Thermomechanical method for the determination of the fractal dimension in fat crystal networks

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Factors affecting the texture of fats and fat-structured foods

1. Solid fat content

2. Primary crystal habit (polymorphism)

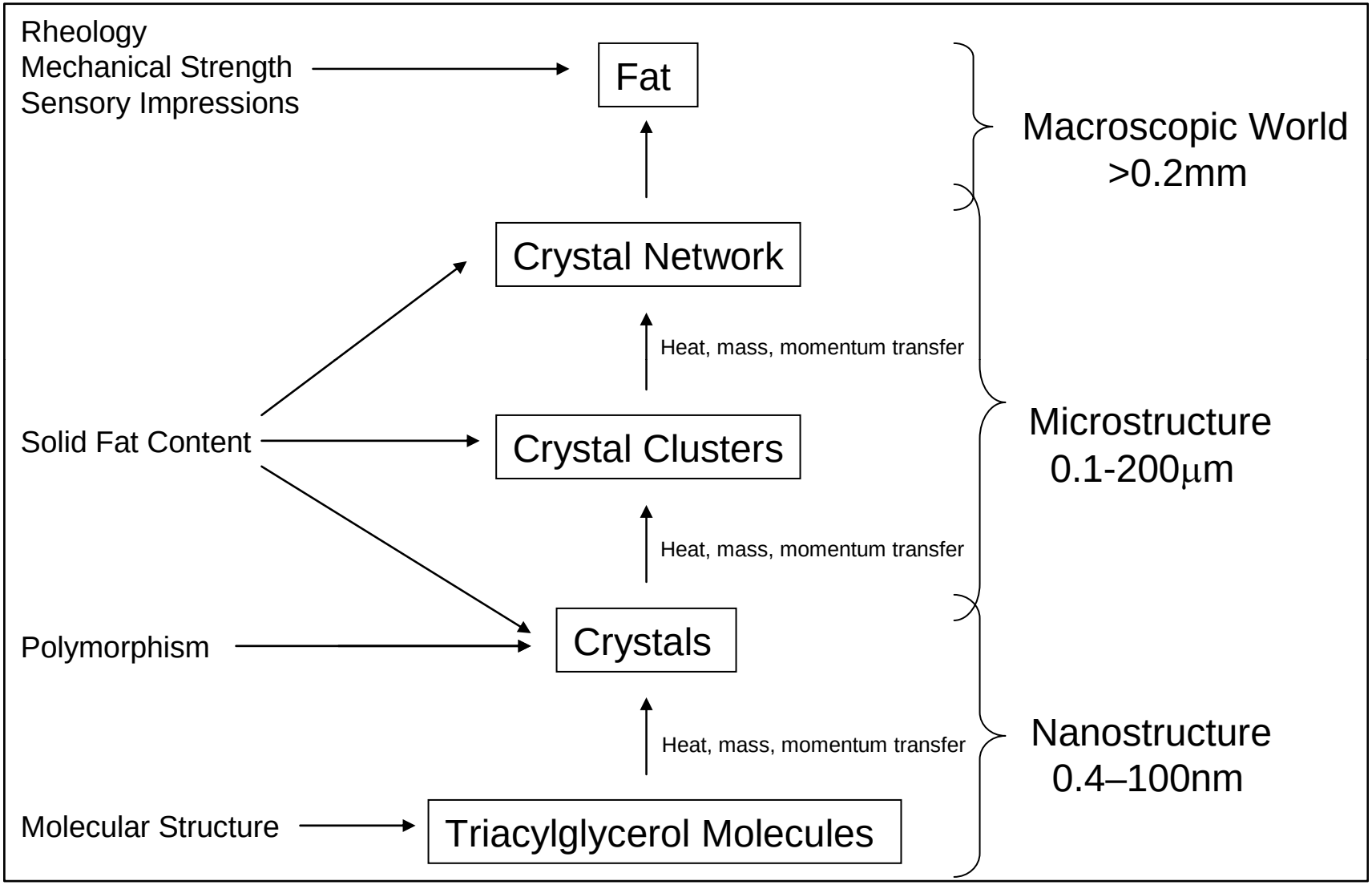
3. Nano and Microstructure
    a. crystallite morphology and size
    b. spatial distribution of network mass

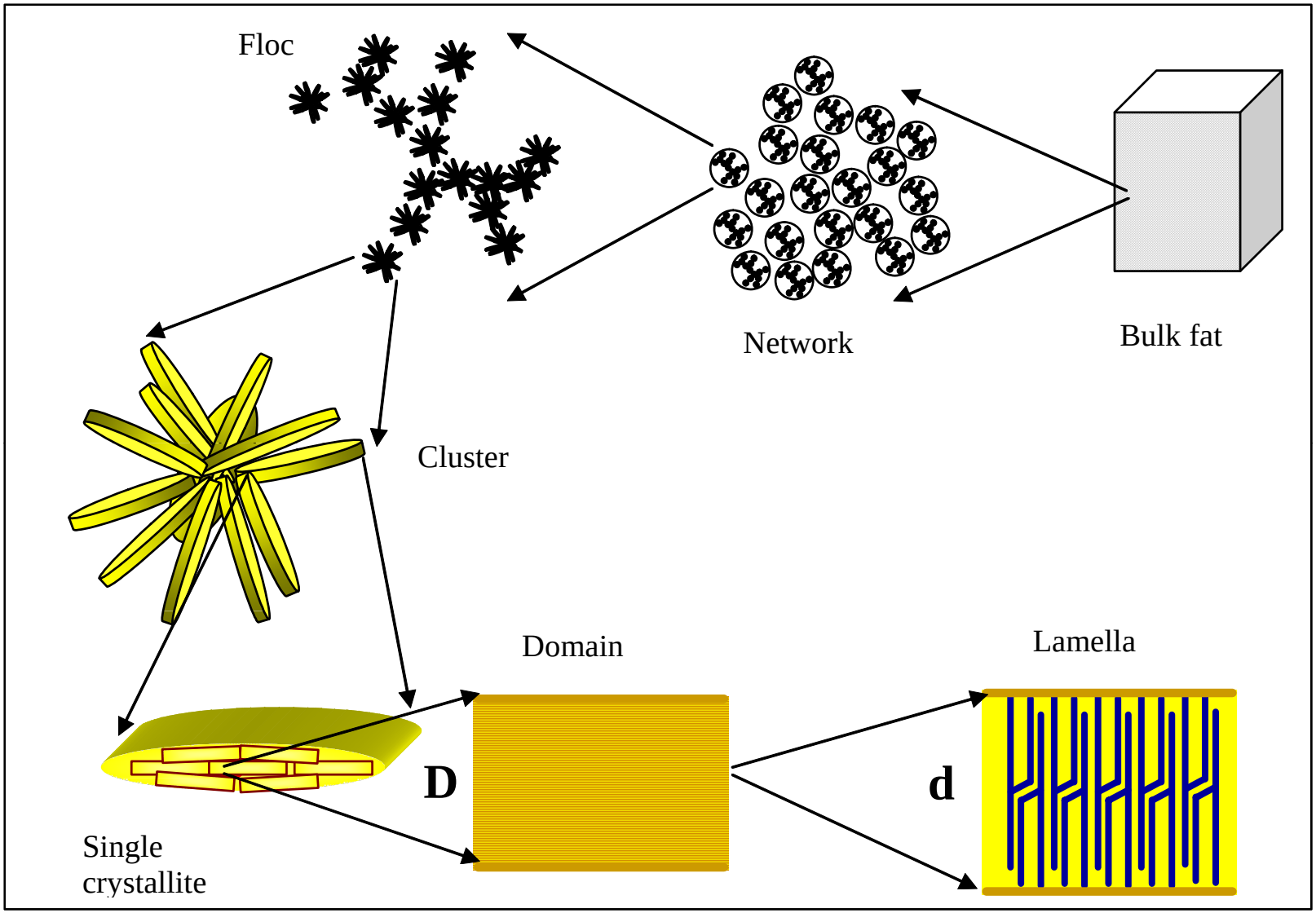
4. Inter-crystal interactions

What controls hardness?

Temperature (ºC)	G´ (Pa)	SFC (%)	F_y (N)	K (N/mm)
5	2.19E+07[a]	90.5[a]	602[a]	231[a]
15	2.64E+07[b]	90.5[a]	593[a]	223[a]
20	1.63E+07[c]	80.5[b]	312[b]	90[b]
24	4.08E+07[d]	60.0[c]	344[b]	96[b]

Means with a common superscript within a column are not significantly different (P>0.05).


Rheology
Mechanical Strength
Sensory Impressions
Fat
Crystal Network
Heat, mass, momentum transfer
Solid Fat Content
Crystal Clusters
Heat, mass, momentum transfer
Polymorphism
Crystals
Heat, mass, momentum transfer
Molecular Structure
Triacylglycerol Molecules
Macroscopic World
>0.2mm
Microstructure
0.1-200μm
Nanostructure
0.4–100nm



Mazzanti, 2004

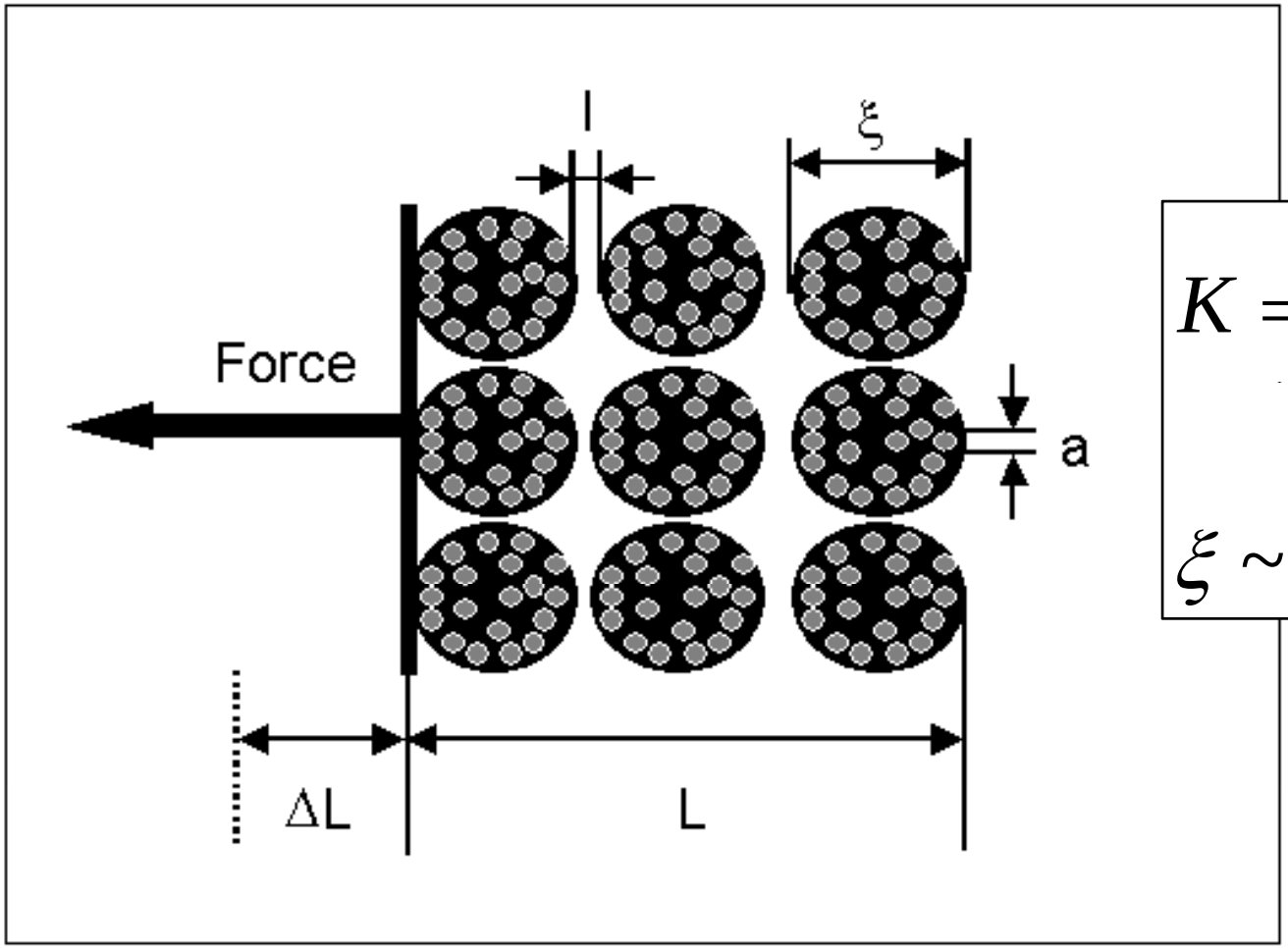
Modeling the microstructure and its relationship to the mechanical response of a fat

The Model

$$G = \frac{2\delta}{a\gamma^*}\Phi^{\frac{1}{3-D}} = \frac{A}{6\pi a\gamma^* d_o^2}\Phi^{\frac{1}{d-D}}$$

The Fractal Dimension

Structure-mechanical model

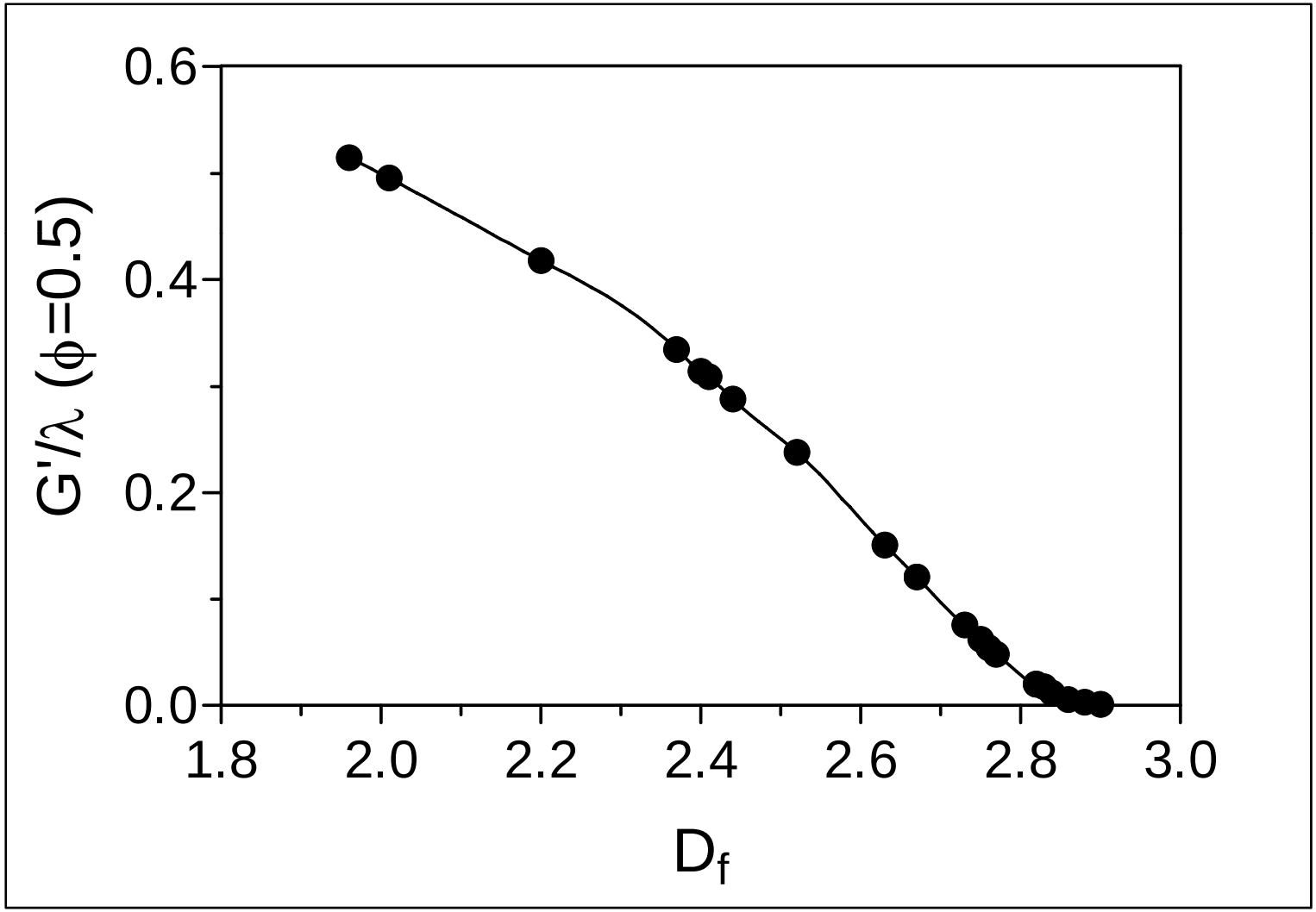


$$K = N_{\xi} k_L = \frac{L}{\xi} k_L$$

$$\xi \sim \Phi^{\frac{1}{D-3}}$$

→ Fractal dimension defines size of cluster

Effect of D on the Elastic Modulus



Determination of the Fractal Dimension by Rheological Means

Weak-link Theory - Fat Crystal Networks

Developed for colloidal gels and adapted to fat crystal networks by our group:

$$G' \sim \Phi^{\mu} \sim \lambda \Phi^{1/(3-D)}$$

G' = dynamic shear elastic modulus (storage modulus)

λ = constant which depends on particle properties and particle-particle interactions

Φ = solids' volume fraction of fat sample

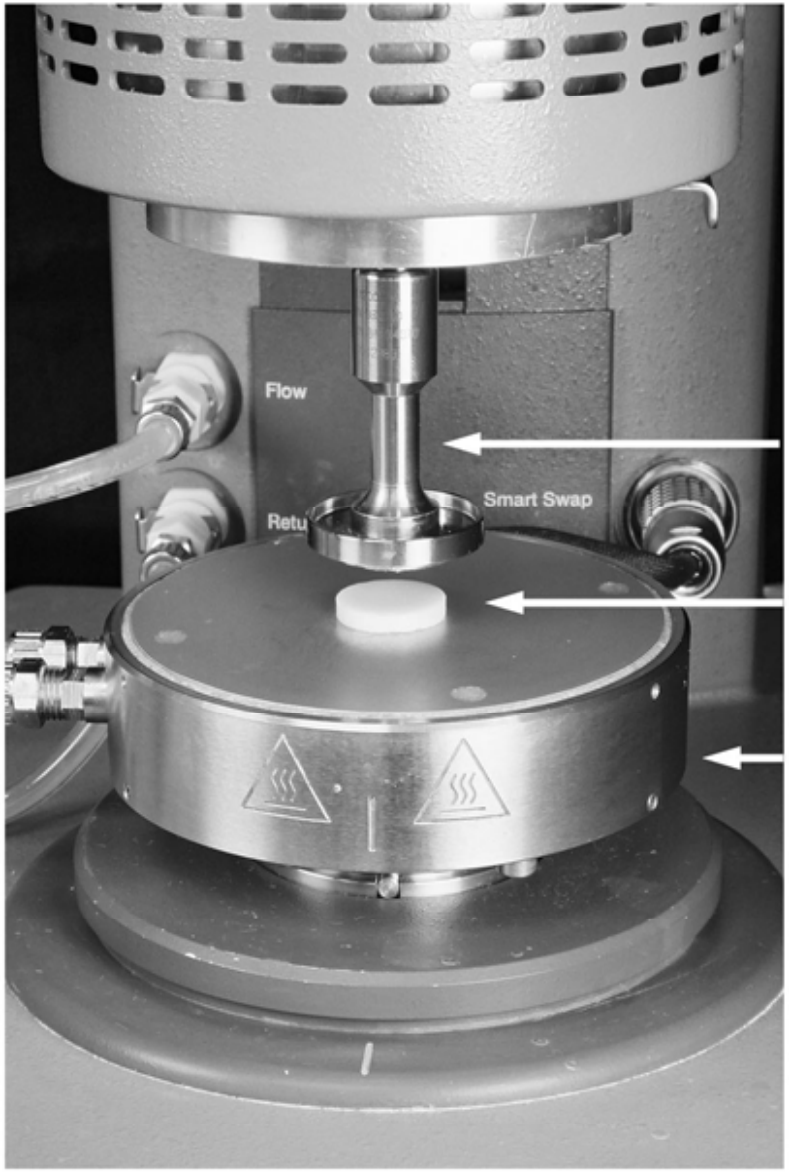
$$G' = \lambda \left(\frac{SFC}{100} \right)^{\mu}$$

$$\ln G' = \ln \lambda + \mu \ln \left(\frac{SFC}{100} \right)$$

$$D = 3 - \frac{1}{\mu}$$

Small Deformation Dynamic Controlled Stress Rheometer

TA AR2000

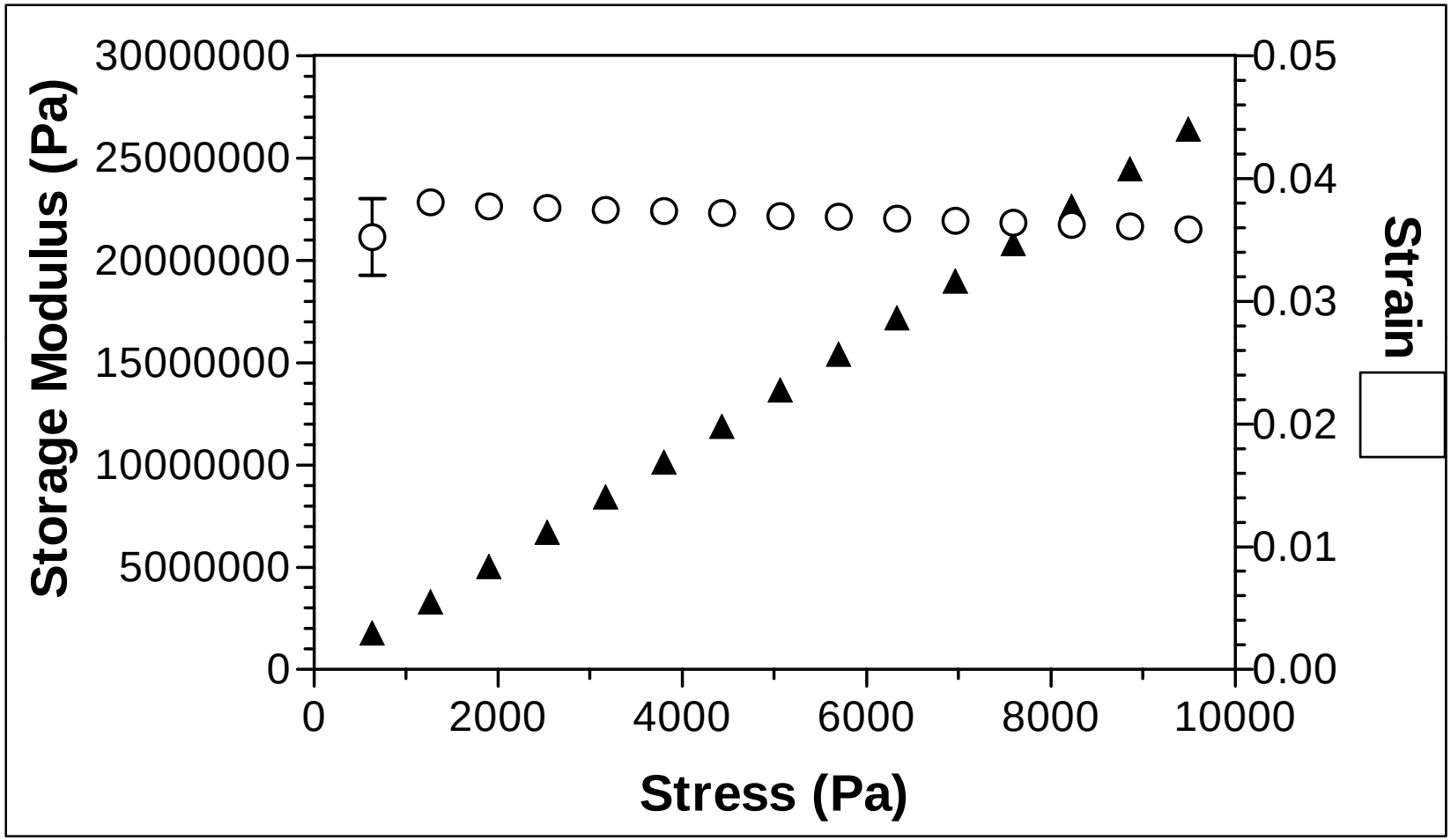

Flow
Smart Swap
Parallel plate geometry
Sample disk
Peltier plate

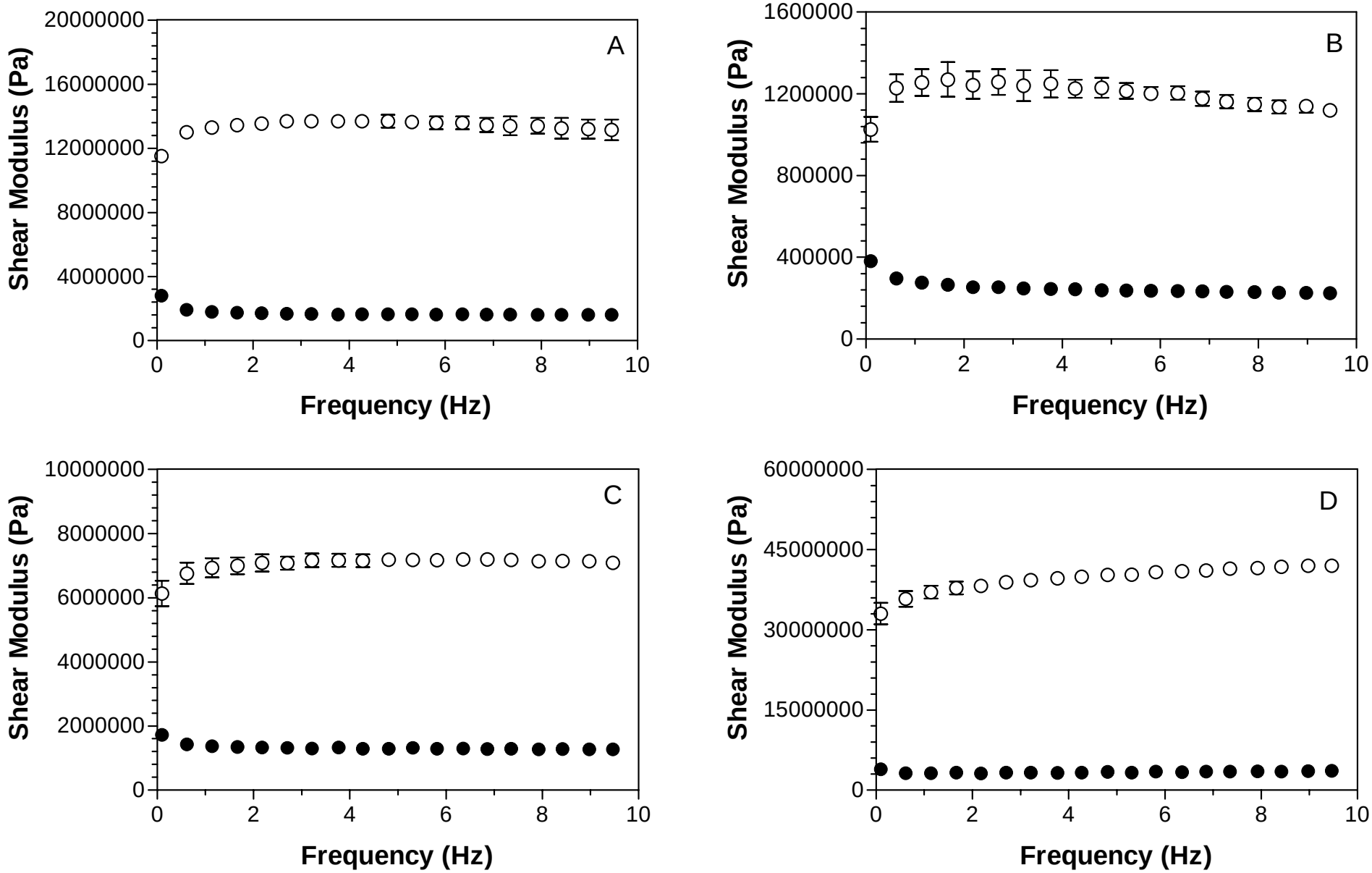
Viscoelasticity of Fats

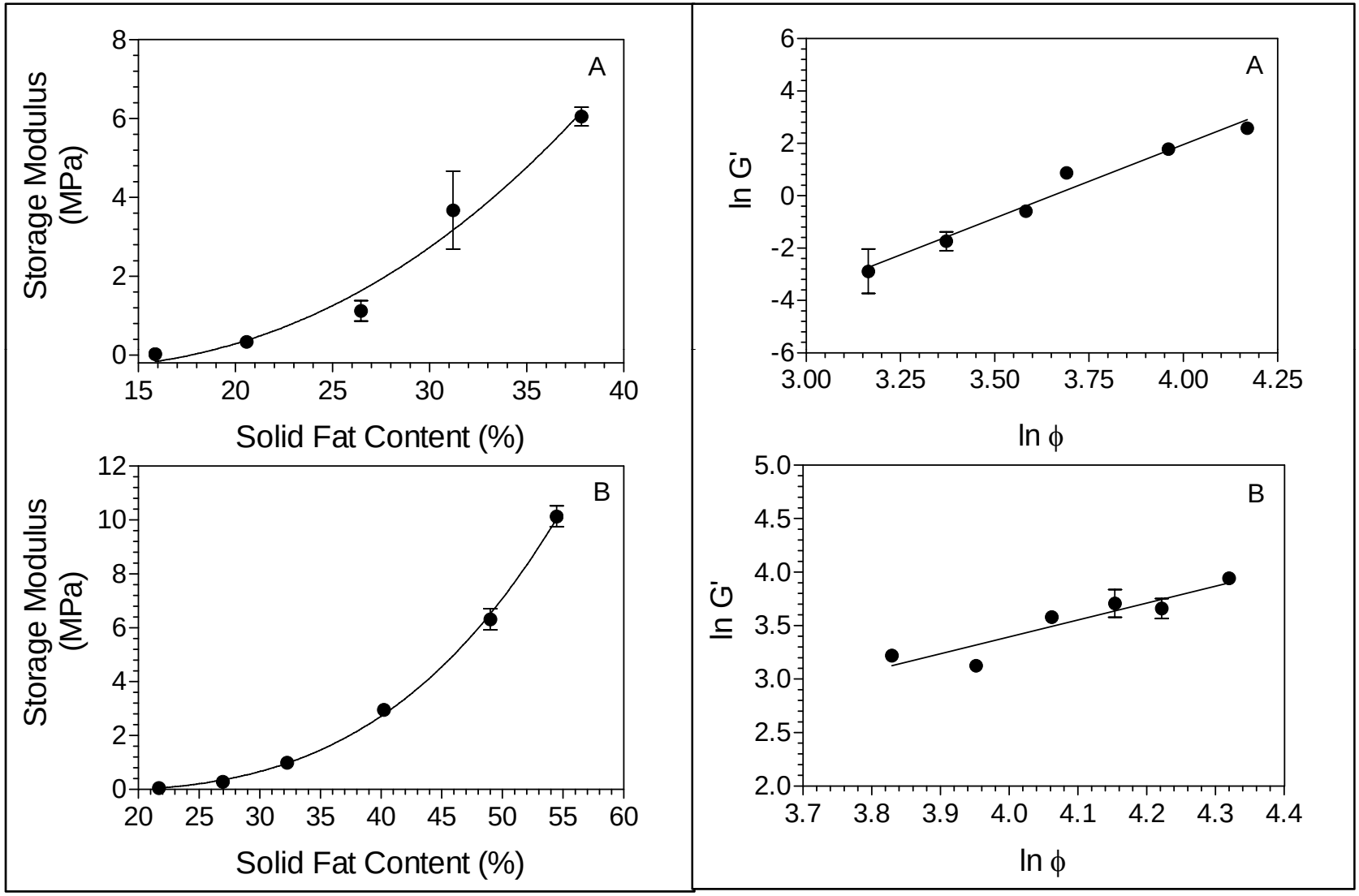
G”/G’ ~ 0.1

Shear strains of ~ 0.1% or less

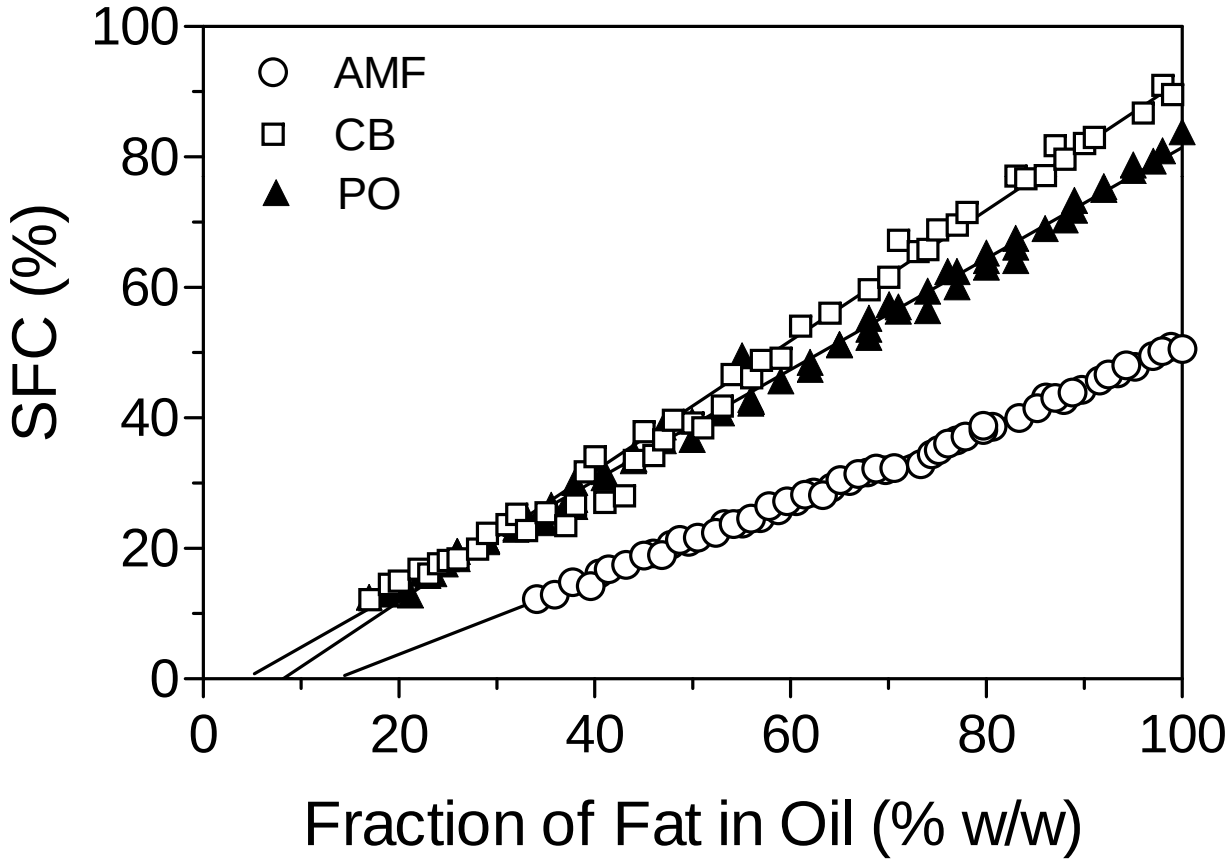
G’ frequency-independent


Storage Modulus (Pa)
30000000
25000000
20000000
15000000
10000000
5000000
0
0
2000
4000
6000
8000
10000
Stress (Pa)
0.05
0.04
0.03
0.02
0.01
0.00
Strain


A
B
C
D
Shear Modulus (Pa)
Frequency (Hz)
20000000
16000000
12000000
8000000
4000000
0
1600000
1200000
800000
400000
10000000
6000000
2000000
60000000
45000000
30000000
15000000
0
2
4
6
8
10

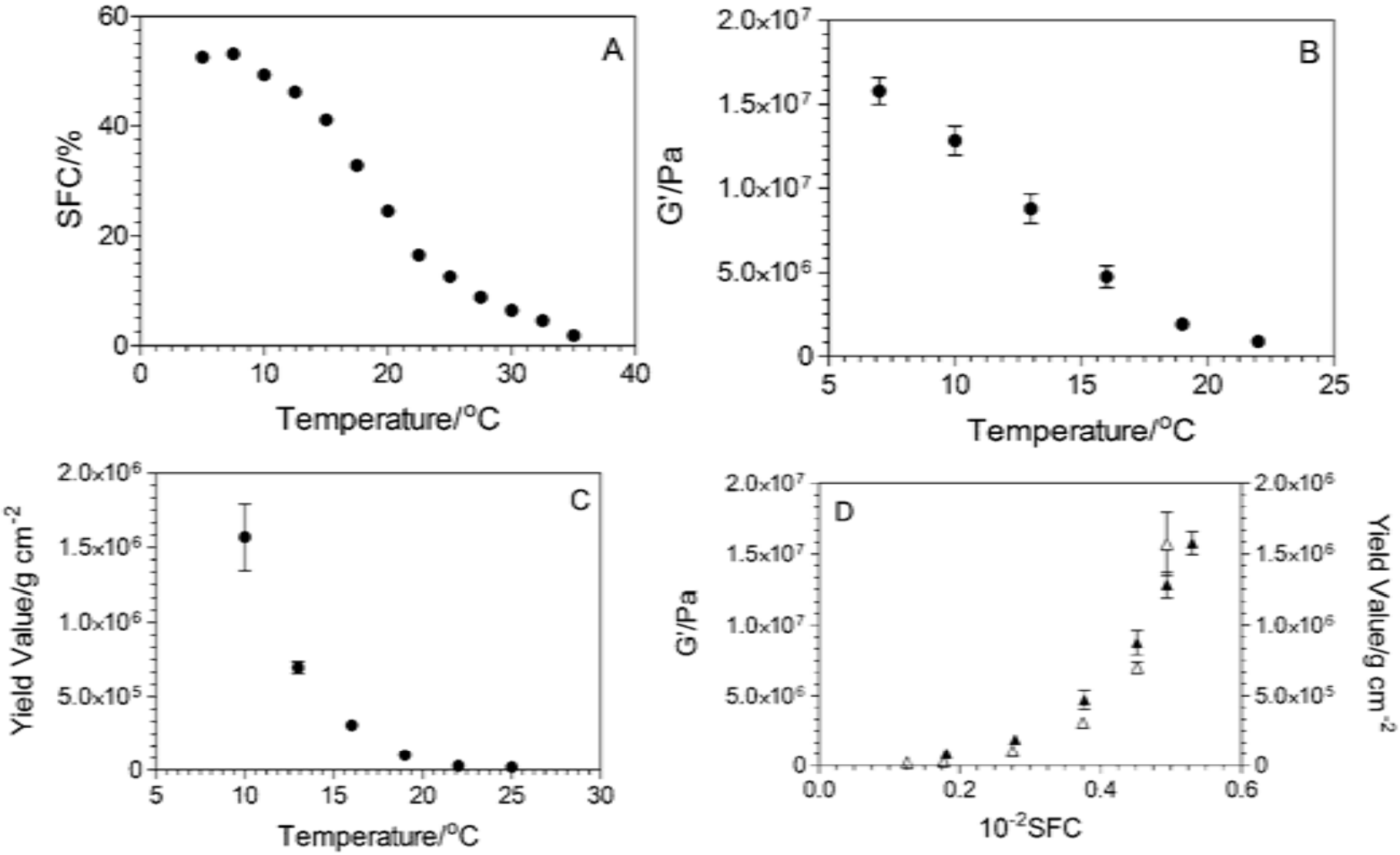

A
Storage Modulus (MPa)
Solid Fat Content (%)
B
Storage Modulus (MPa)
Solid Fat Content (%)
A
ln G'
ln ϕ
B
ln G'
ln ϕ

Dilute fat with vegetable oil

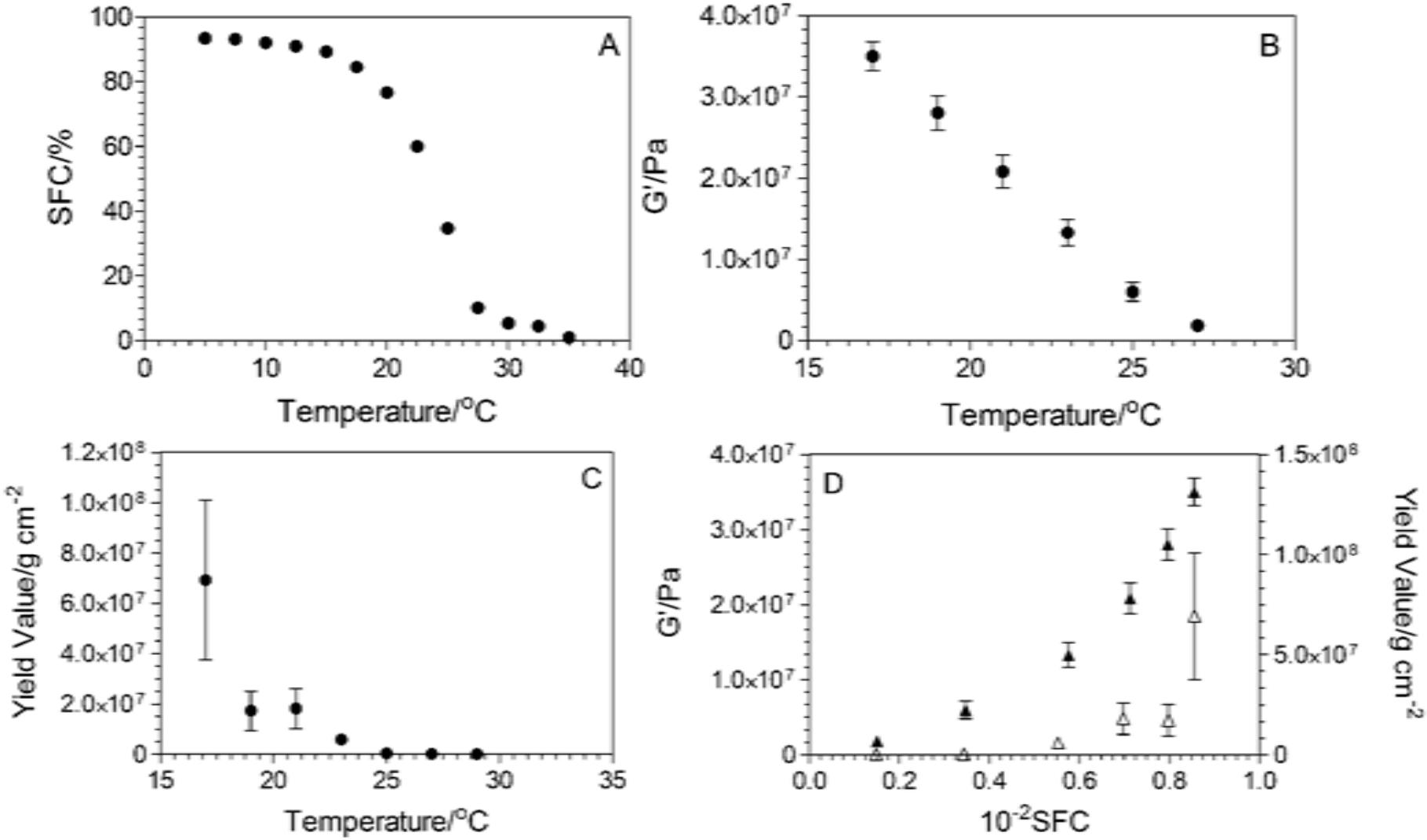


Thermomechanical Method for the Determination of the Rheology Fractal Dimension

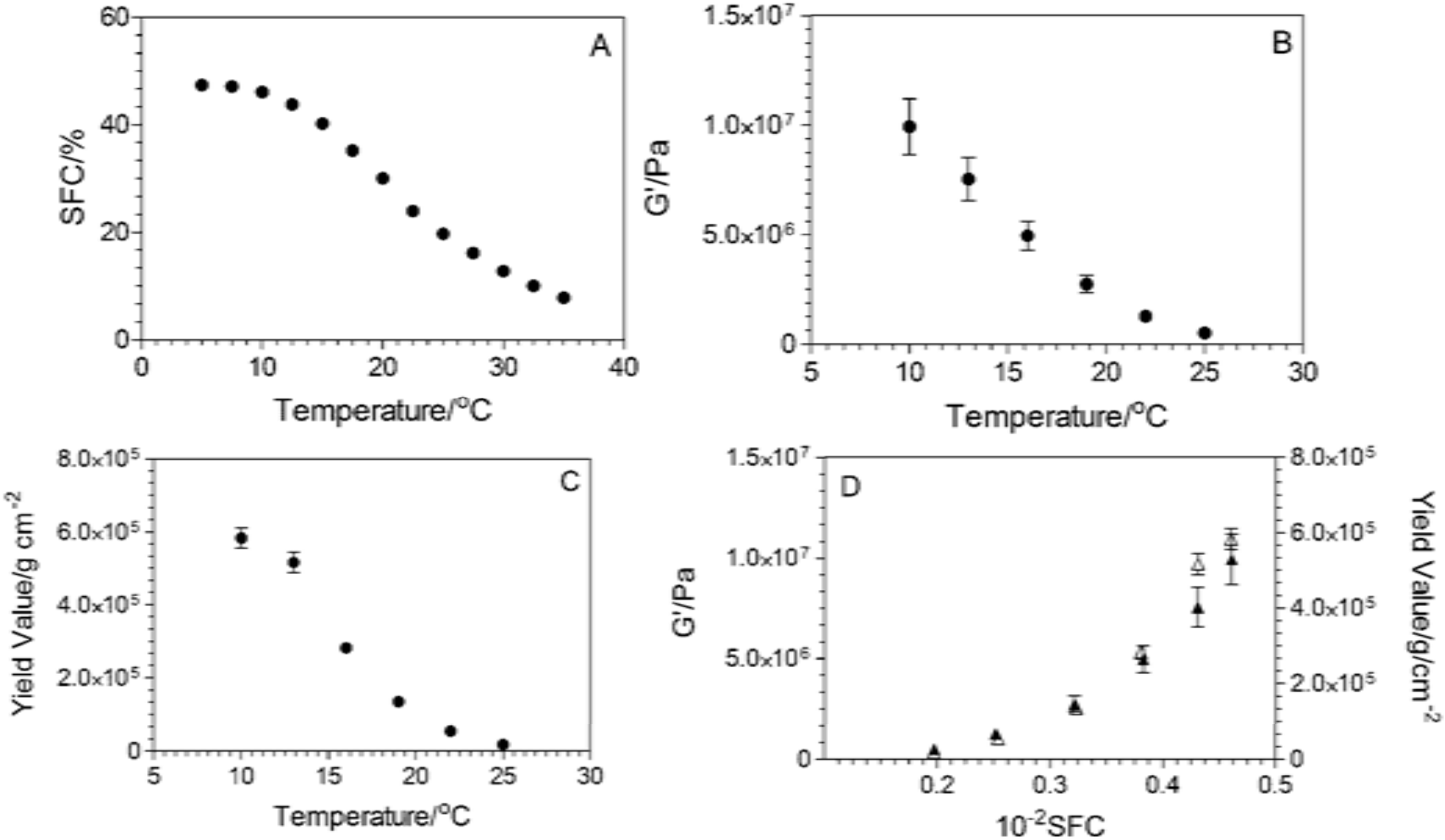
Milkfat


A
SFC/%
Temperature/°C
B
G'/Pa
Temperature/°C
C
Yield Value/g cm-2
Temperature/°C
D
G'/Pa
Yield Value/g cm-2
10-2SFC

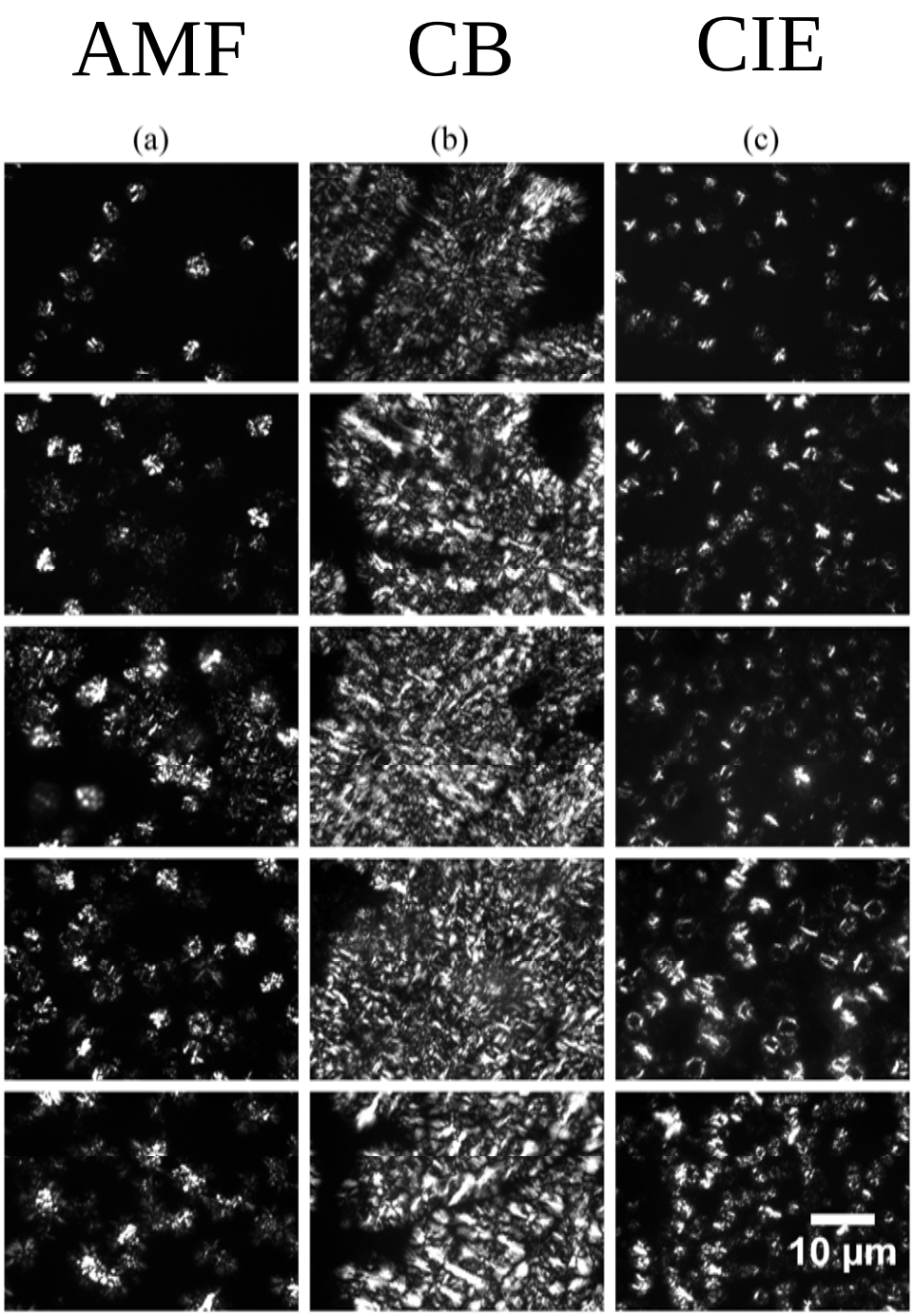
Cocoa Butter



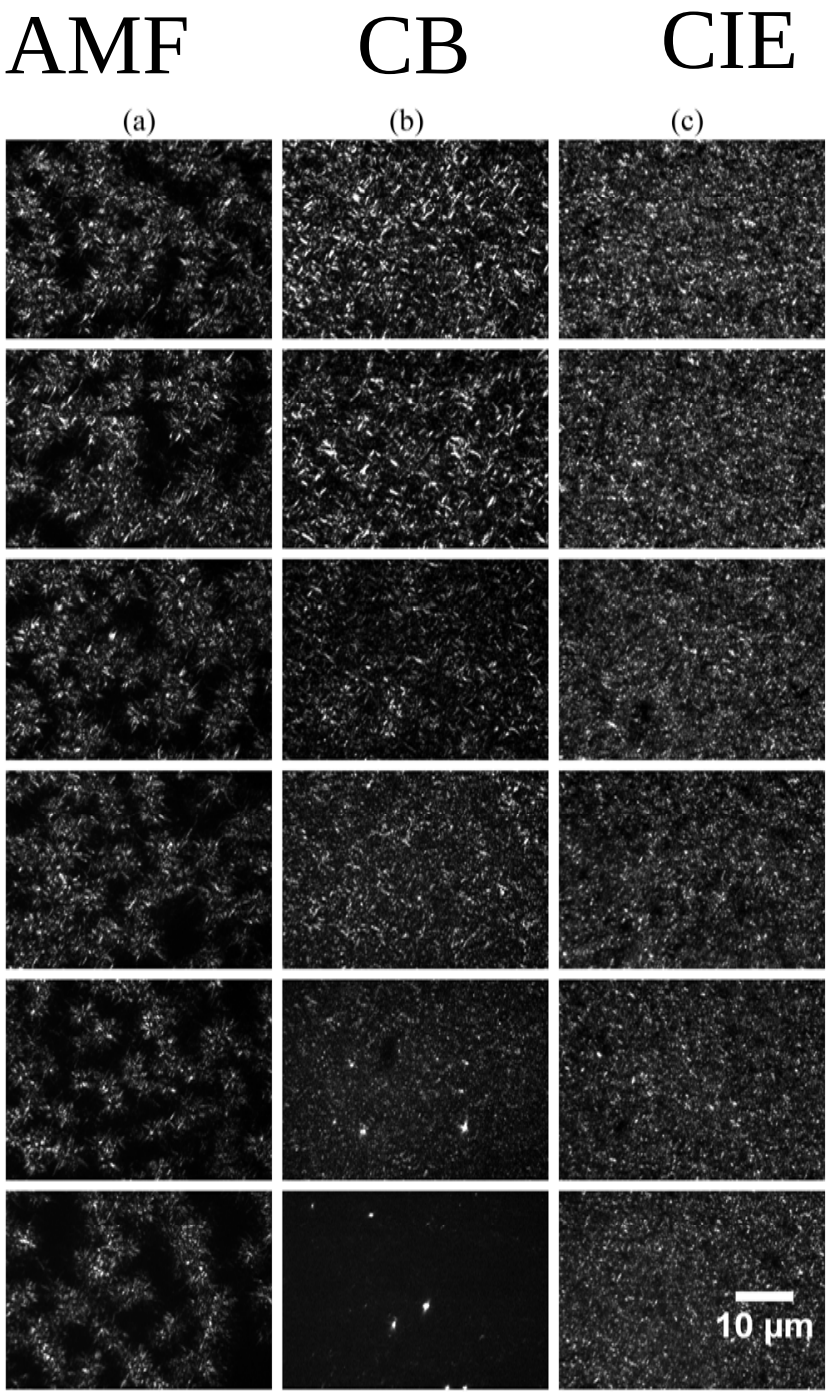
CIE FHCO-HOSO



Dilution Method (CO)



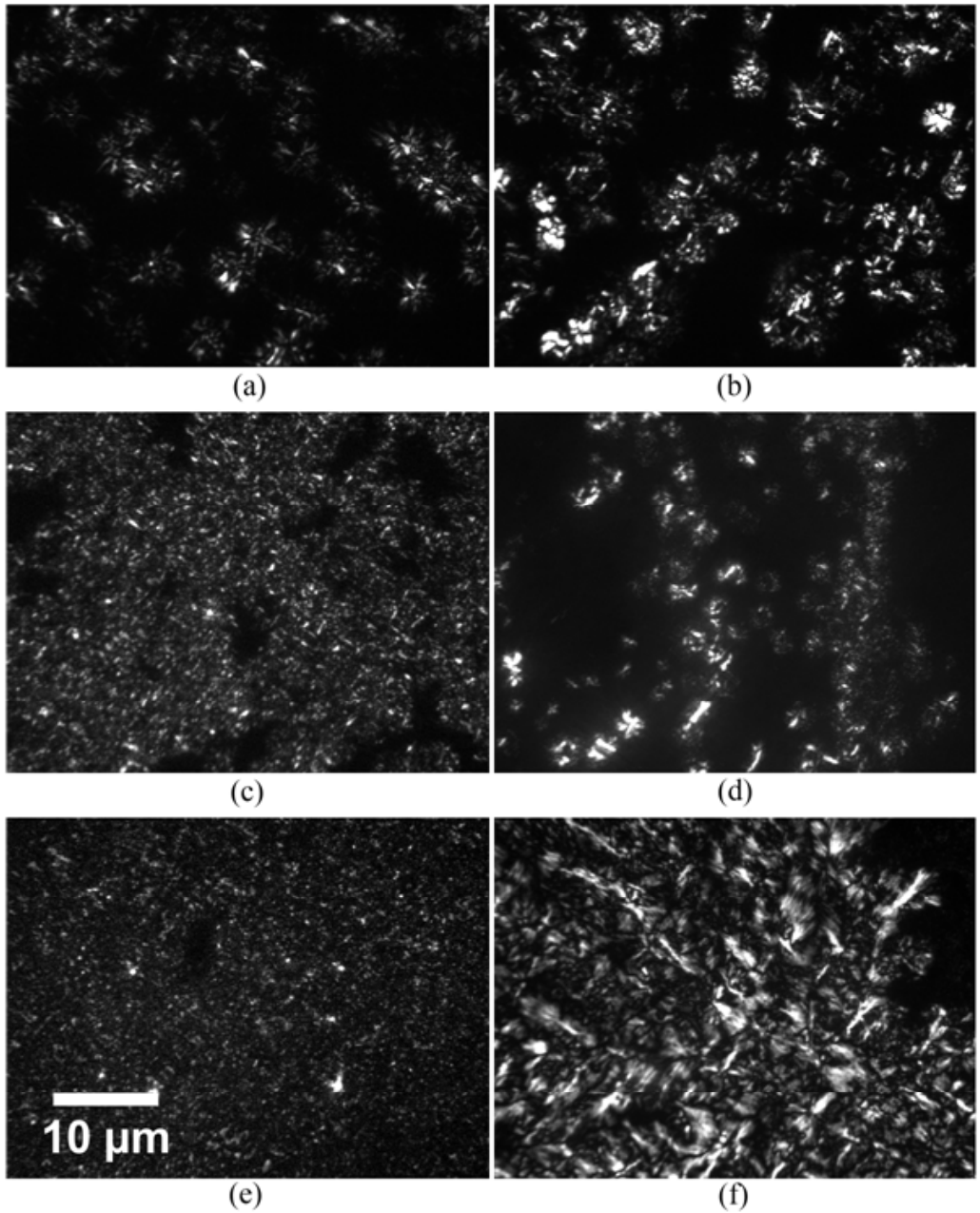
Thermo-mechanical Method

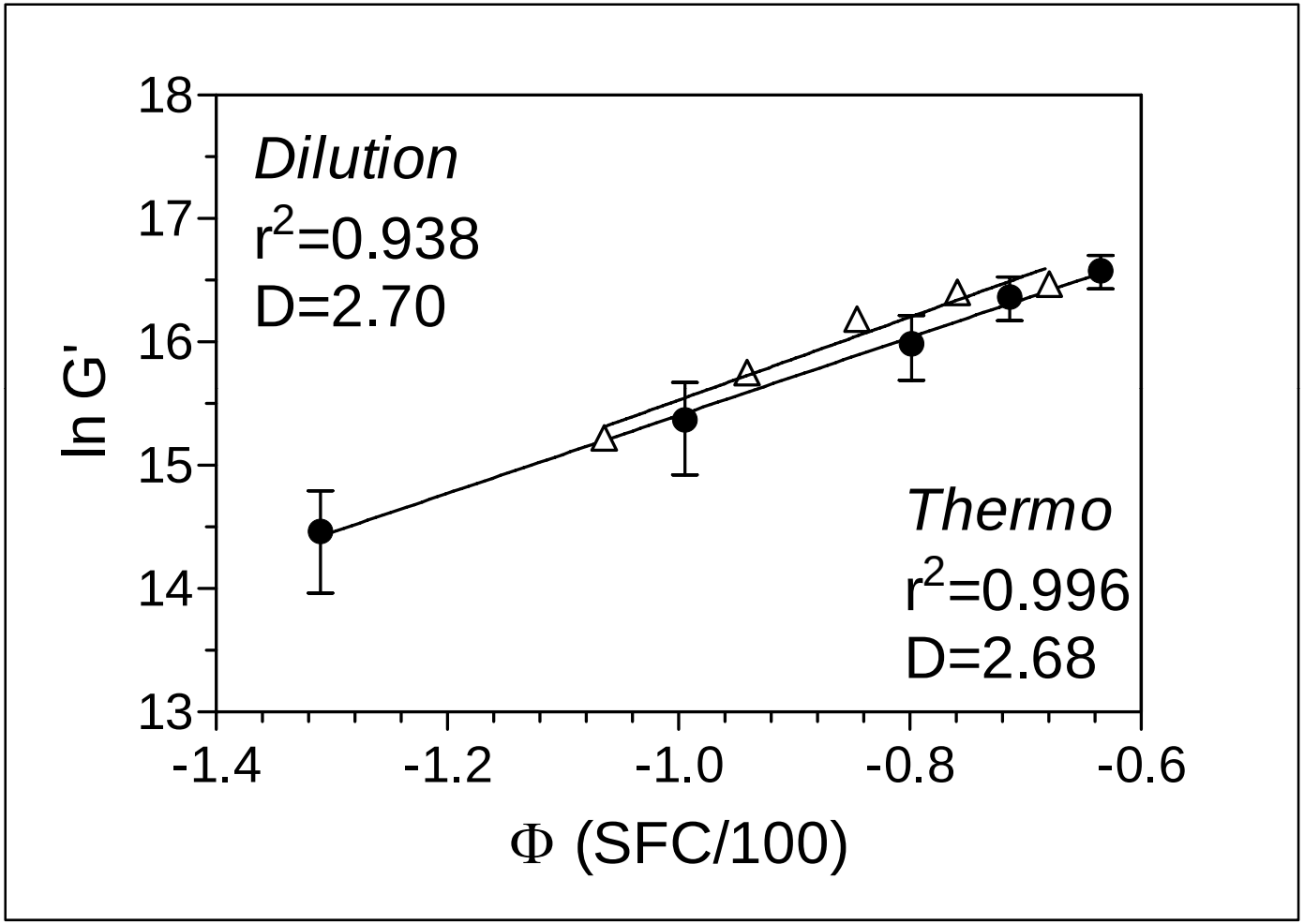


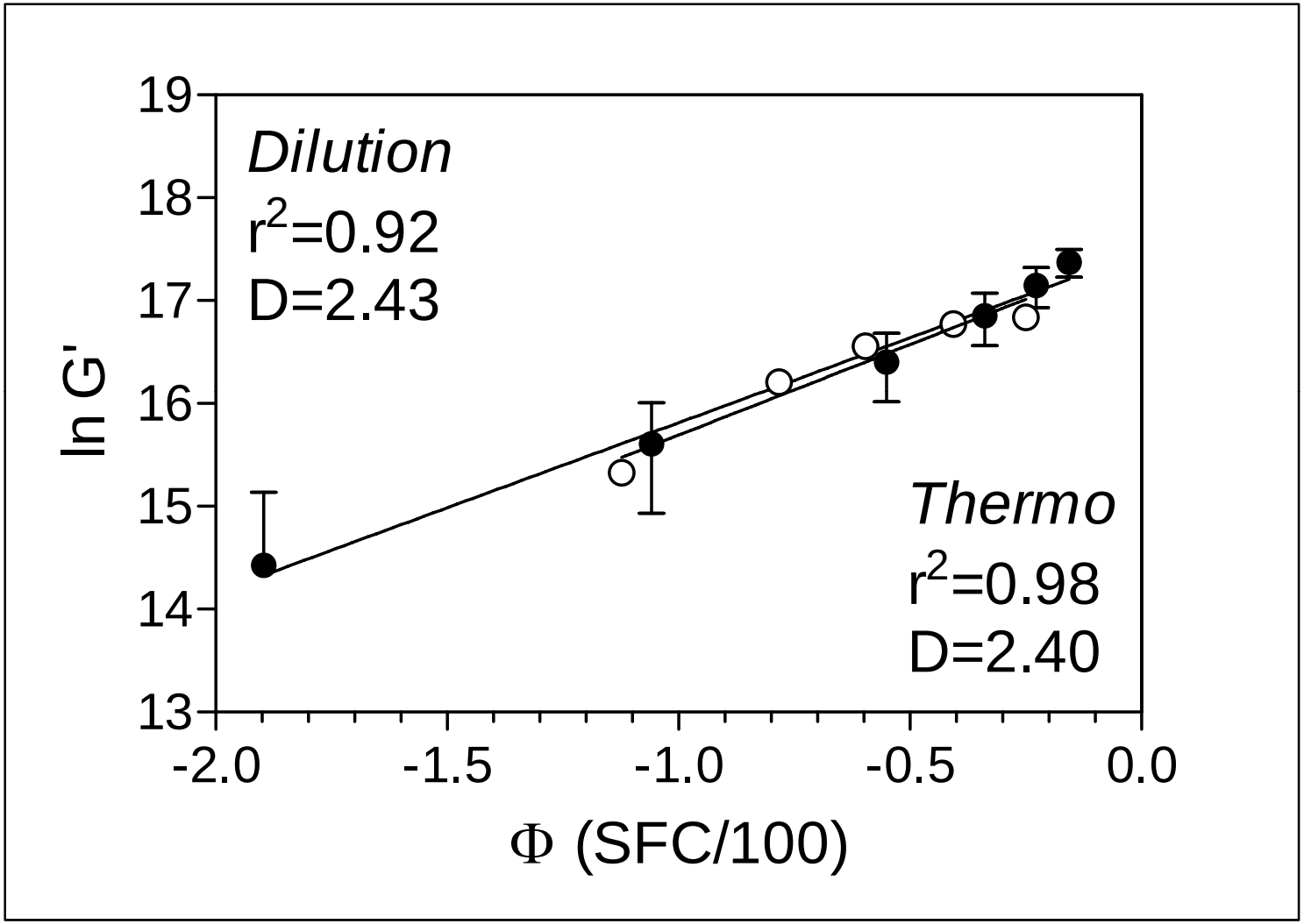
AMF
17%SFC

CIE
~15% SFC

CB
34% SFC




Dilution
r2=0.938
D=2.70
Thermo
r2=0.996
D=2.68
ln G'
Φ (SFC/100)
18
17
16
15
14
13
-1.4
-1.2
-1.0
-0.8
-0.6


Dilution
r2=0.92
D=2.43
Thermo
r2=0.98
D=2.40
ln G'
Φ (SFC/100)
19
18
17
16
15
14
13
-2.0
-1.5
-1.0
-0.5
0.0

The fractal dimension (D) and λ parameter* for the three samples used in this study, determined by three different methods.

	D	λ (Pa)	r^2
AMF_d	2.83	1.254×10^9	0.7125
AMF_t	2.65	8.264×10^7	0.9185
AMF_c	2.68	8.121×10^6	0.9380
CB_d	2.72	1.631×10^8	0.4787
CB_t	2.51	4.358×10^7	0.8060
CB_c	2.62	2.186×10^7	0.6971
CIE_d	2.81	5.295×10^9	0.8622
CIE_t	2.71	1.283×10^8	0.8784
CIE_c	2.76	1.540×10^7	0.9876

$_d$ indicates dilution method using small deformation oscillatory rheology
$_t$ indicates thermo-mechanical method using small deformation oscillatory rheology
$_c$ indicates thermo-mechanical method using cone penetrometry
*The parameter λ is inversely proportional the size of the primary particles and directly proportional to the strength of their van der Waals' interactions

Acknowledgments

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