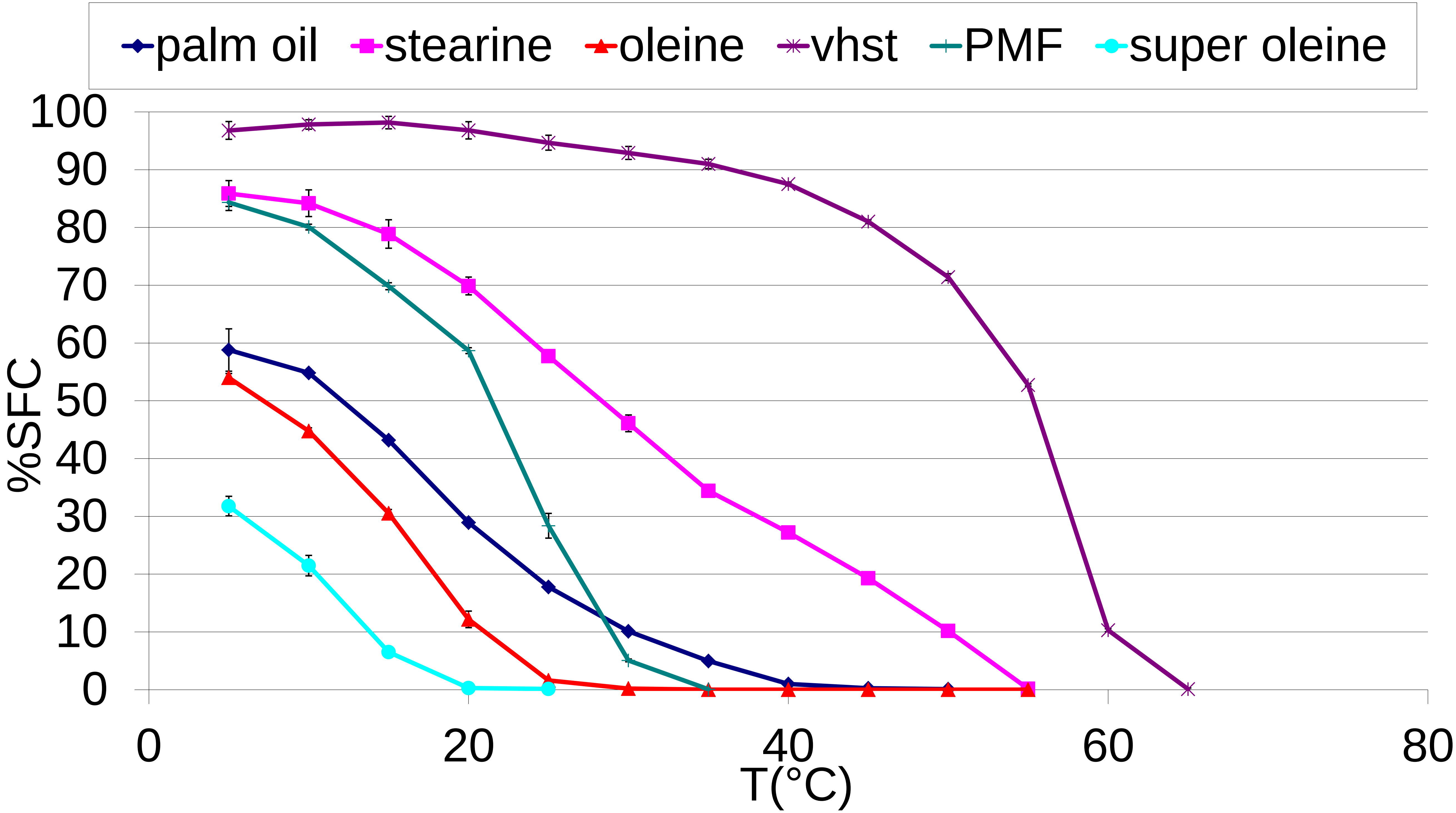
Isothermal at 15°C



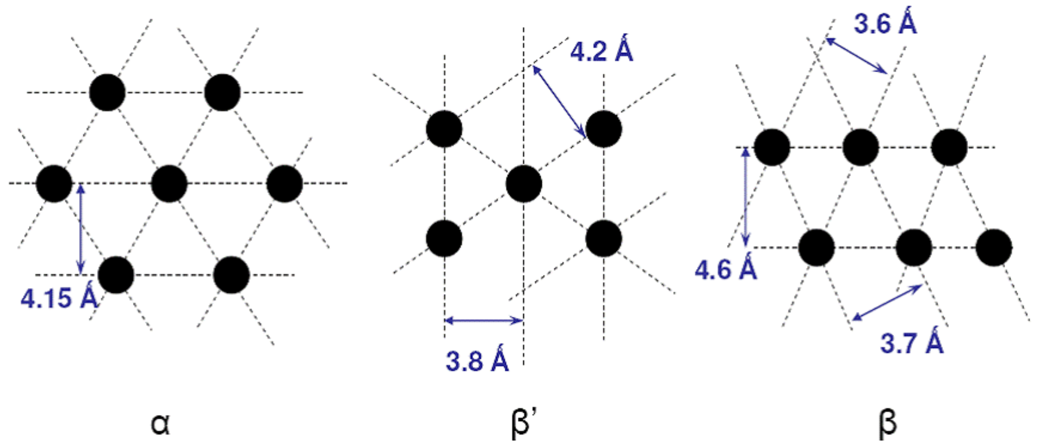
Non-isothermal



SFC of different palm oil fractions as a function of temperature

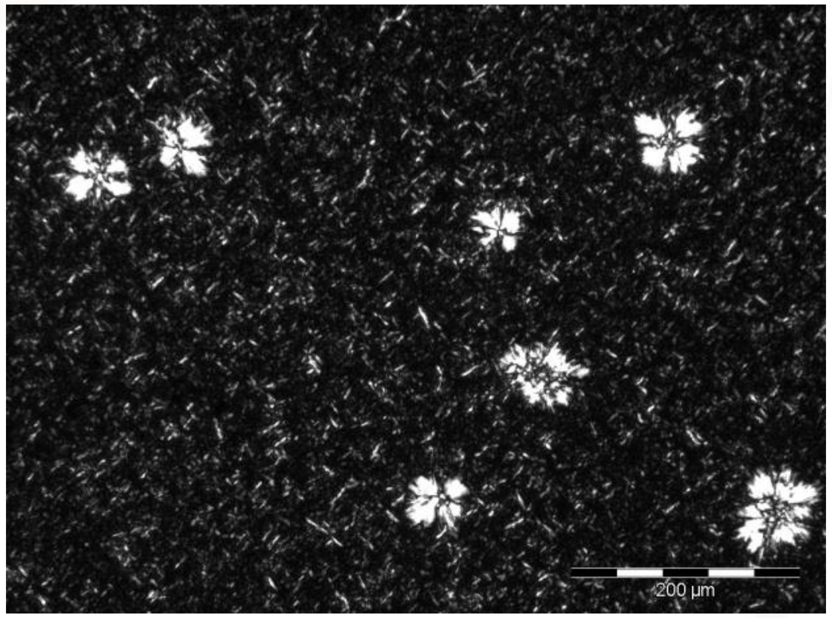


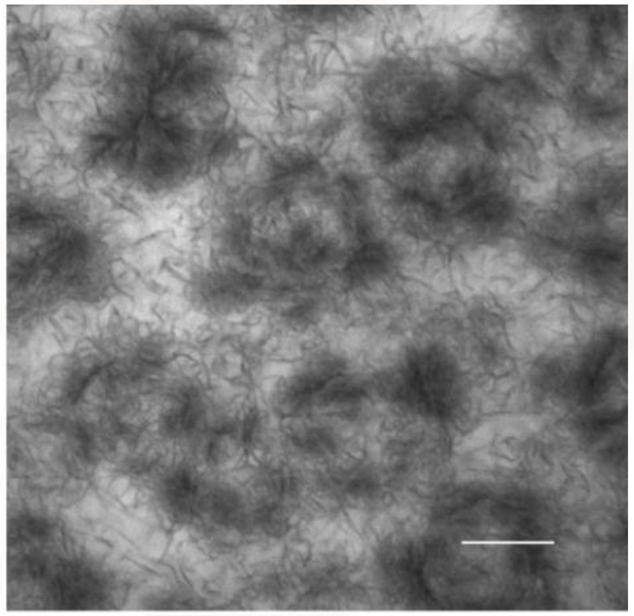
- XRD (X-ray Diffraction)
  - 100% certainty on the polymorphic form
- Synchrotron radiation (ESRF (European Synchrotron Radiation Facility) in Grenoble)
  - More intense X-rays ➔ recording time is limited to a few seconds

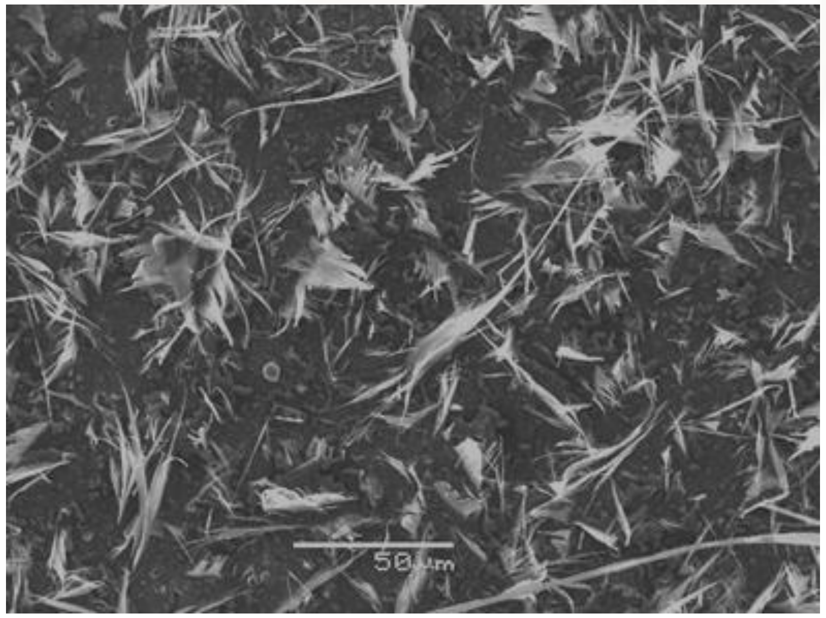


Microstructure: how to measure?

- Microscopy
  - Visual representation
    - Morphology, size, number of crystals
    - Aggregation and network formation
  - Several techniques
    - Polarized light microscopy
    - Confocal scanning laser microscopy
    - (Cryo-) Scanning electron microscopy



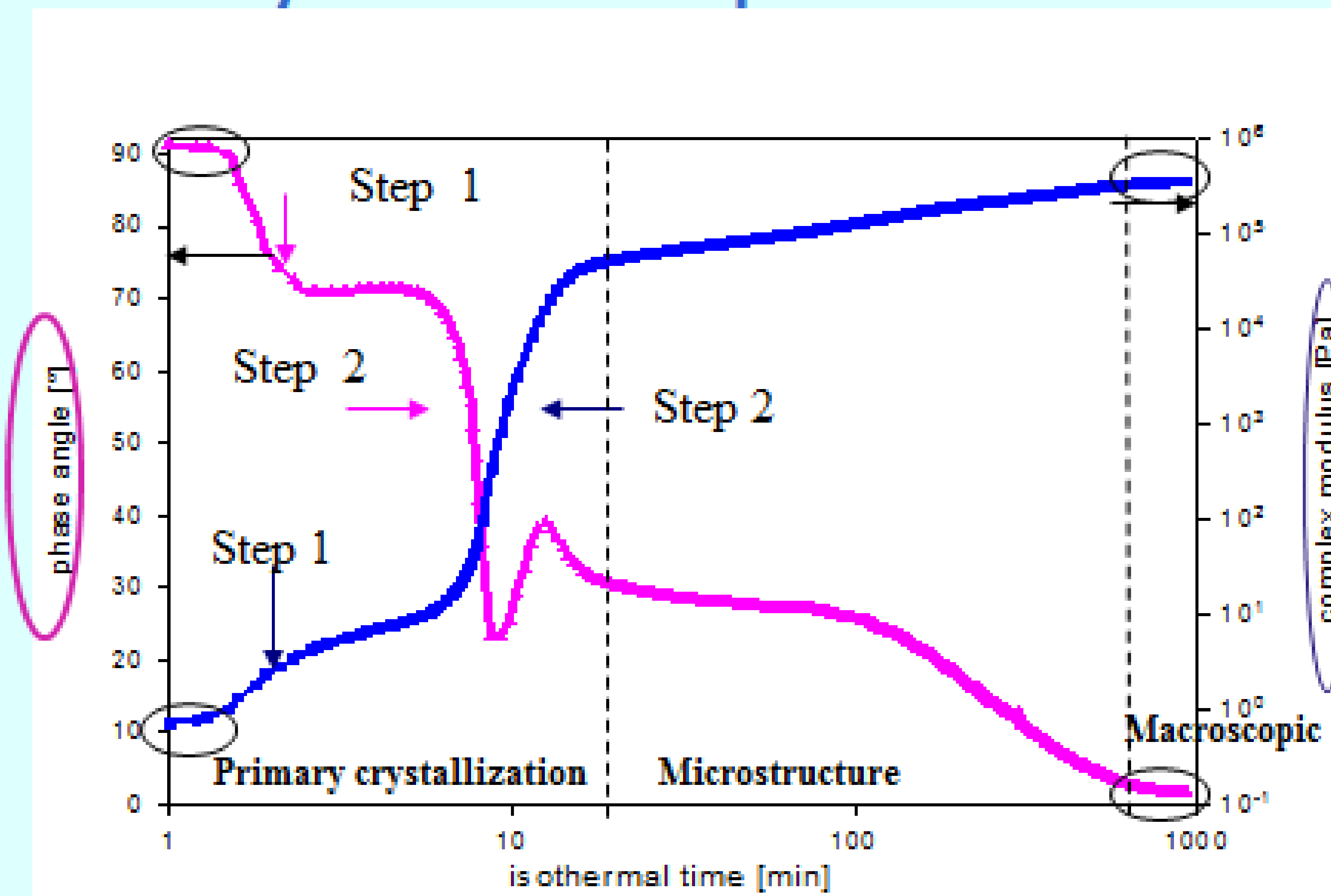




Microstructure: how to measure?

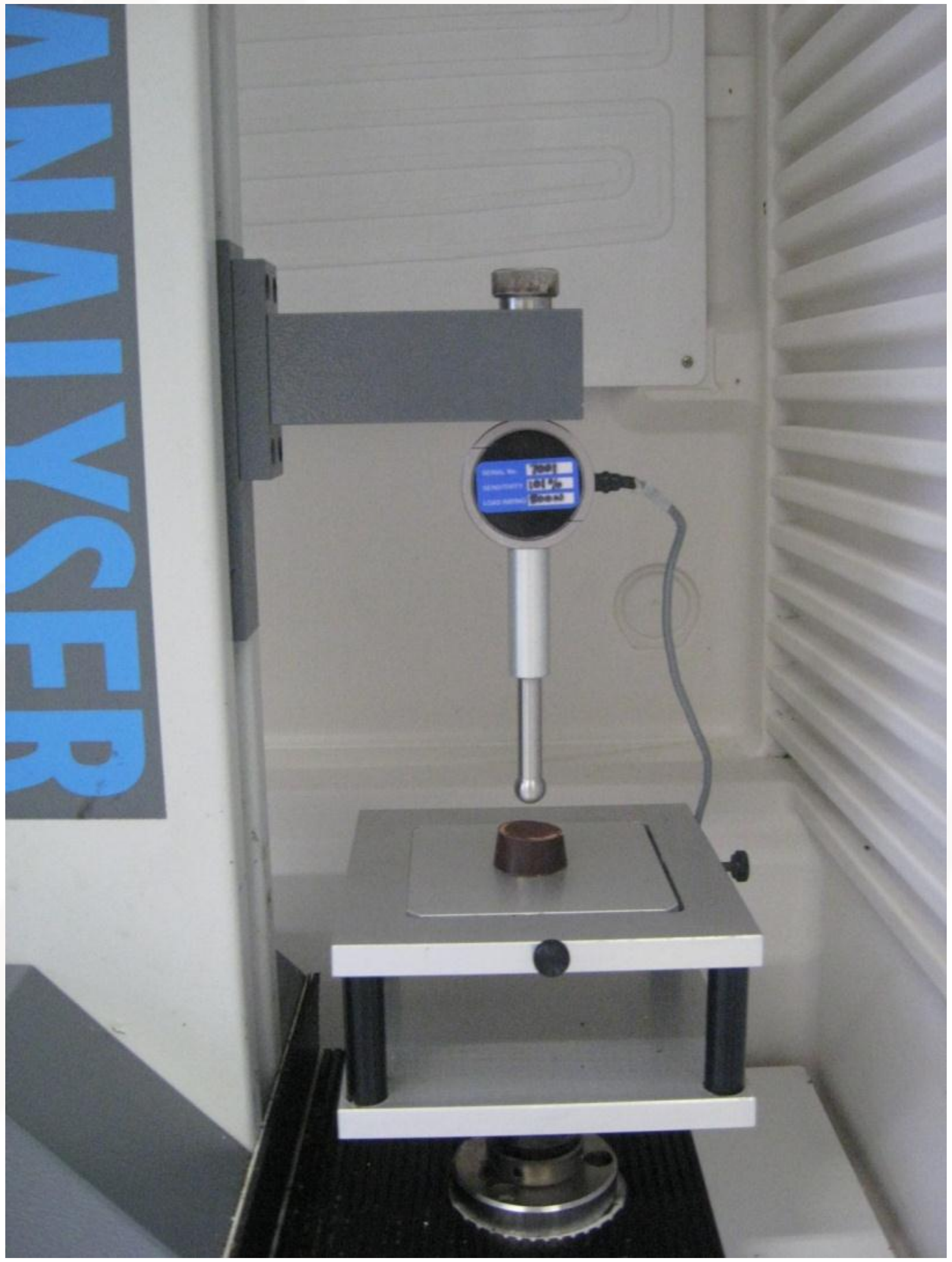
- Rheology

Crystallization of palm oil at 18°C



Macroscopic properties: how to measure?

- Texture analysis
  - Puncture test
  - Breaking test
  - Texture profile analysis test
- Sensorial analysis
  - Taste panel

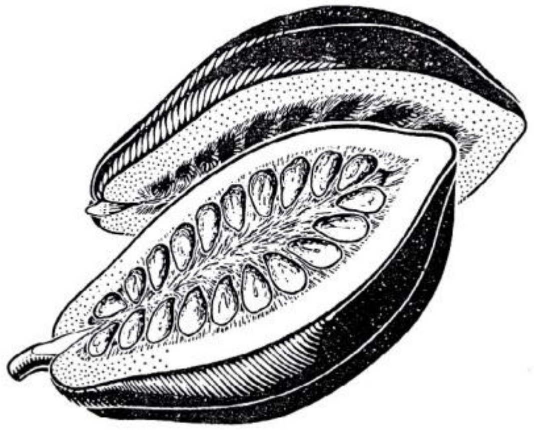


Outline

- Fats and oil: chemistry
- Importance of fat crystallization
- Structural levels in fat crystallization
  - Primary crystallization
    - Thermodynamic driving force, nucleation, crystal growth, polymorphism
  - Microstructural development
  - Macroscopic properties
- How to measure?
- Case study cocoa butter

Cocoa butter

- *Theobroma cacao* :
  - Up to 6 m tall
  - Cocoa fruit: 20 cm
  - Contains 30-40 seeds (65% moisture)
  - Originally from tropical Amazon forest
  - Cultivated by
    - Mayas from Yucatan, Guatemala
    - Aztecs from Mexico

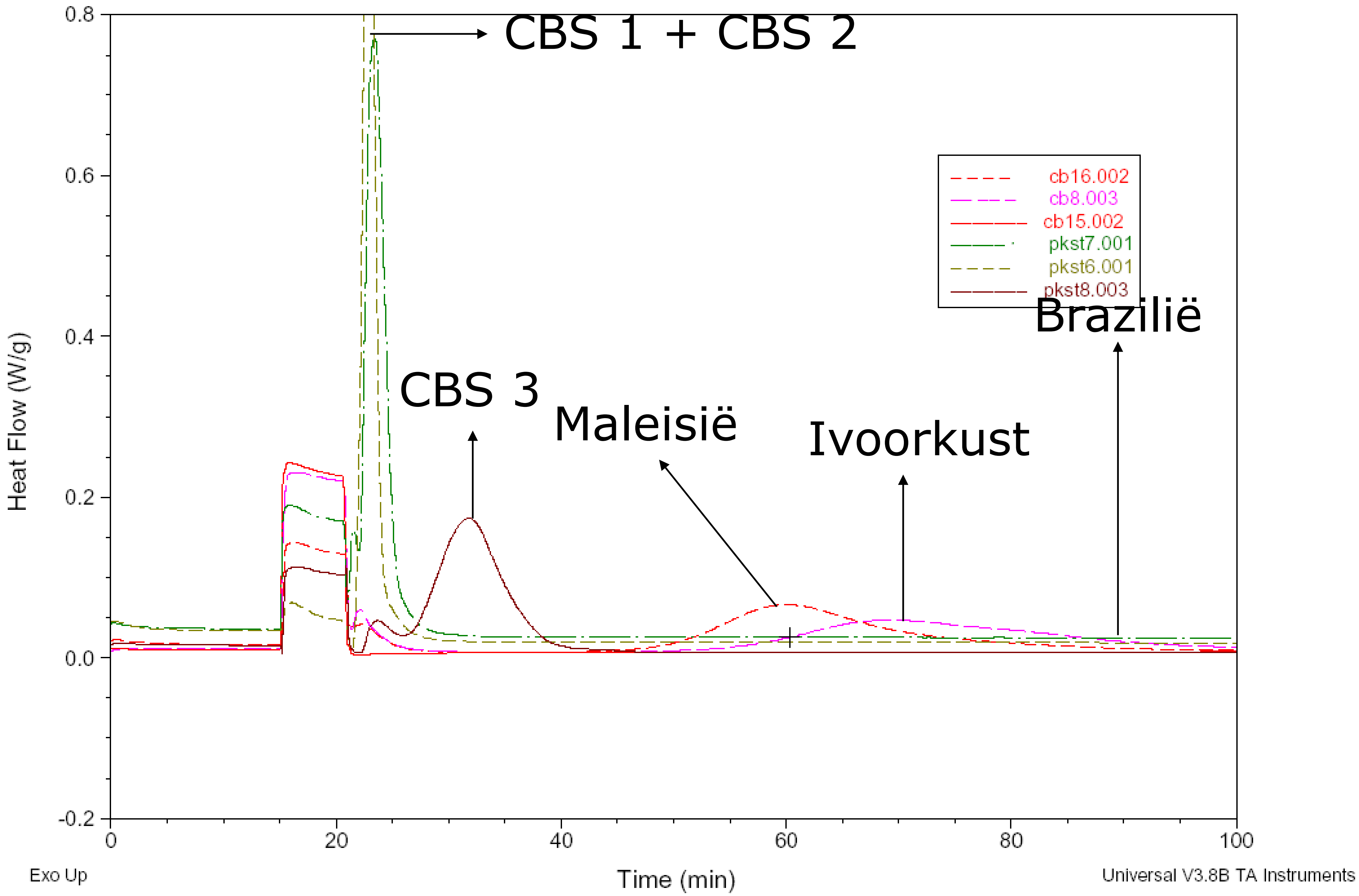


Chemical composition

- Narrow triacylglycerol composition:
  - Mainly POP, POS & SOS
  - But also PLP, POO, PLS, SOO, SLS & SOA
- Variation in triacylglycerol composition depending on geographical origin

Land	#stalen	PLP	POO	PLS	POP	SOO	SLS	POS	SOS	SOA
Bolivië	1	1.1	3.3	3.5	22.6	4.0	2.1	40.4	22.8	0.5
Brazilië	6	0.9	3.9	3.7	17.9	6.7	3.2	37.1	26.0	0.4
Ecuador	3	1.2	3.0	3.2	19.2	5.4	2.3	38.4	26.9	0.4
Dom. rep.	4	1.1	3.3	3.2	18.4	6.1	2.7	38.2	26.5	0.6
Ivoorkust	9	1.0	1.9	3.0	19.0	3.9	2.5	39.6	28.5	0.6
Ghana	3	1.2	2.2	3.4	17.8	4.9	2.2	39.0	27.5	0.4
Indonesië	2	1.1	1.6	3.0	19.9	3.6	1.7	40.6	28.1	0.5
Maleisië	20	0.7	1.2	2.8	18.4	2.9	2.2	40.0	31.1	0.8

Crystallization



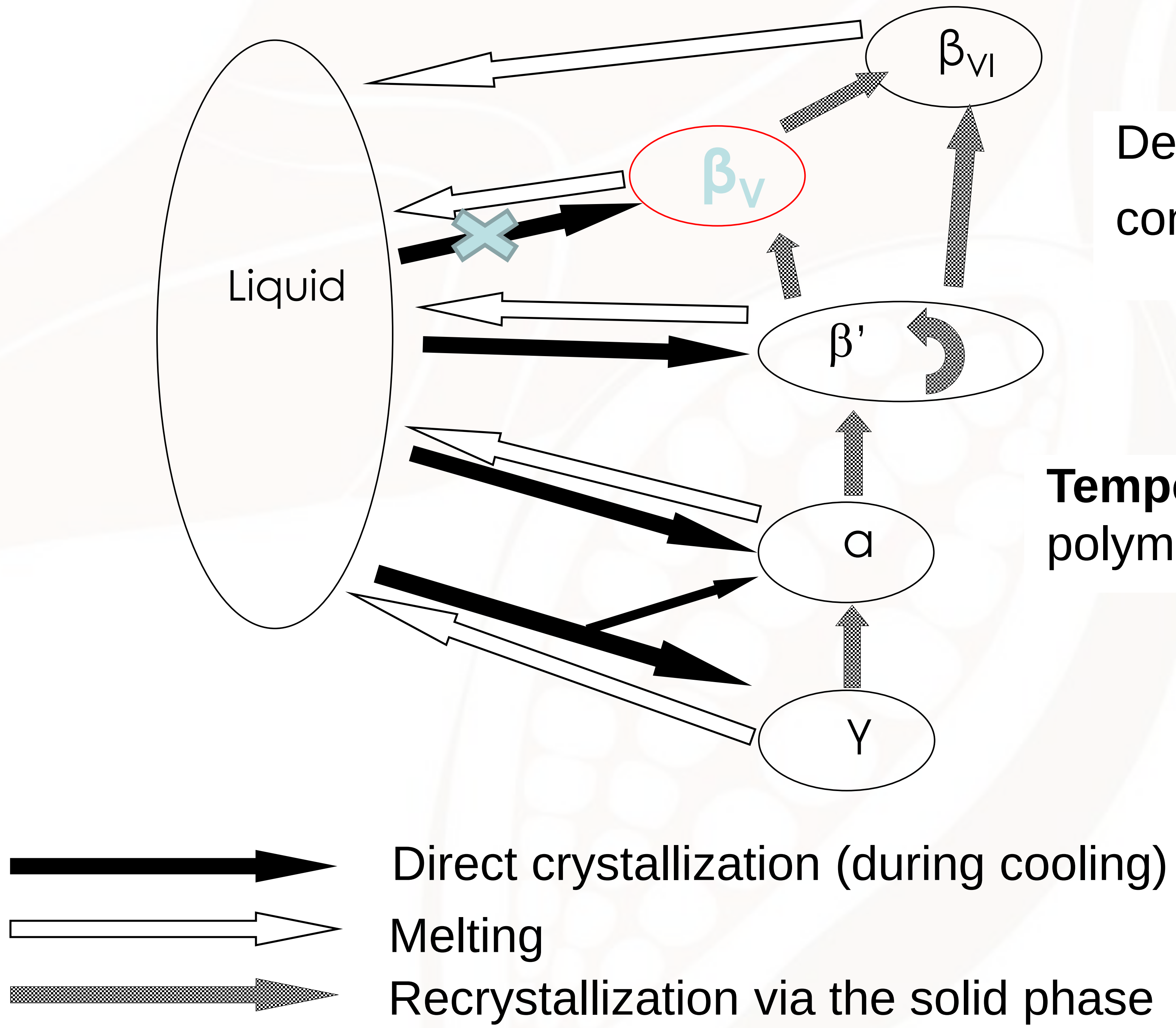
Isothermal crystallization (20°C) of cocoa butters of various origins and CBS monitored by DSC

Polymorphism

- Narrow triacylglycerol composition
  → complex crystallization behavior/ polymorphism
- 3 basic polymorphs + # sub polymorphs
- 4 to 6 polymorphs recognized and named depending on the author

Author	Polymorphic form					
Vaeck (1961)	γ	α		β'	β	
Larsson (1966)	β'_2	α	*	β'	β_2	β_1
Wille & Lutton (1966)	I	II	III	IV	V	VI
Van Malssen et al. (1999)	γ	α		β'	β^{V}	β^{VI}
Systematic nomenclature	β'_3 (sub-α)	α-2	β'_2-2	β'_1-2	β_2-3	β_1-3

Possible phase transitions in cocoa butter (Van Malssen et al., 1999)



Desired polymorphic form:

contraction, gloss, snap

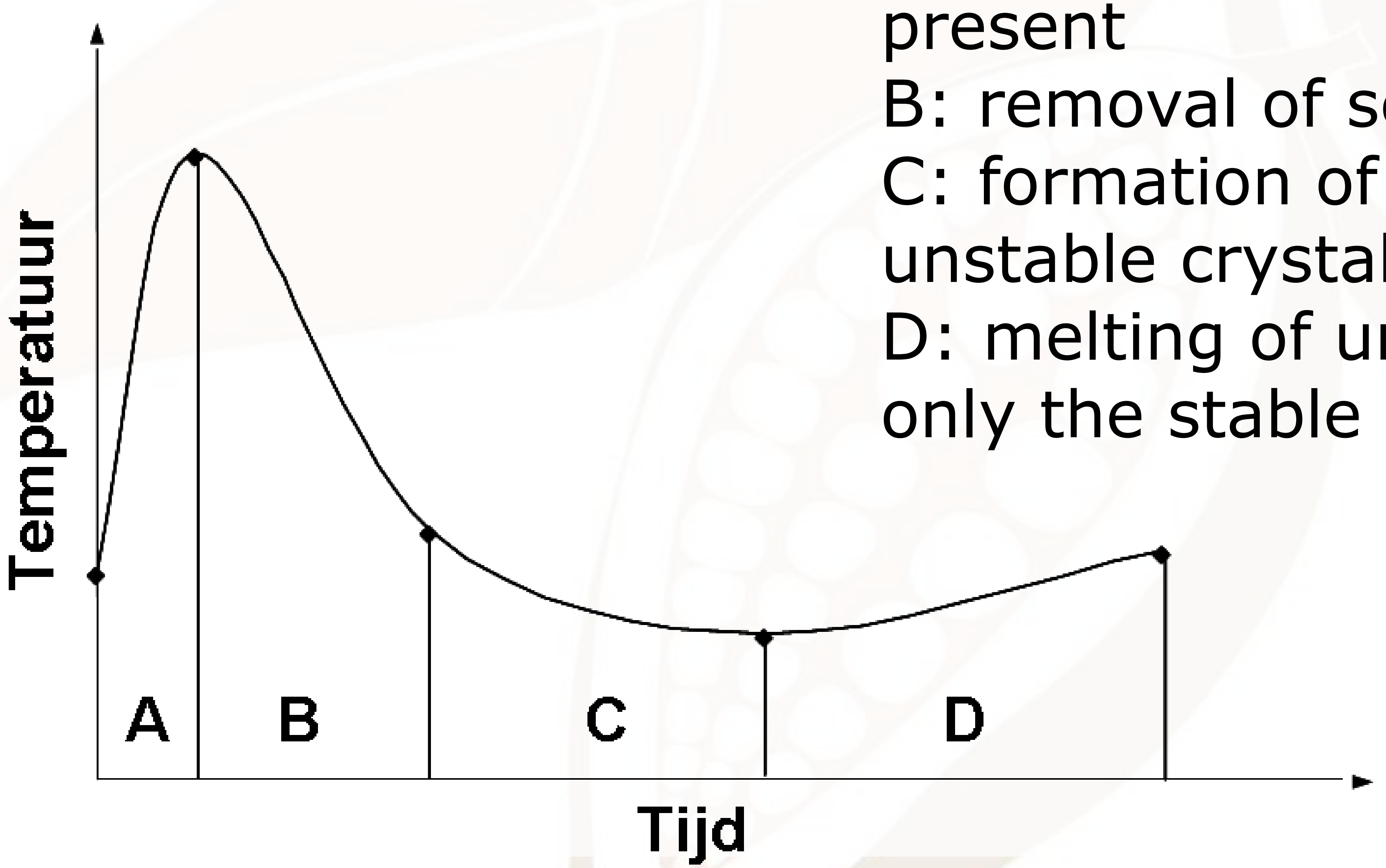
Tempering of chocolate to the desired polymorphic form

Importance of crystallization in chocolate production

- TEMPERING
  - = step in the production process during which seed crystals are formed in the molten chocolate
  - Important to obtain crystals in polymorph V as this results in the desired properties such as gloss, color, hardness, snap and shelflife
  - The seed crystals in polymorph V created during tempering will ensure that the rest of the chocolate also crystallizes in polymorph V

Importance of crystallization in chocolate production

- TEMPERING
  - Several steps can be identified (see figure)



A: melting all the crystals present
B: removal of sensitive heat
C: formation of stable and unstable crystals
D: melting of unstable crystals , only the stable crystals remain

Importance of crystallization in chocolate production

- COOLING
  - Further crystallization based on seeds formed during tempering
  - Proper time-temperature program in cooling tunnel is important: gloss, sufficient hardening at the end of the cooling
- STORAGE
  - Ongoing crystallization (depending on the cooling): crystallization heat can get trapped in the wrapping
  - Amongst others, polymorphic transition to form VI

➔ Fat bloom

Tempering

- VIDEO !

Case study:
Influence of refining on the cocoa butter properties

Cocoa butter refining

- <u>Good quality refined cocoa butter</u>
  - < 1.75% free fatty acids
  - Free from foreign material
  - Molds
  - Rancidity

<u>Conventional Cocoa Butter Refining</u>

Crude Cocoa Butter

↓

Polish Filtration

↓

Deodorization
Steam stripping ← Batch/Continuous, Long/Short time

↓

Refined Cocoa Butter

Cocoa butter refining

- High demand → more poor quality crude cocoa butter
  - High FFA, high (non-hydratable) phosphatides, Fe
  - High alkalinity, dark colour (difficult to bleach)
- Increasing demand for different types of cocoa butter
  - Colour ranges
  - Degree of neutral flavours
- Removal of alkaloids: theobromine and caffeine
  - Deposit on the surface of vapour scrubbers → reduce the performance
- Steam refining should preserve unique crystallisation properties of cocoa butter

→ ***Improved refining process required***

Cocoa butter refining

Conventional Cocoa Butter Refining

Crude Cocoa Butter

↓

Polish Filtration

↓

Deodorization
Steam stripping

→ **Refined Cocoa Butter**

Improved Cocoa Butter Refining

Crude Cocoa Butter

↓

Silica Pretreatment — Acid and/or silica - 80°C/atm. pressure

↓

Bleaching — Bleaching earth (and activated carbon) 90°C/50 mbar

↓

Deodorization
Steam stripping — Packed column stripping or tray deodorization short time/low pressure, adjustable temp.

→ **Refined Cocoa Butter**

Research question

Cocoa butter refining conditions

↓ ?

Milk chocolate quality

Experimental design

Crude cocoa butter

Silica pretreatment

Packed Column Steam Refining
150°C – 175°C – 200°C – 225°C – 250°C

Milk chocolate production

Evaluation:

- FFA, trace elements, soaps, tocopherols, alkaloids
- Colour, oxidation parameters
- Crystallization properties

Evaluation:

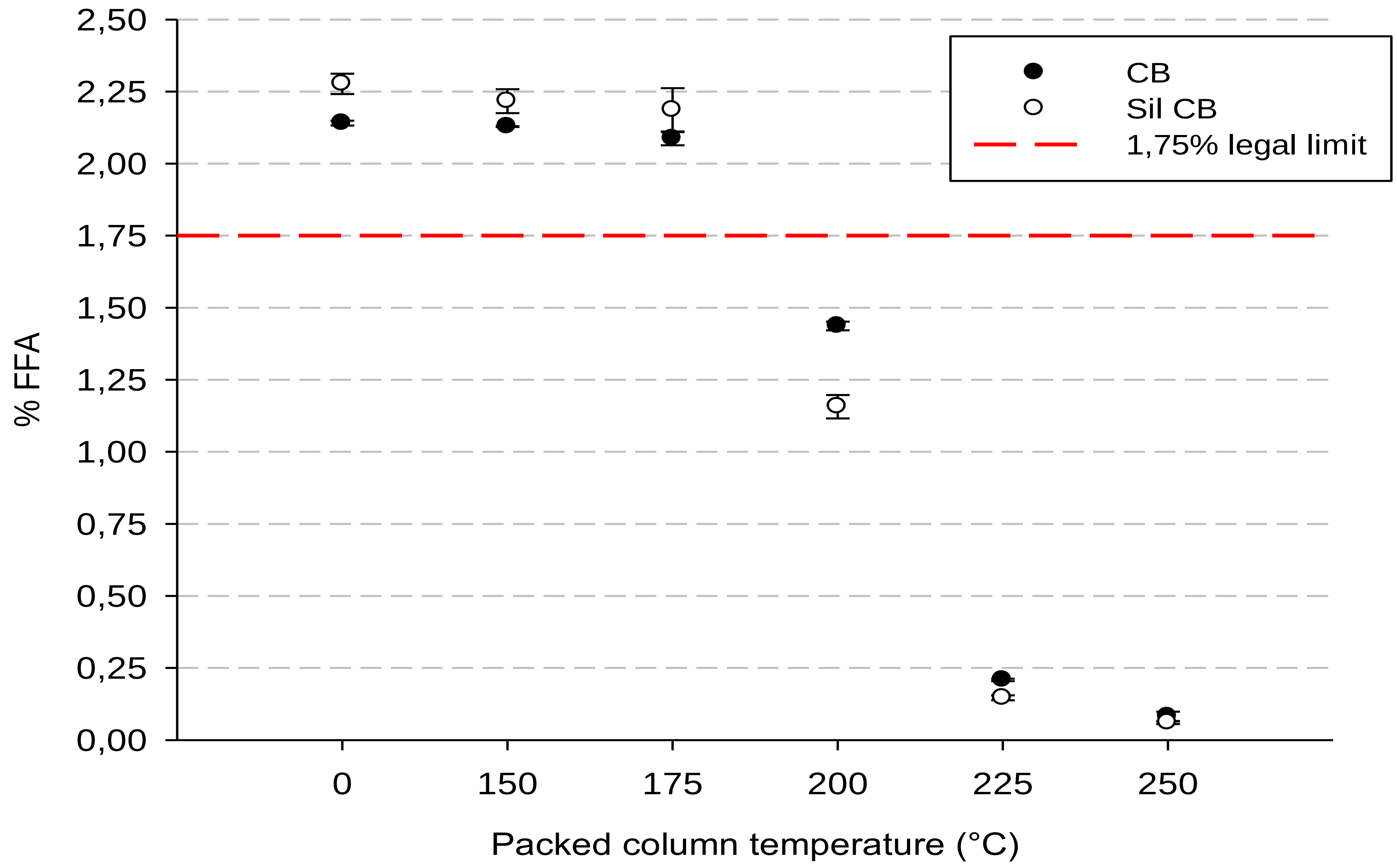
- PSD, rheological properties, sensory properties

Influence of silica pretreatment

	Crude CB	Silica pretreatment	Observation
FFA (%)	2.14	2.28	≈
Trace elements			
P (ppm)	63.52	8.66	**~90% ↘ Degumming**
Fe (ppm)	3.20	0.24	**~90% ↘**
Tocopherols	264.64	246.55	≈
Alkaloids			
Theobromin	75.71	35.17	**~54 % ↘**
Caffeine	437.96	331.36	**~25 % ↘**
Soaps (ppm sodium oleate)	392	N.D.	**Complete removal**
Colour	*L** **37***a****3.8***b****59.2**	*L** **73***a****-4.83***b****100.5**	**L*↗ Bleaching effect** **b*↗ more yellow**
OSI (hours)	32.43	61.30	**~50 % ↗**

Influence of temperature during packed column steam refining

FFA removal as function of refining temperature: sigmoid decrease

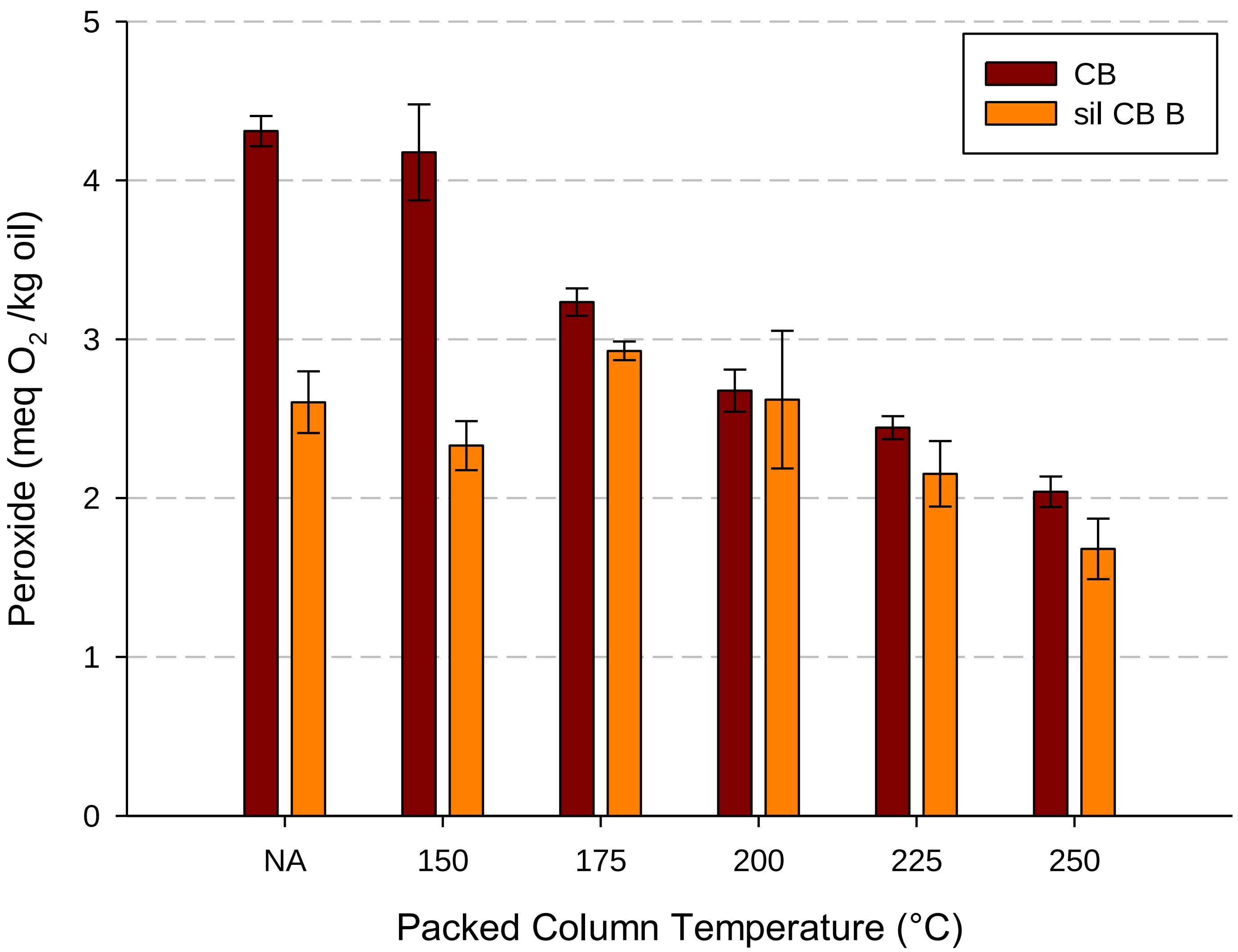


Influence of temperature during packed column steam refining

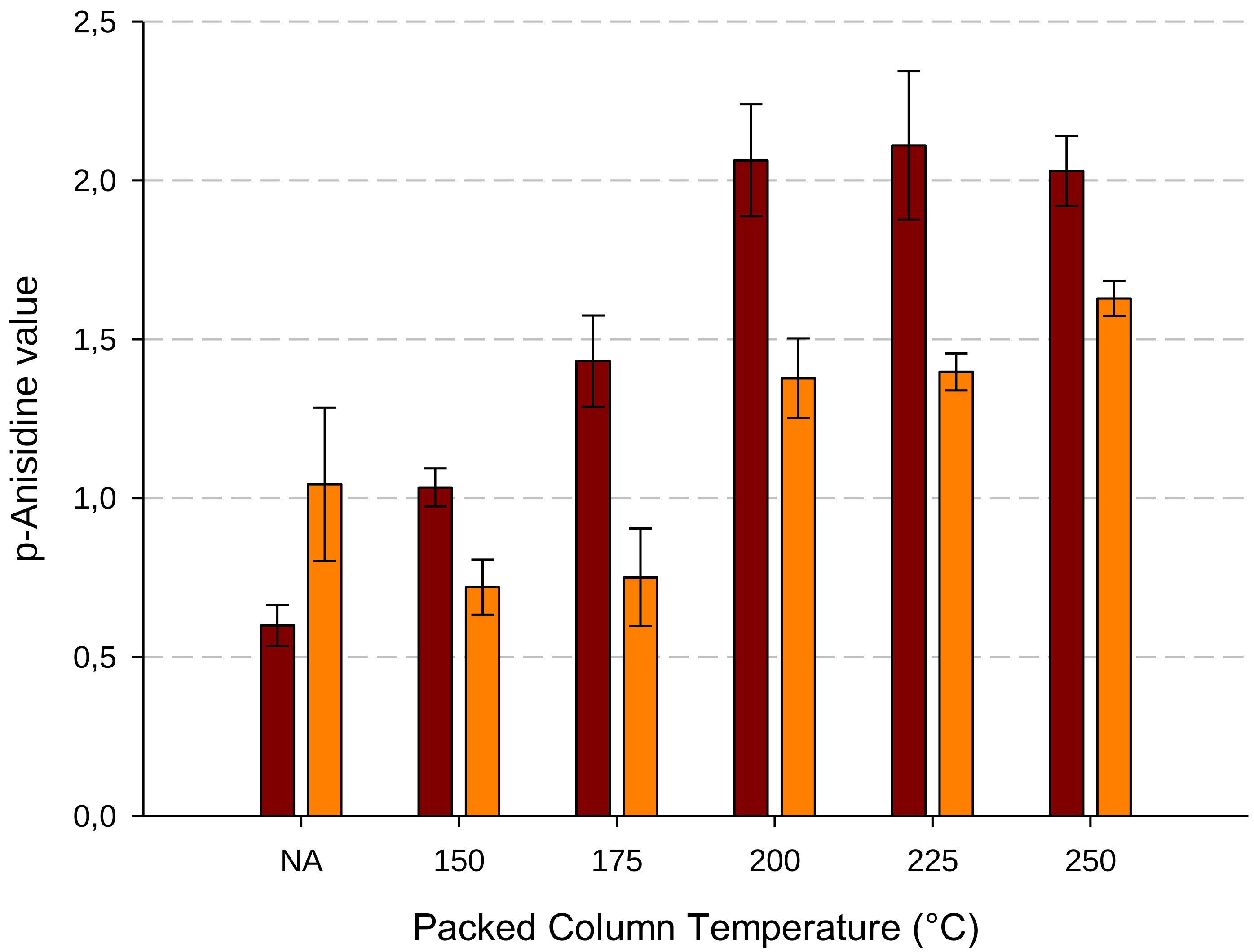
- Temperature during packed column steam refining
  - No influence
    - ✓P and Fe
    - ✓Acylglycerol composition
  - Limited influence
    - ✓T > 175°C: 30% reduction soaps
    - ✓T > 175°C: limited reduction tocopherols
  - Complete removal theobromine and caffeine at T ≥ 200°C
  - Exponential decrease of b* as function of temperature: less yellow

Influence of temperature during packed column steam refining

Oxidative properties: T ↗ primary oxidation products transform to secundary oxidation products



Peroxide



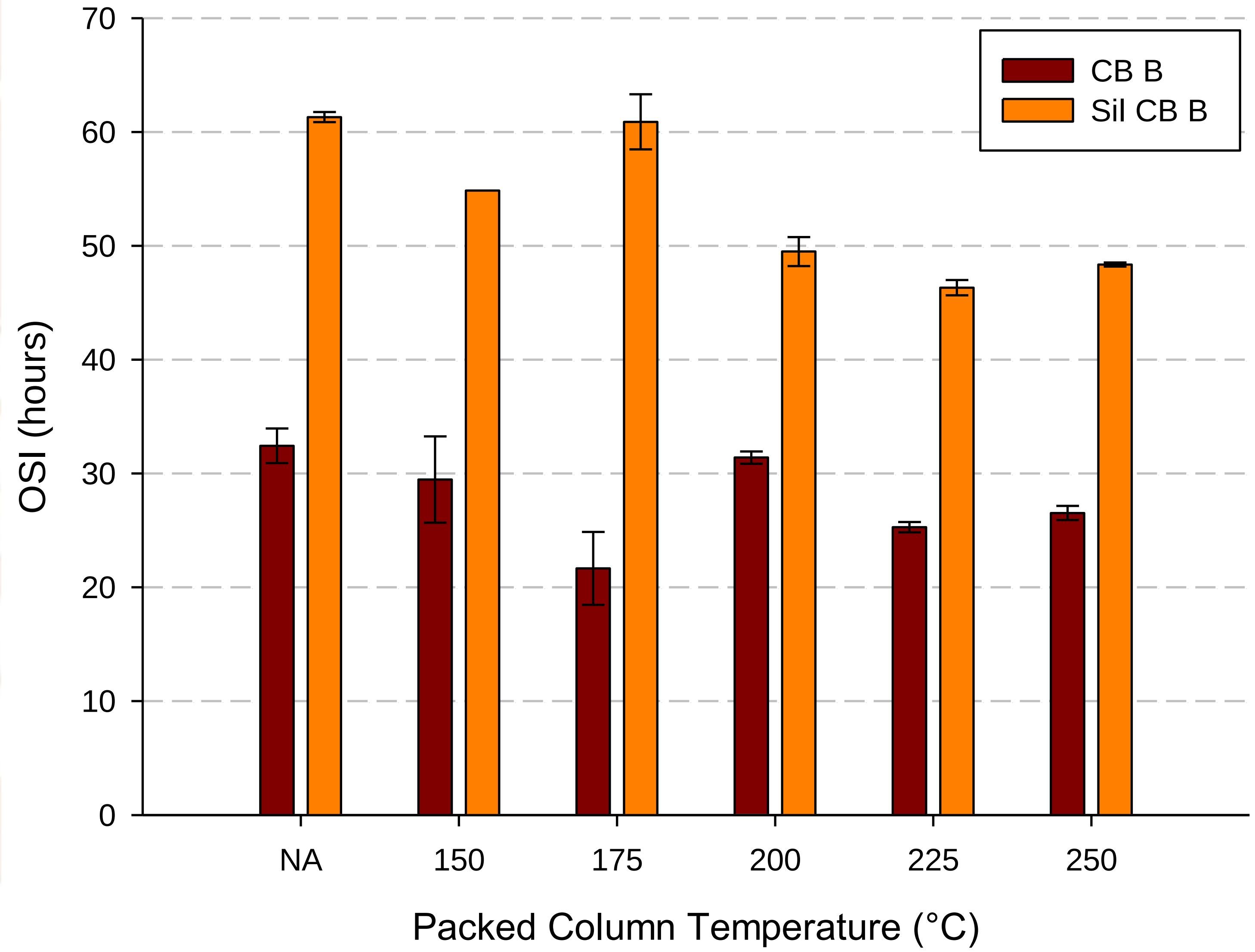
p-Anisidine

Influence of temperature during packed column steam refining

<u>Oil stability index (OSI):</u>

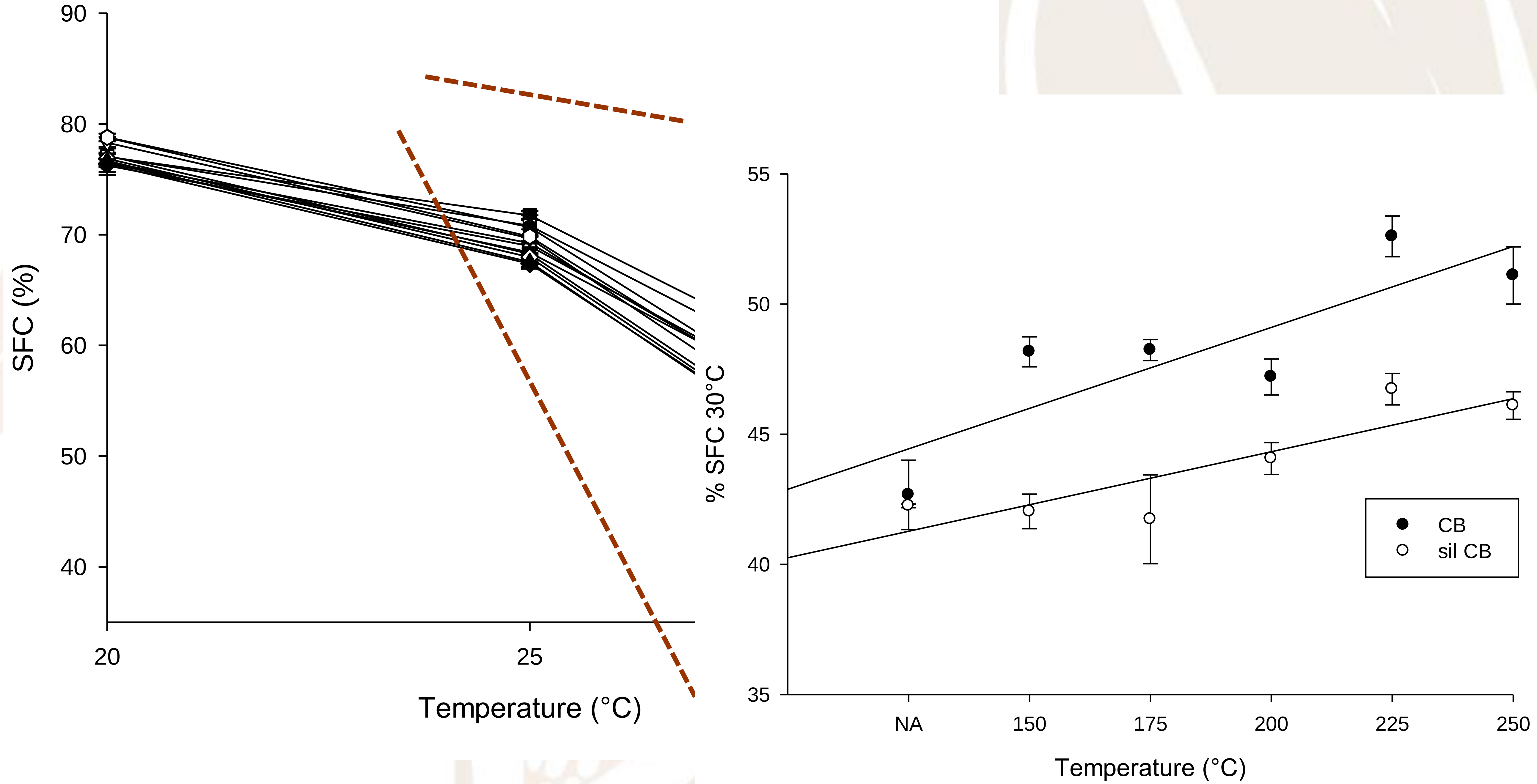
- Limited influence of temperature
- Si-pretreatment: less prone to oxidation

→ Removal of Fe

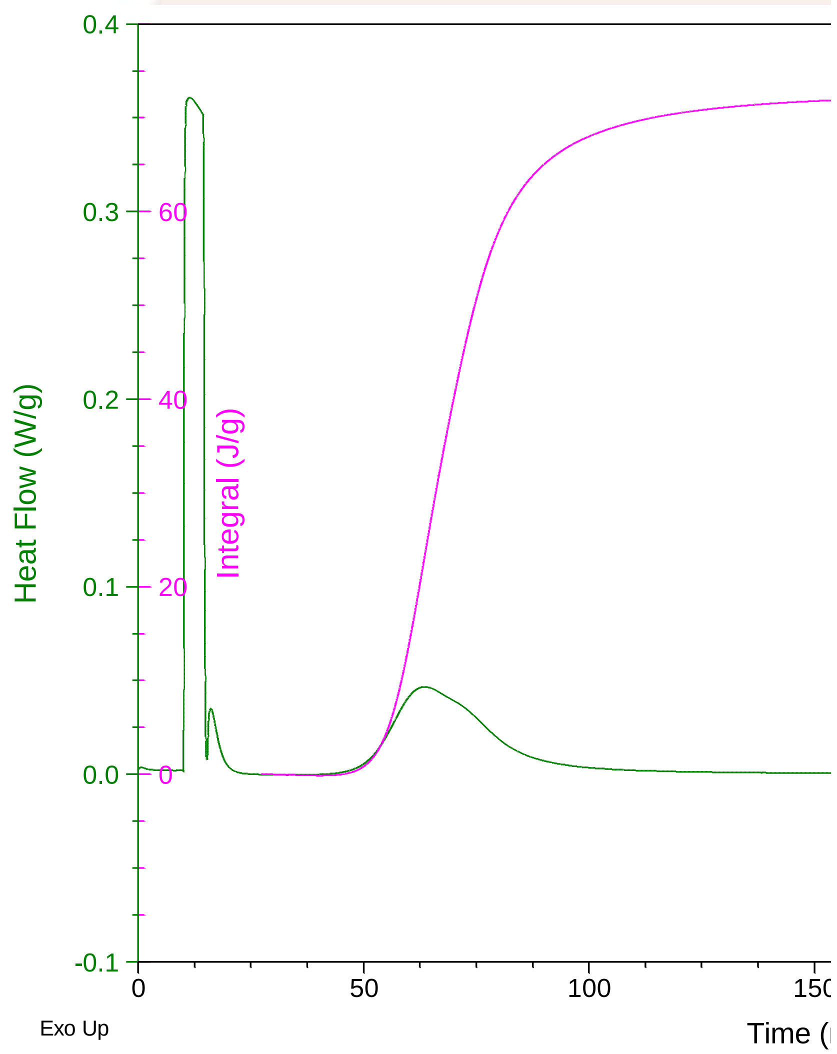


Crystallization properties

SFC content in temperature range 20°C to 30°C (tempered IUPAC procedure: 40 hours at 26°C)



Crystallization properties



- Isothermal crystallization at 20°C for 240 min
- Start wih formation of α, followed by transition to the β'-polymorph
- Kinetics of the β' crystallization: Foubert Model parameters
  - t_ind: time needed to achieve 1% crystallization: decrease as function of column temperature
  - K: rate constant: increase as function of column temperature
  - a: no clear effect

→ sooner and faster crystallization as T increases, so as function of FFA removal

Influence of refining on CB properties

- Read more
  - Ayala et al. 2007, JAOCS, 84, 1069-1077
  - Calliauw et al. 2008, Journal of Food Engineering, 89, 274-284
  - De Clercq et al., 2012, Journal of Food Engineering, 111, 412-419

Case study:
Influence of DAG on the crystallization of CB

(crude) cocoa butter

↓

MODIFICATION

↓

chocolate

CB Diacylglycerols

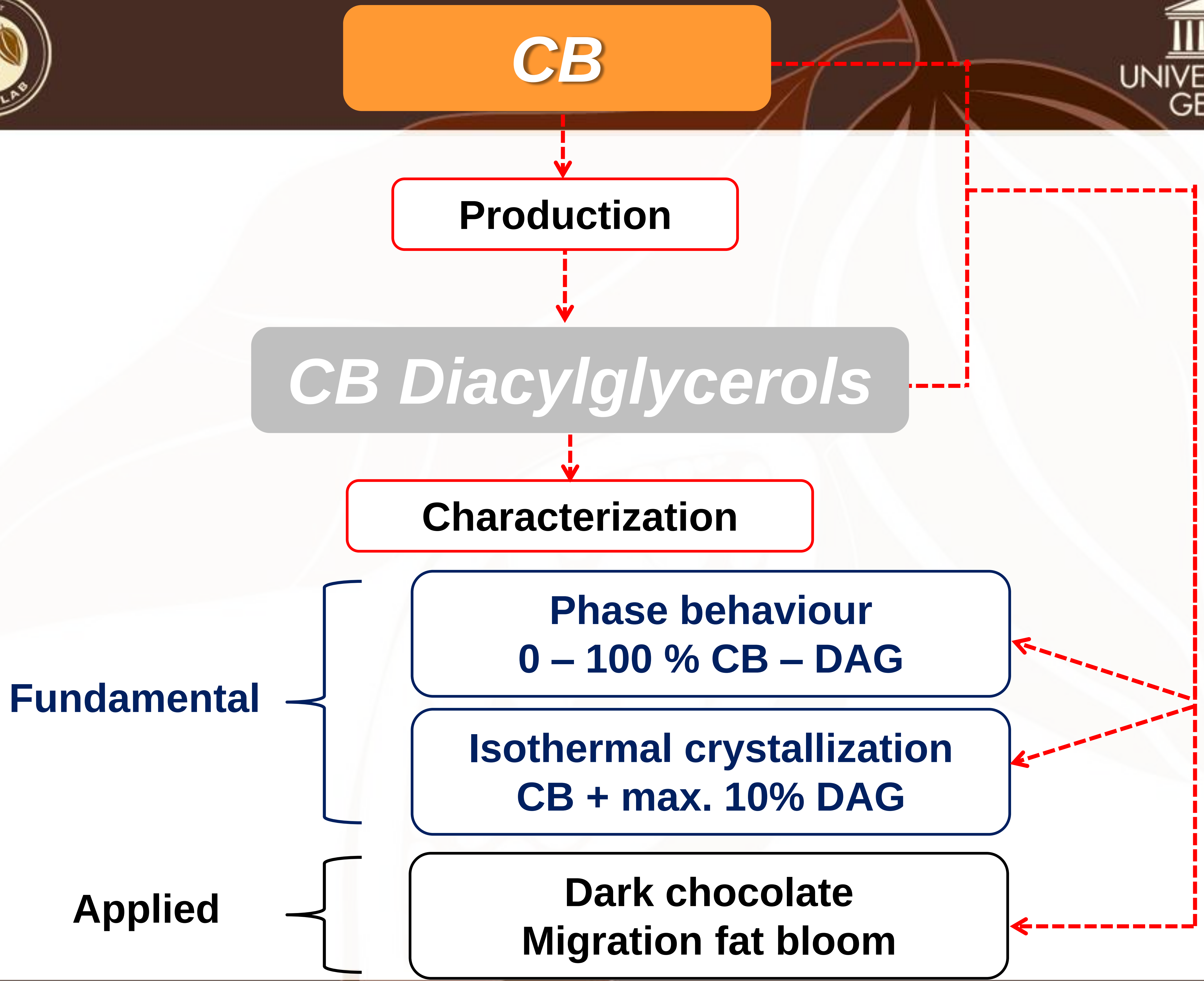
- **Innovation**

  = Creation of new products, high added value

  - Nutritionally, taste, appearance, functionality
  - BUT with same quality level as the standard product

→ Modification of cocoa butter

- Cocoa butter based diacylglycerols
- DAG
  - Distinct physicochemical properties compared to TAG
  - More hydrophillic and water soluble
  - Nutritional benefits (mainly 1,3-DAG)
    - Different metabolic pathyway
    - Lower body weight gain and body fat accumulation


CB
Production
CB Diacylglycerols
Characterization
Fundamental
Phase behaviour
0 – 100 % CB – DAG
Isothermal crystallization
CB + max. 10% DAG
Applied
Dark chocolate
Migration fat bloom

CB

Production

CB Diacylglycerols

Characterization

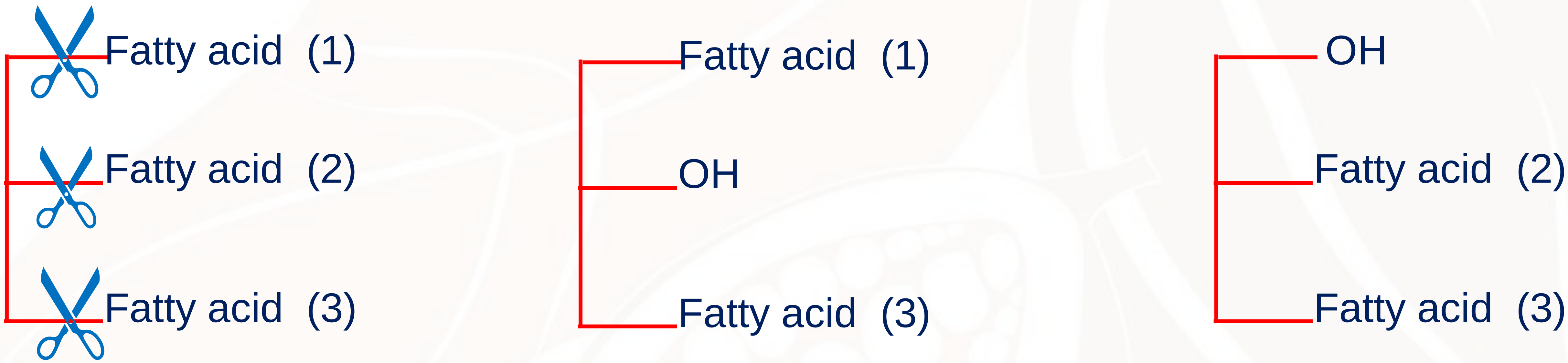
Phase behaviour
0 – 100 % CB – DAG

Isothermal crystallization
CB + max. 10% DAG

Dark chocolate
Migration fat bloom

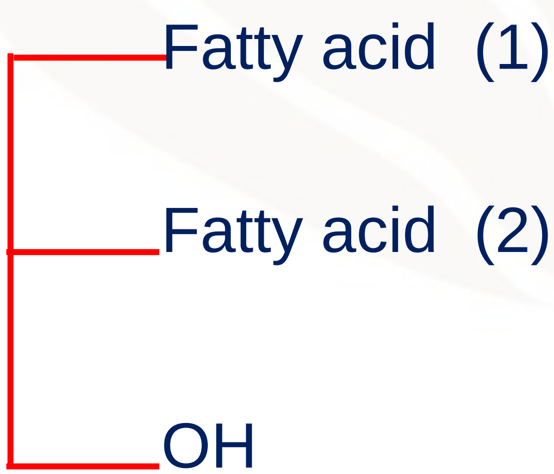
DAG production

- Diacylglycerol= DAG= 2 fatty acids + glycerol



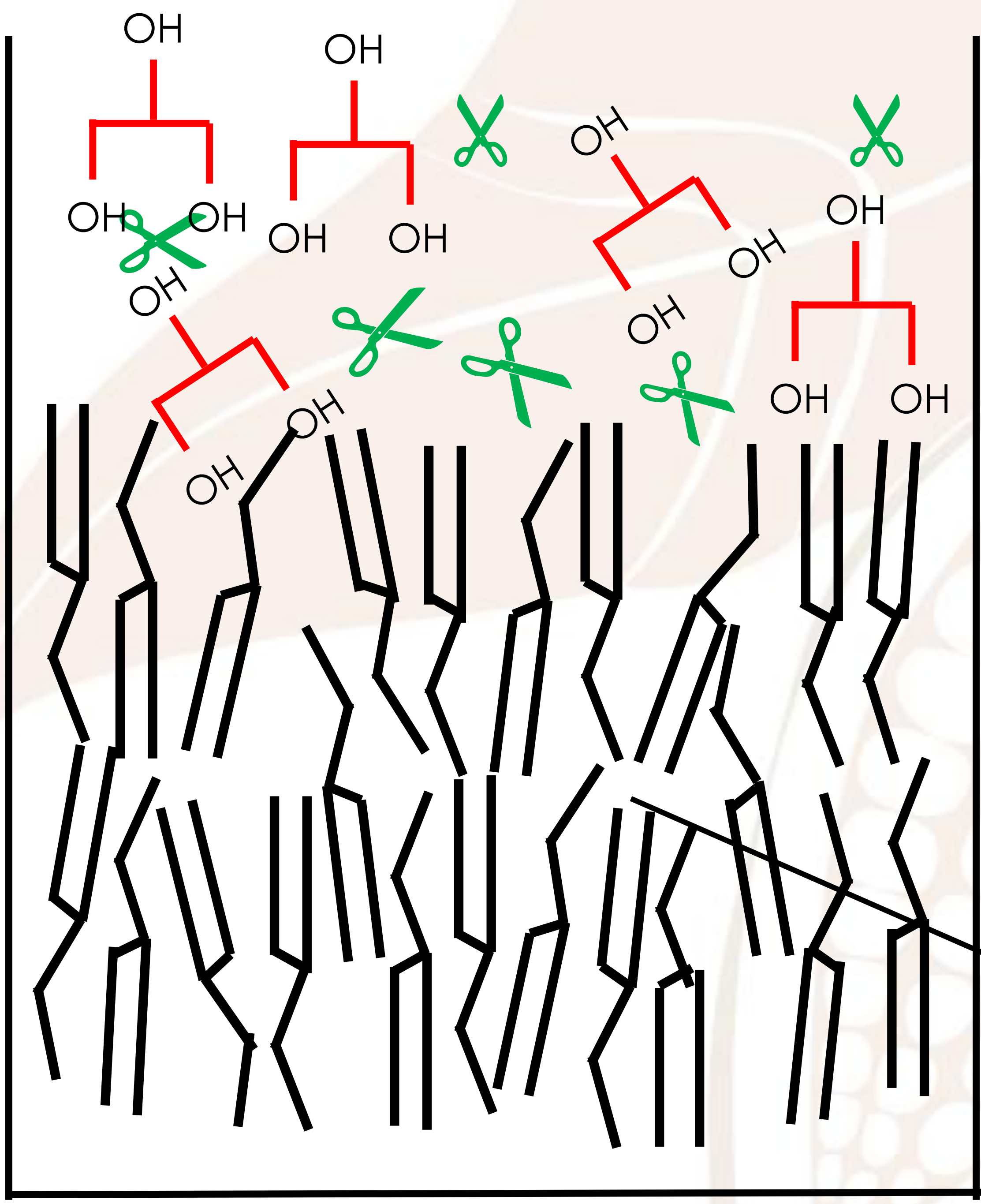
- 1,3-DAG
- 2,3-DAG

  = 1,2-DAG



DAG production

enzymatic glycerolysis

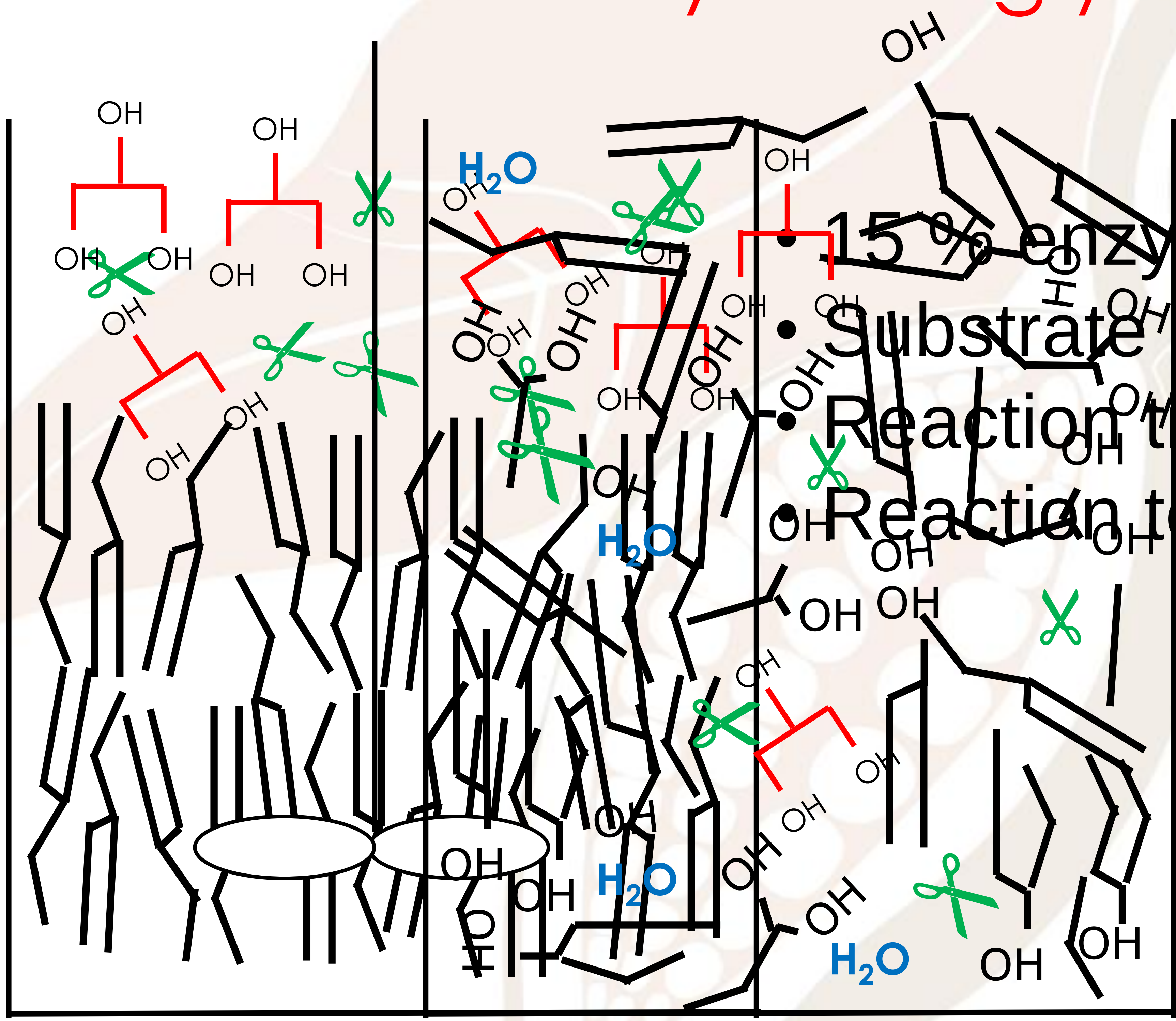


- 15 % enzyme
- Substrate molar ratio: 1.12
- Reaction temperature: 70°C
- Reaction time: 6 hours

Cocoa butter TAG

DAG production

enzymatic glycerolysis



- 15 % enzyme
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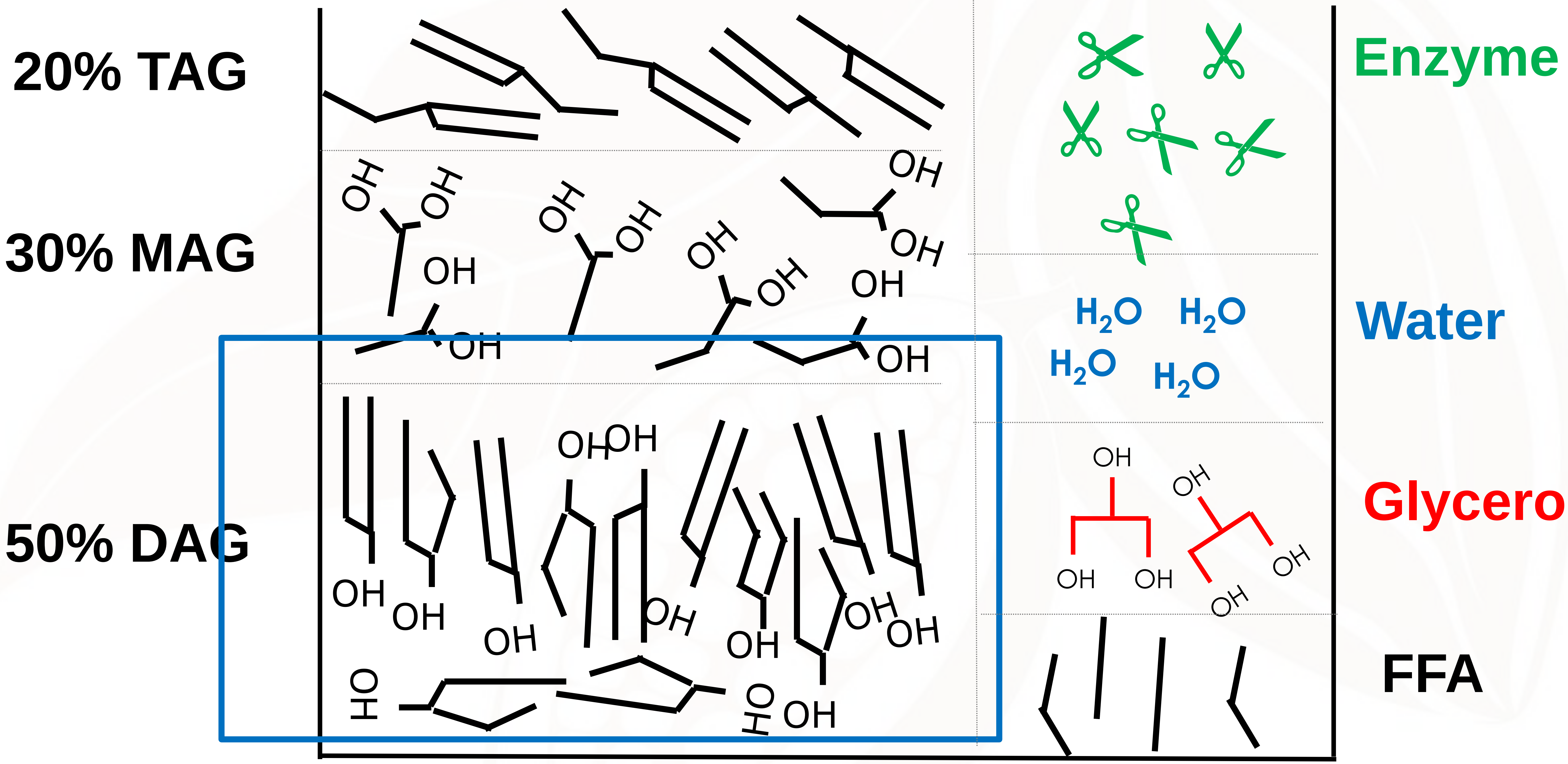
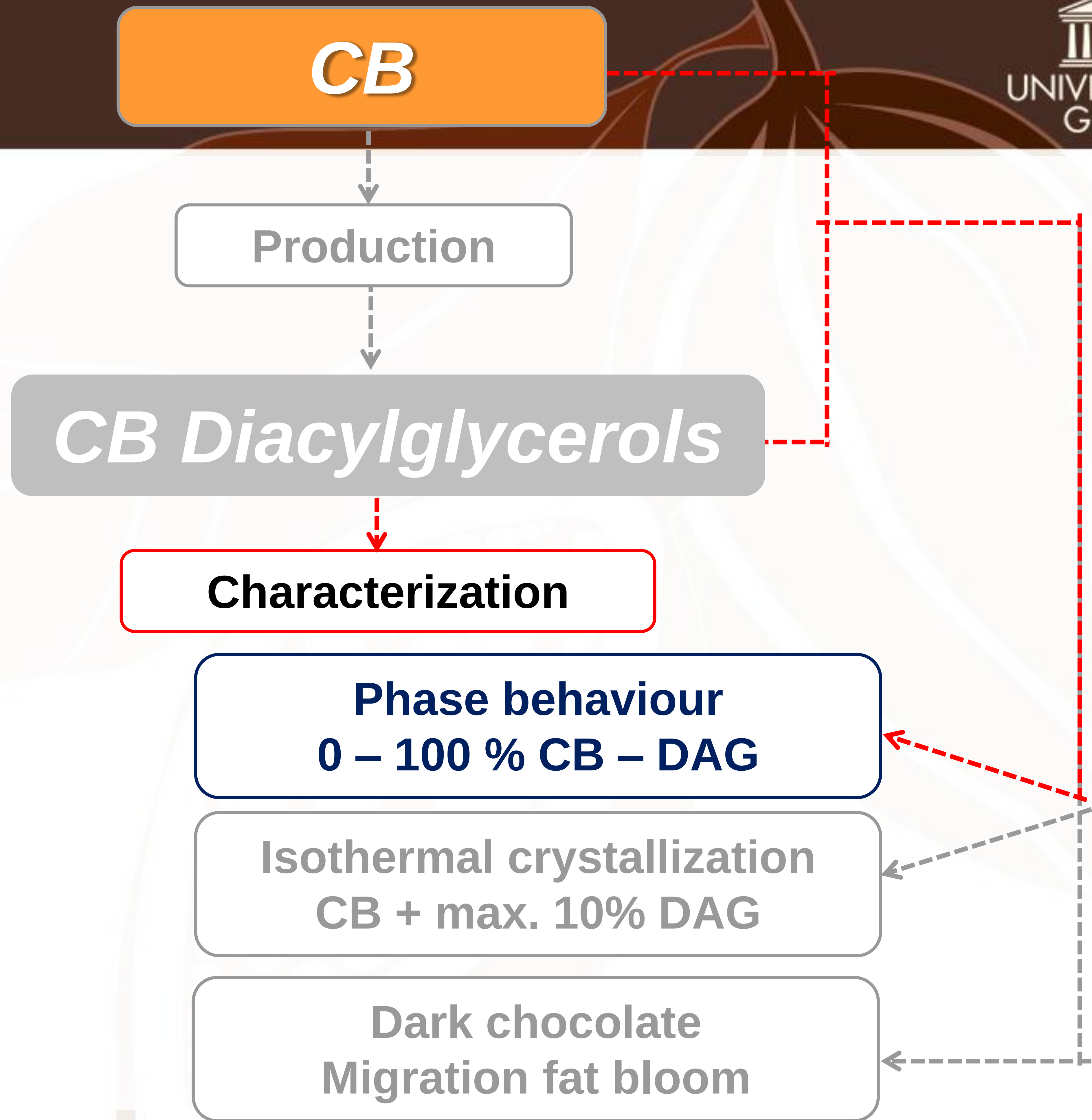
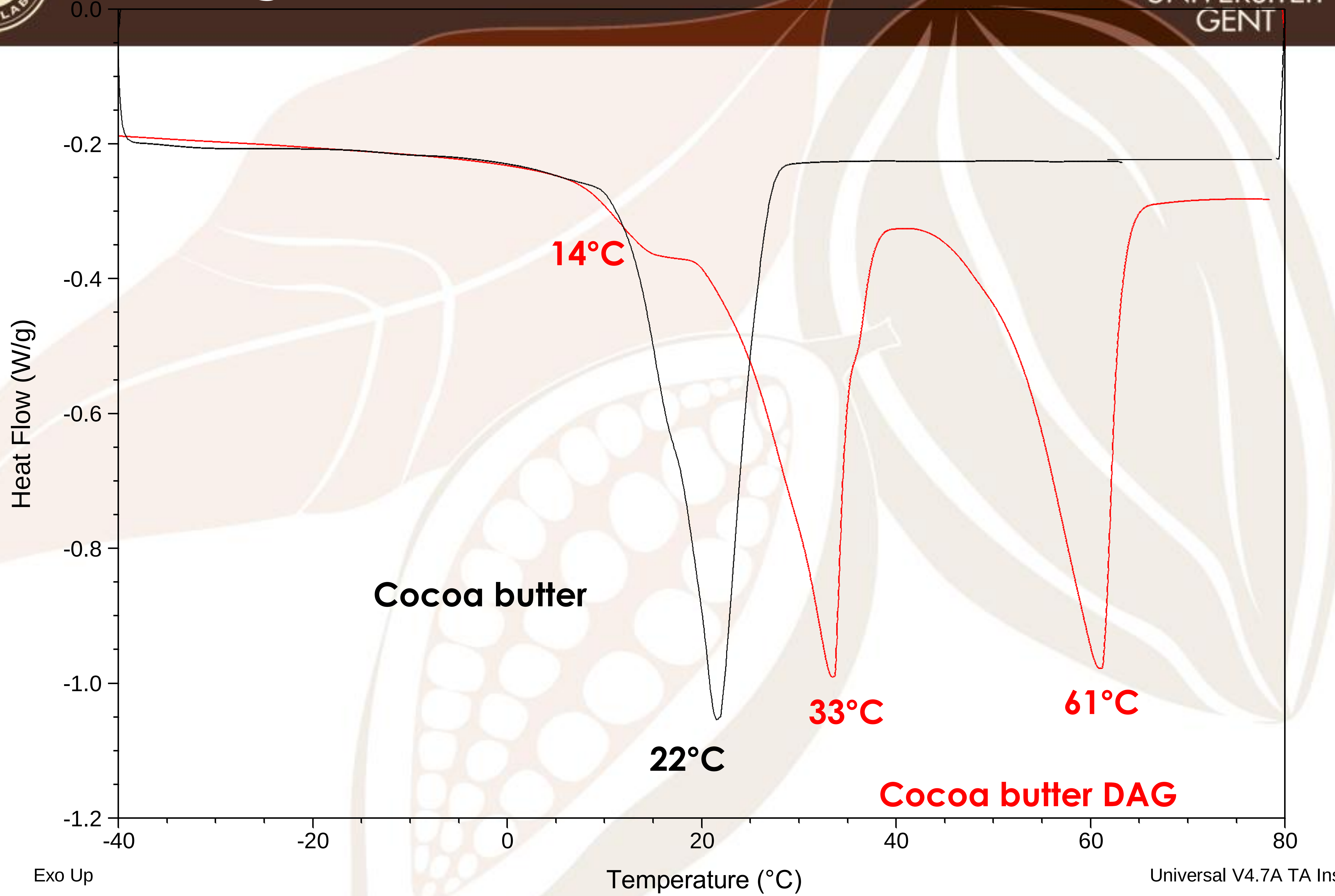


Short path distillation:

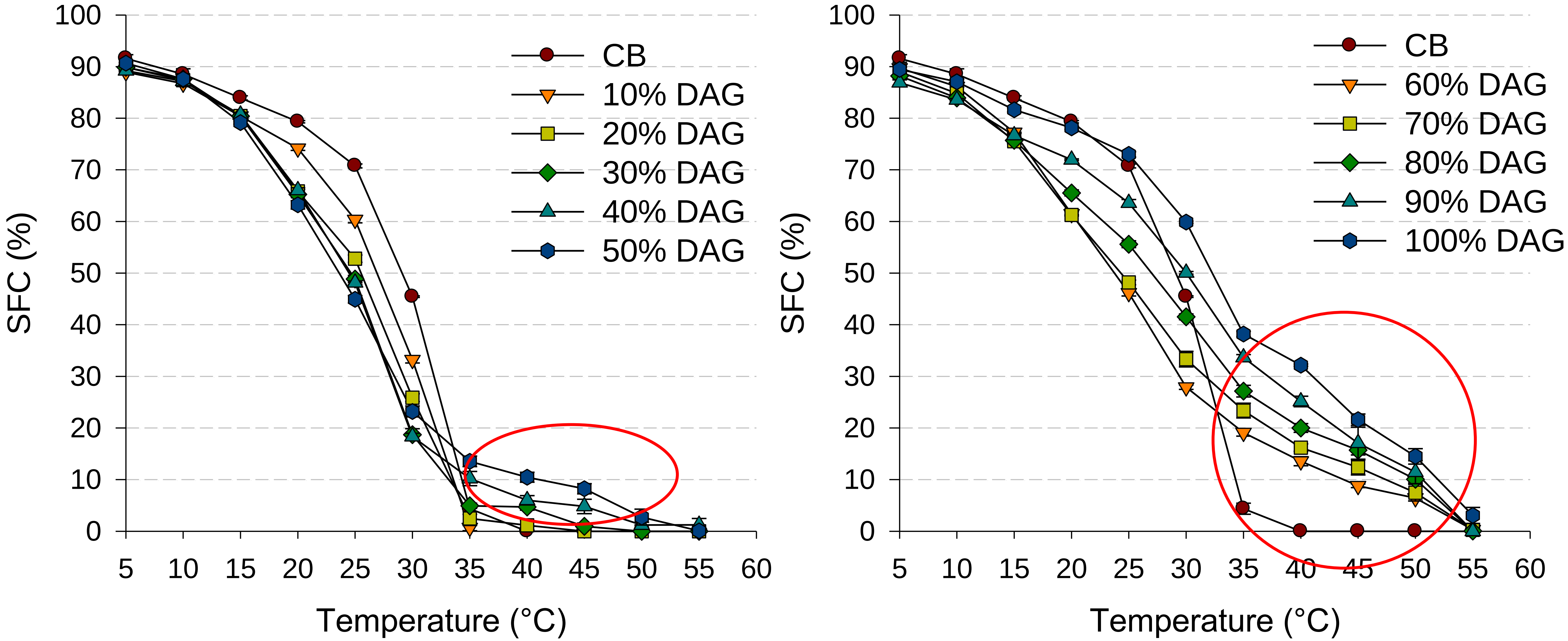
4 steps, combination temperature and reduced pressure

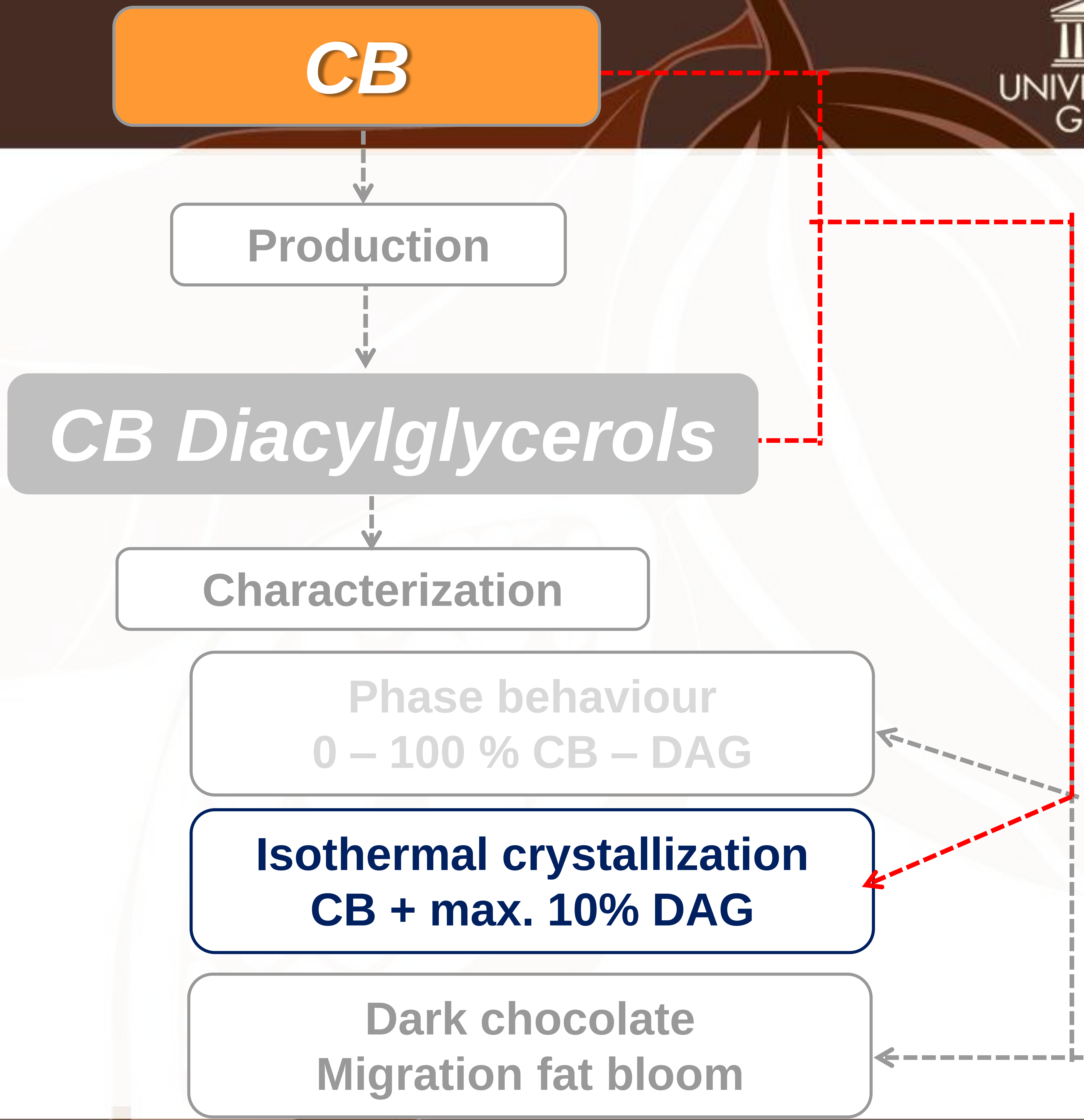

CB
Production
CB Diacylglycerols
Characterization
Phase behaviour
0 – 100 % CB – DAG
Isothermal crystallization
CB + max. 10% DAG
Dark chocolate
Migration fat bloom

Melting behaviour of CB vs CB DAG



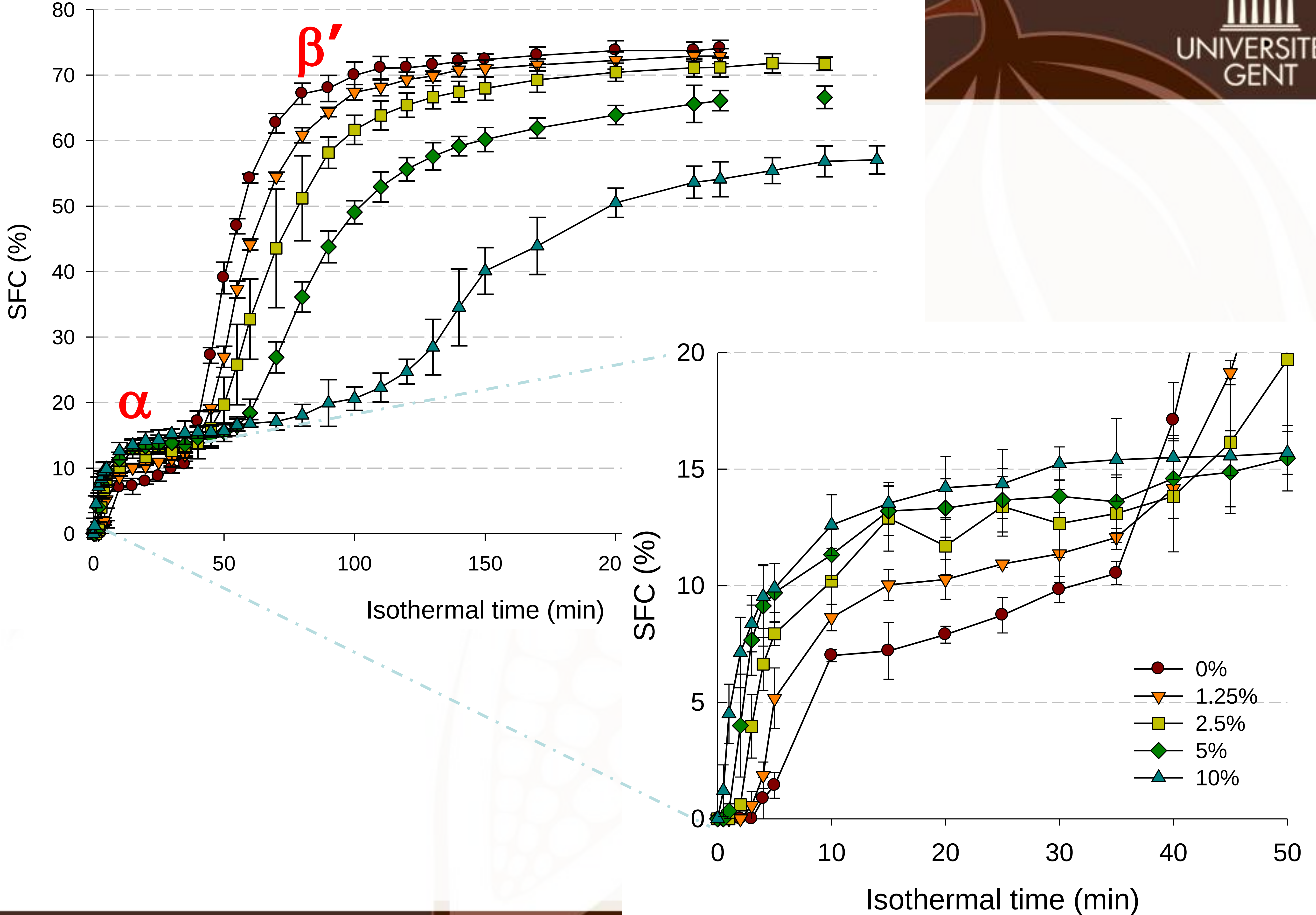
Cocoa butter /diacylglycerol: 100/0; 90/10 … 10/90; 0/100




CB
Production
CB Diacylglycerols
Characterization
Phase behaviour
0 – 100 % CB – DAG
Isothermal crystallization
CB + max. 10% DAG
Dark chocolate
Migration fat bloom

Cocoa butter + maximum 10% DAG

- Isothermal crystallization behaviour
  - Heating to melt all the crystals
  - Cooling at 10°C/min
  - Isothermal at 20°C for a defined time
- Different experimental techniques
- At 20°C: two step crystallization process: α to β'



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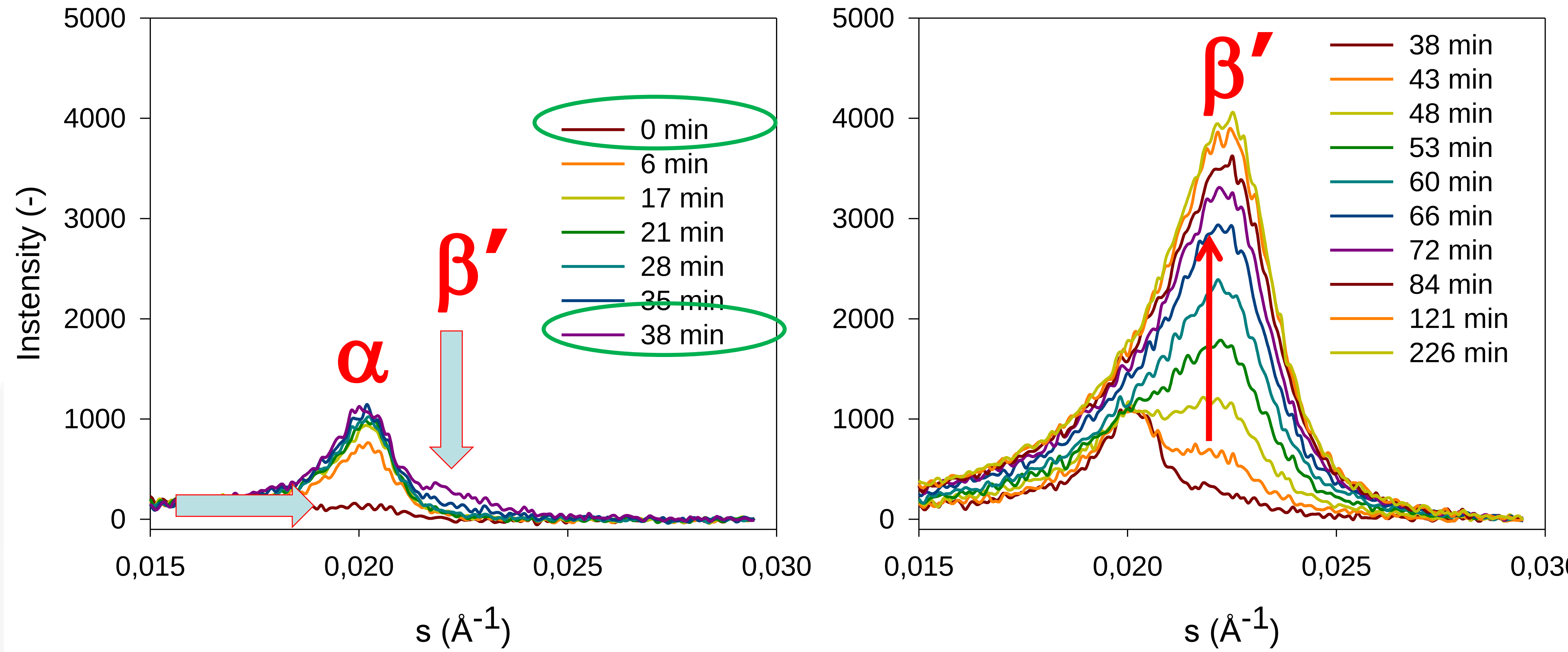
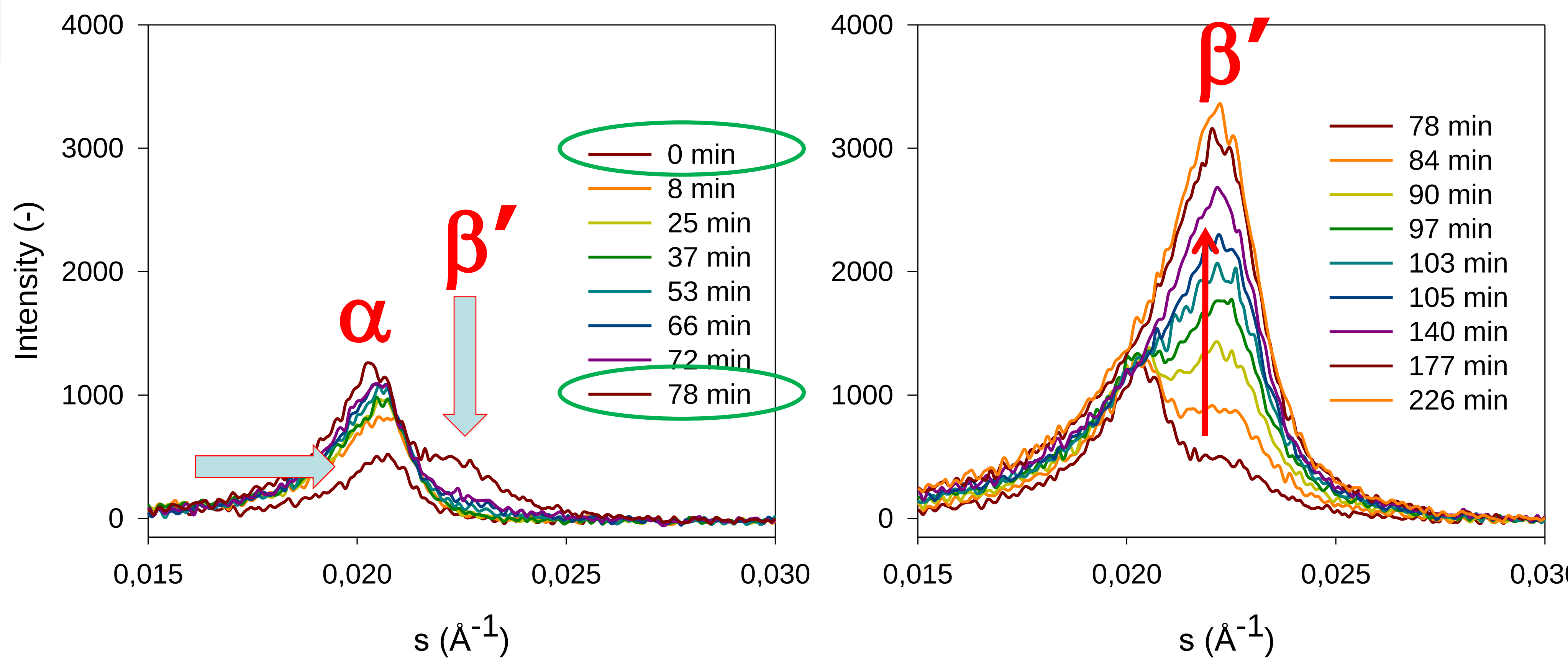
VLIR UOS

SAXS diffraction patterns

Cocoa butter

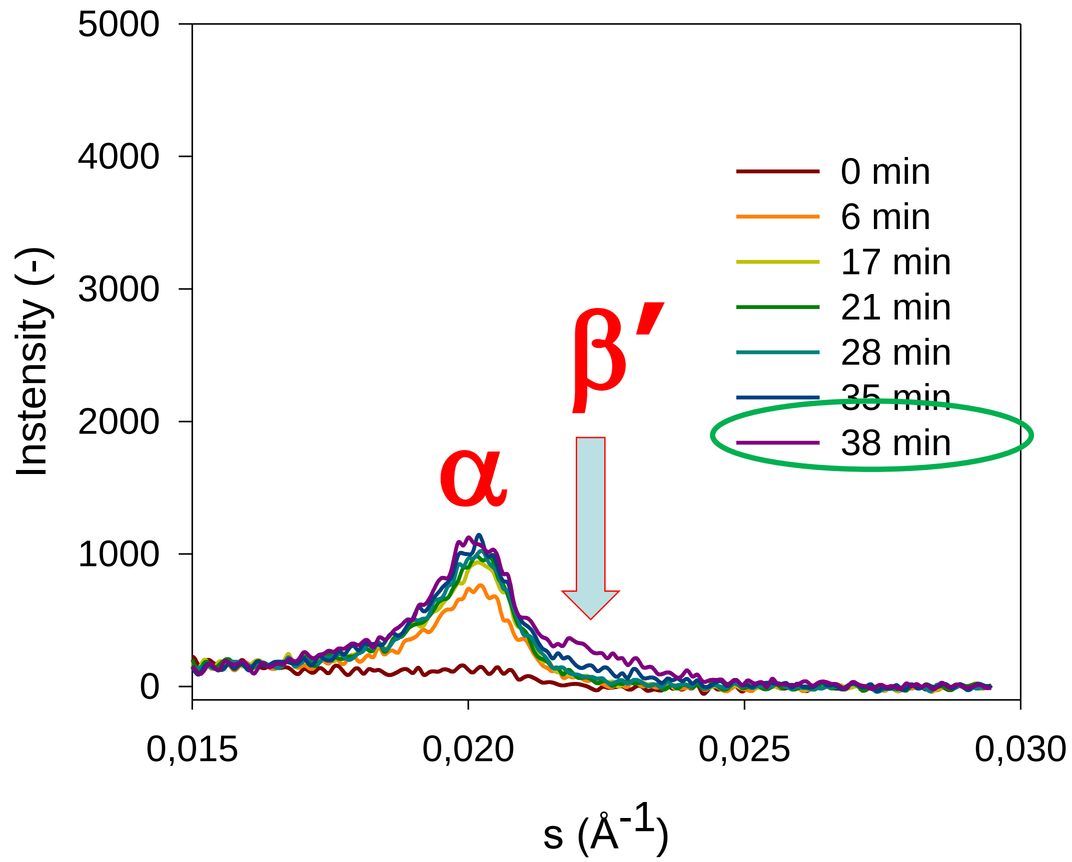


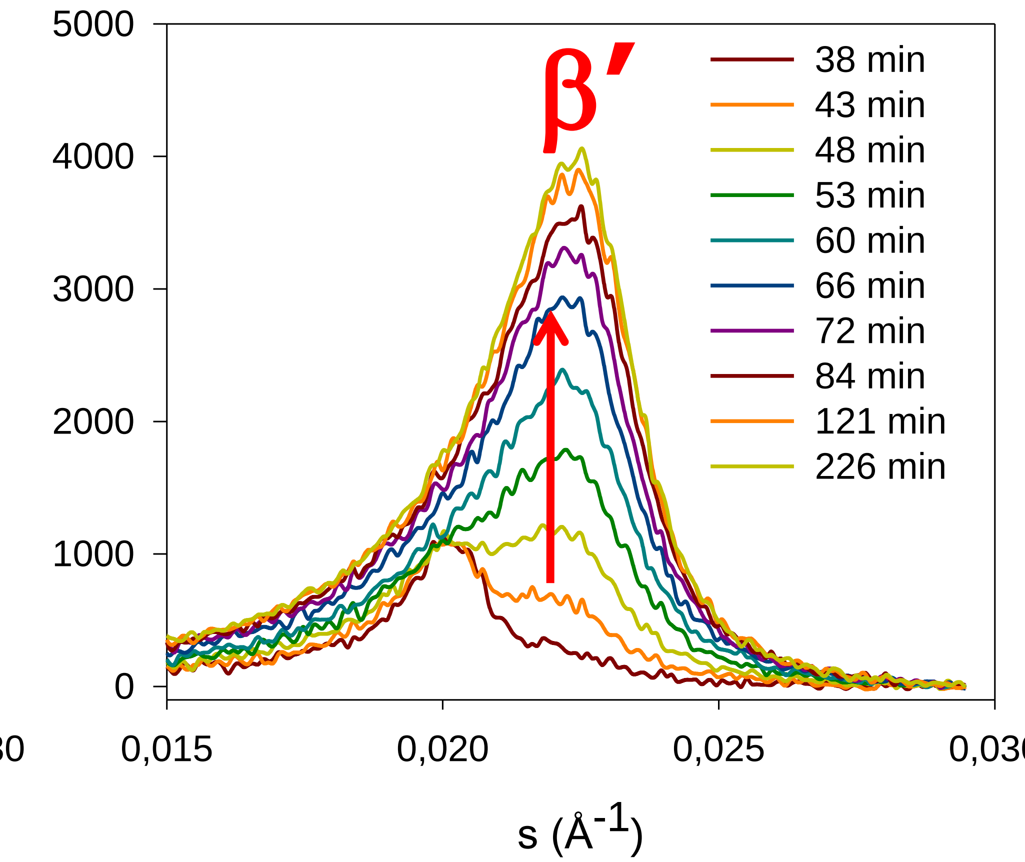
2.5% DAG



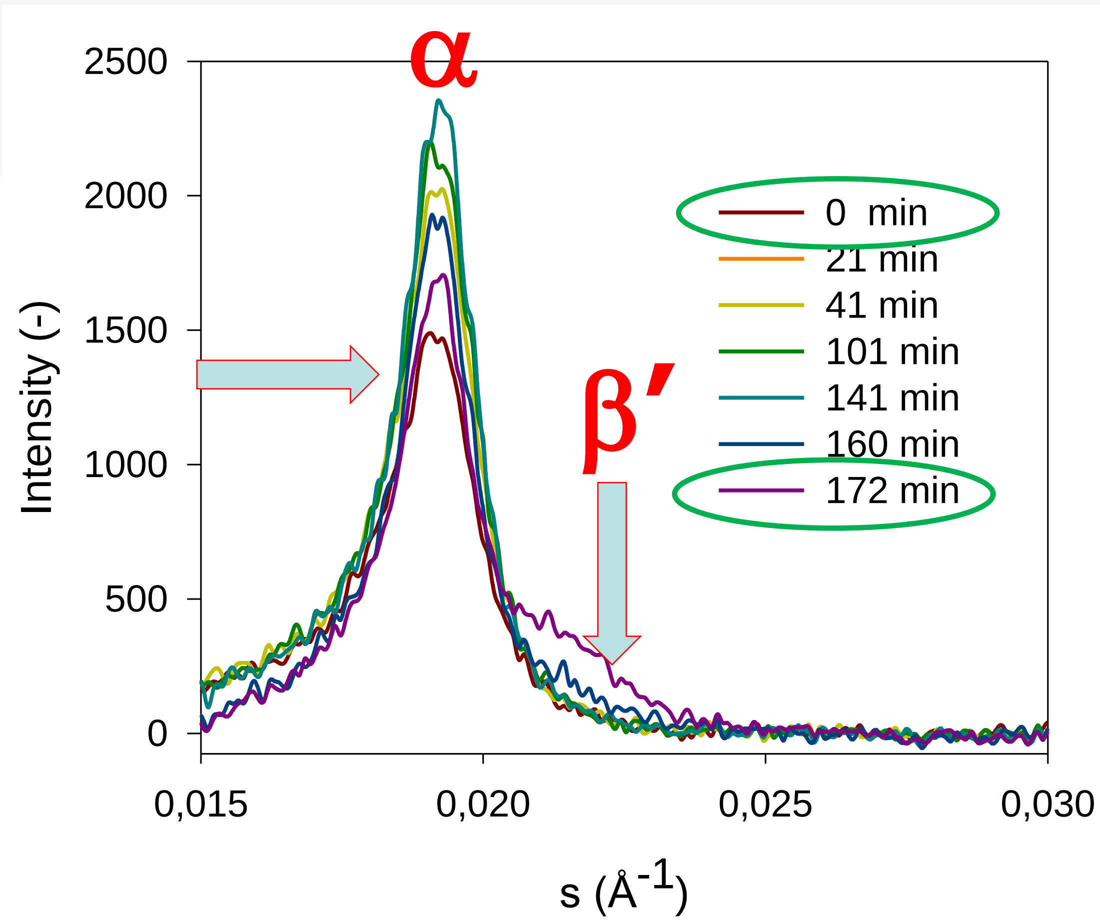
SAXS diffraction patterns

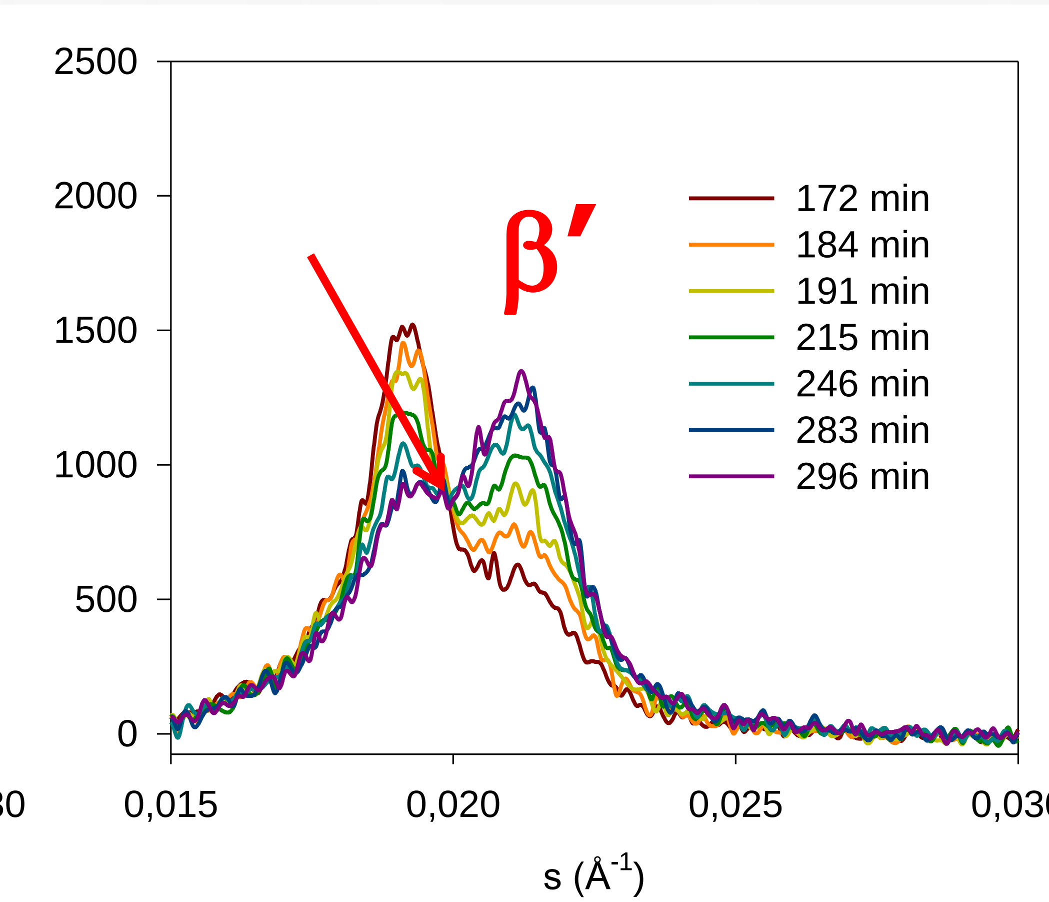
Cocoa butter





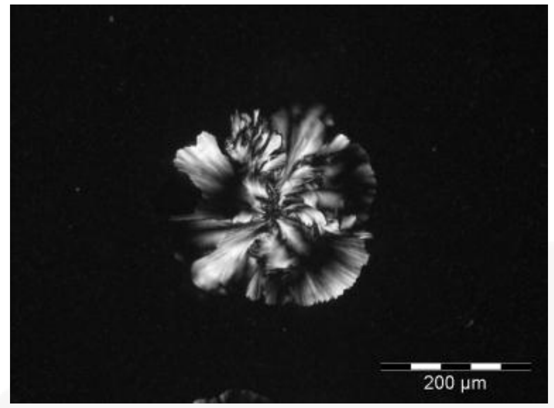
10% DAG

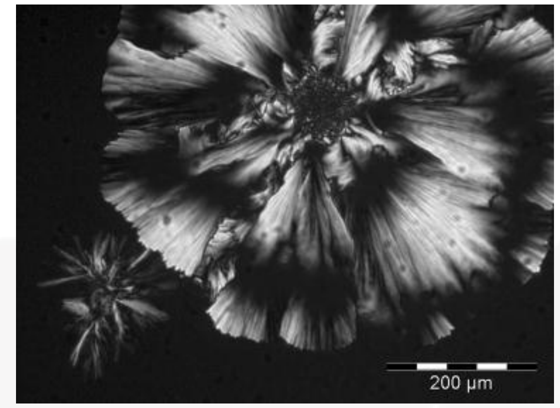




WEEK 1 | WEEK 3

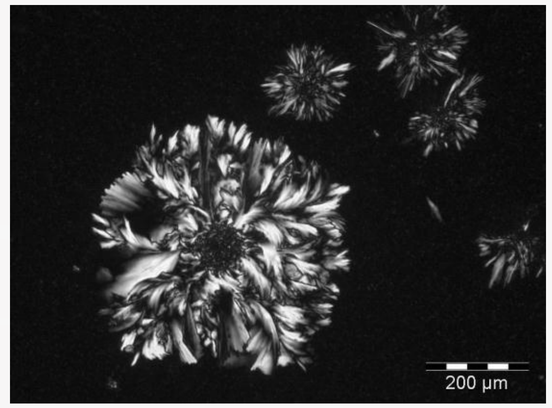
Cocoa butter

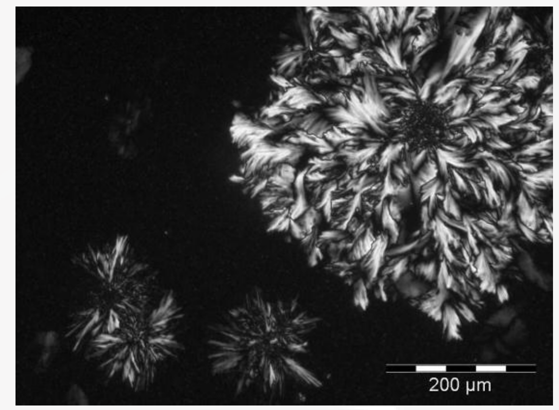




Cocoa butter

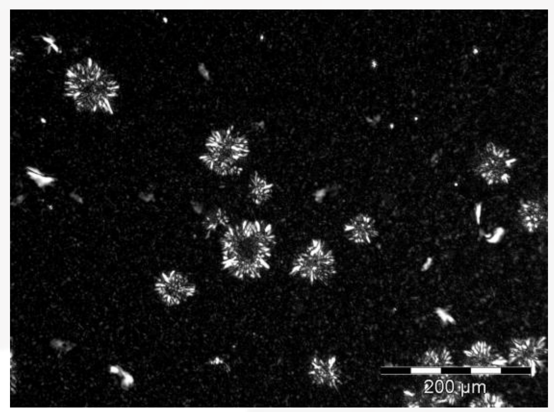
1.25% DAG

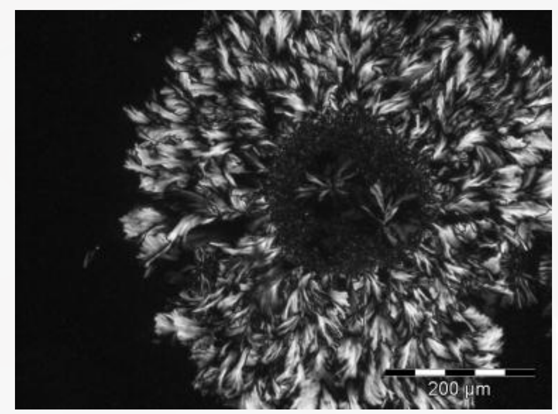




1.25% DAG

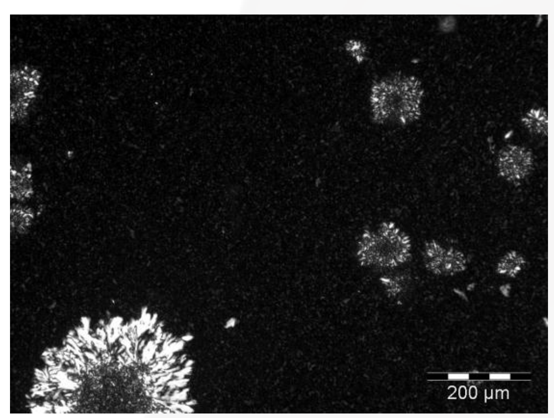
2.5% DAG

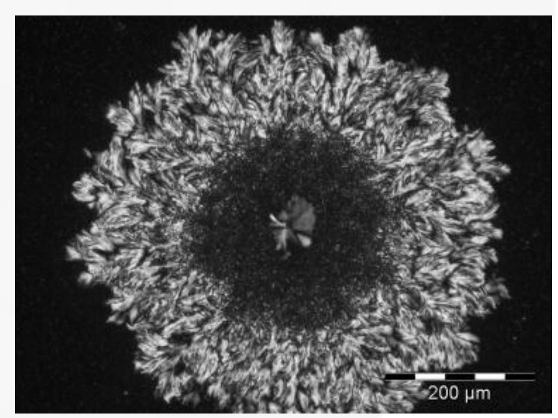




2.5% DAG

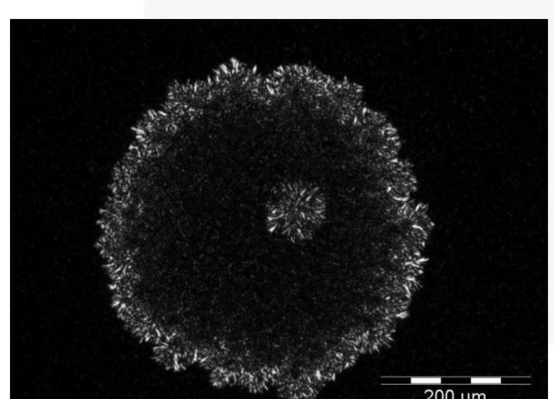
5% DAG

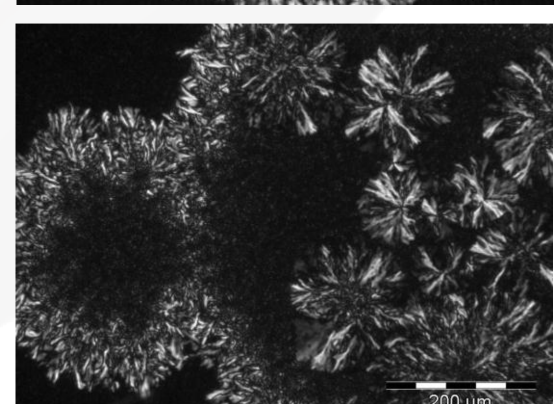




5% DAG

10% DAG





10% DAG

Conclusion

- Crystallization mechanism is changed !
- Microstructure ≠ → Macrostructure ≠

Crystallization of fat and oils

Dr. ir. Nathalie De Clercq

9th of September