ICE CREAM MICROSTRUCTURE

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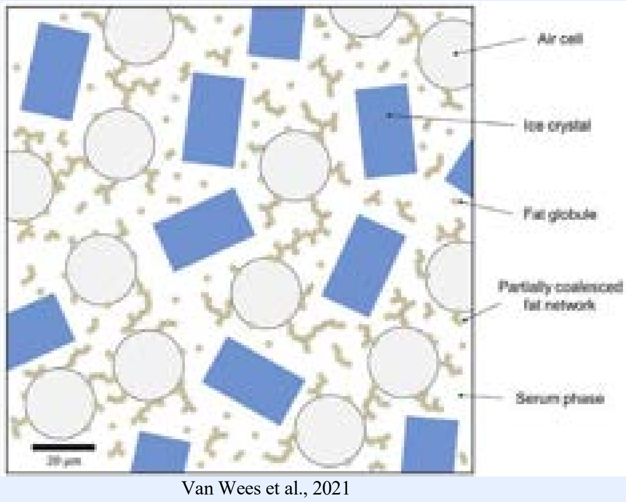
FDC

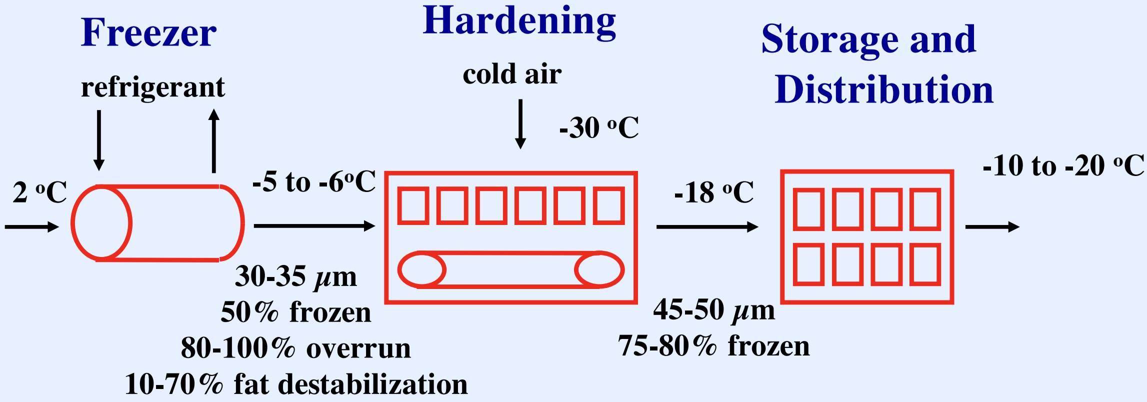
Ice Cream at a Structural Level

- Ice crystals
  - Provide cooling effect and hardness
- Air cells
  - Reduce density
- Partially-coalesced fat globule network
  - Affects melt-down rate and hardness of ice cream
- Proteins and hydrocolloids
  - Network in serum phase
- Serum phase
  - Dissolved sugars, minerals, proteins, etc.
  - Some liquid even at very low temperature



Van Wees et al., 2021

Ice Cream Processing



<u>Ice</u>
- nucleation
- growth

<u>Air</u>
- incorporation
- breakdown

<u>Lipid</u>
- growth
- partial coalescence

<u>Ice</u>
- growth

<u>Air</u>
- coalescence

<u>Lipid</u>
- growth

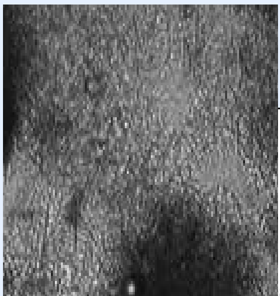
<u>Ice</u>
- melting
- growth
- ripening

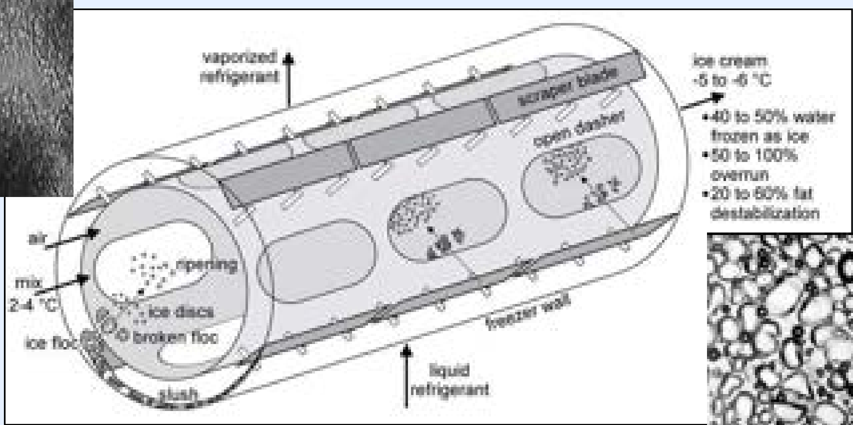
<u>Air</u>
- coalescence

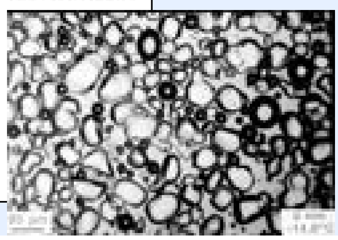
<u>Lactose</u>
- crystallization

Scraped Surface Freezer (SSF) Development of Structures

- Formation of ice crystals
  - Scraping of slush off wall of freezer; mixing of slush in center of barrel; ripening and growth to form ice crystal size distribution



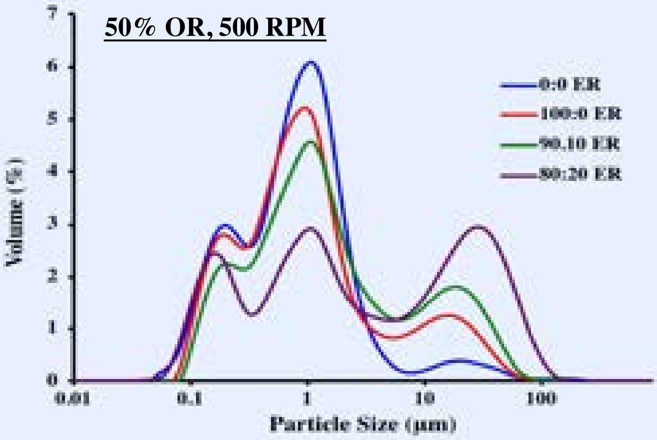




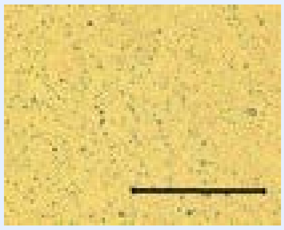
Cook & Hartel, 2010

Scraped Surface Freezer (SSF) Development of Structures

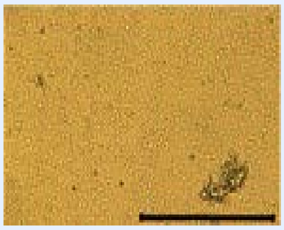
- Continued crystallization of lipid during freezing
- Fat destabilization
  - Breakdown of emulsion due to shearing forces in freezer; partial coalescence due to liquid fat



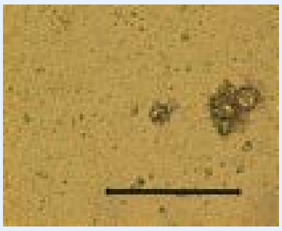
Warren & Hartel (2017)



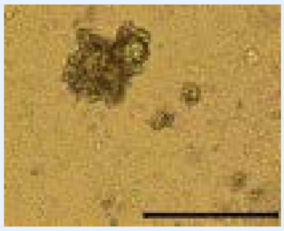
0:0 ER, 5.9%



100:0 ER, 19.6%



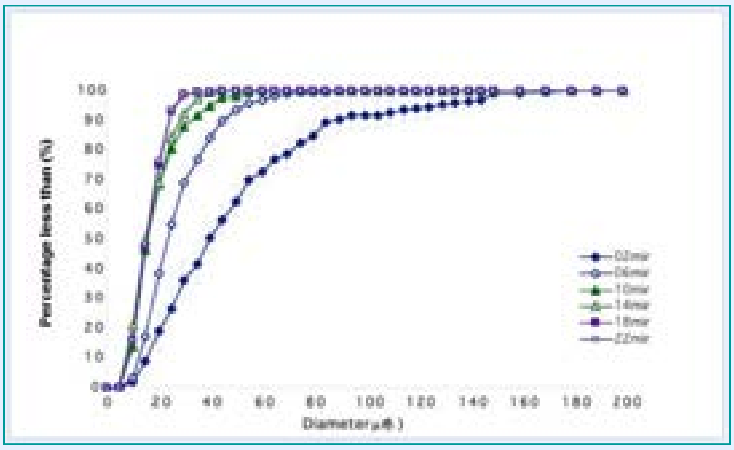
90:10 ER, 28.3%

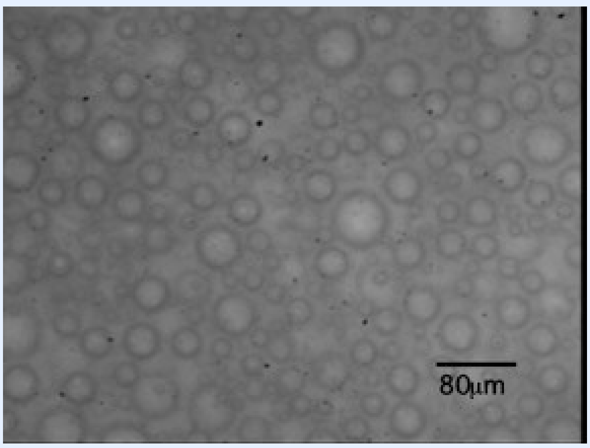


80:20 ER, 56.2%

Scraped Surface Freezer (SSF) Development of Structures

- Aeration
  - Increase in overrun; breakdown of air cells into tiny bubbles; development of air cell distribution; stabilization of air cells by proteins, destabilized fat globules and viscous unfrozen matrix





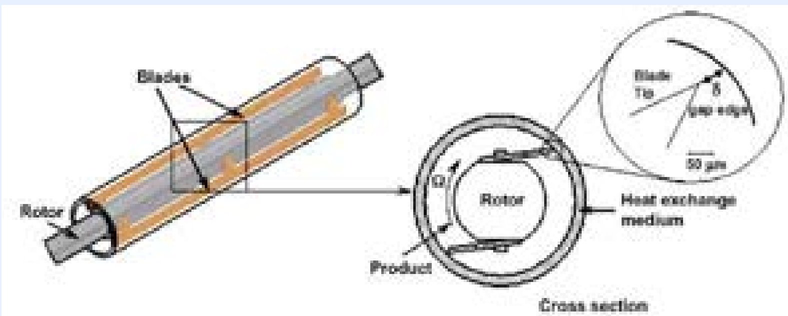
Chang (2002)

Scraped Surface Freezers

- Exactly what goes on within the barrel of the freezer with all of these structures being developed at the same time is still uncertain
- Recent attempts at modeling the processes within the freezer may provide better understanding

Residence Time Distribution (RTD)

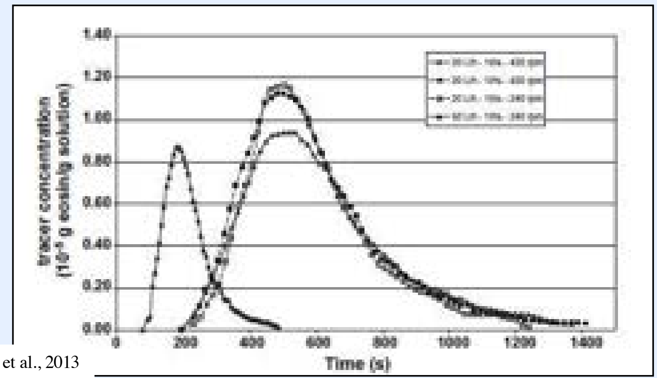
- The path of an element of fluid from inlet to outlet of a scraped surface heat exchanger is complicated
  - Scraping at wall and distribution of cooler fluid into the center of the barrel
- This complicated flow pattern results in a distribution of times for any element to dwell within the heat exchanger



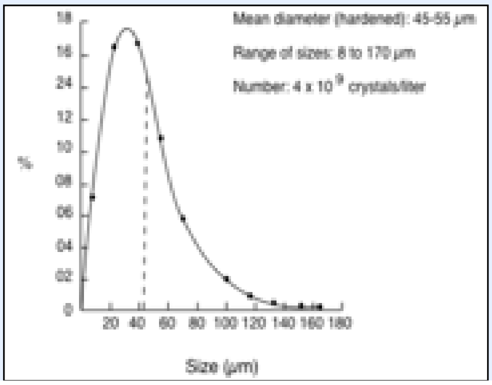
Yataghene et al., 2008

Residence Time Distribution (RTD)

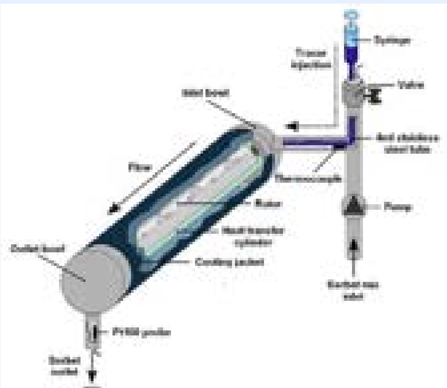
- Some fluid elements exit earlier than others
- Not all fluid elements see the same conditions within the freezer barrel
  - Some ice crystals remain in the barrel longer and can grow to larger size than those that exit much quicker
  - Similar for air bubbles and partially-coalesced fat globules
  - This behavior explains, in part, the distribution in sizes of these structural elements



Fayolle et al., 2013



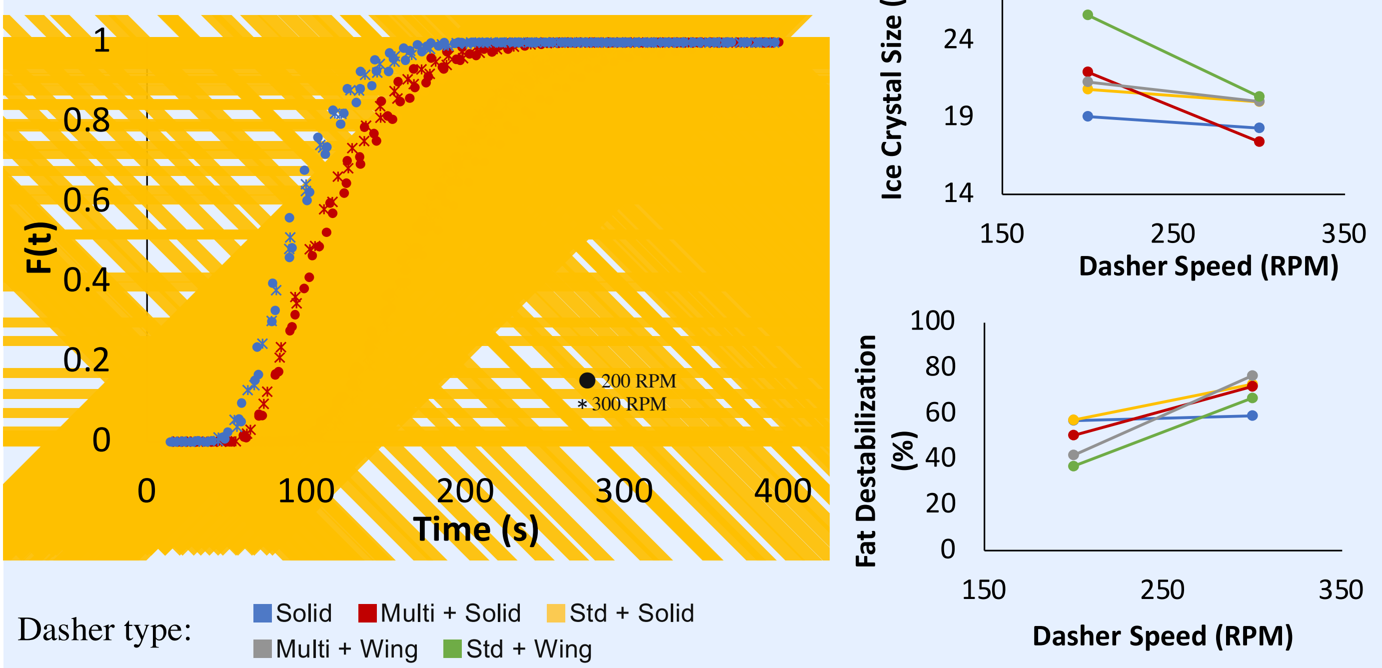
Measuring RTD in a Scraped Surface Freezer



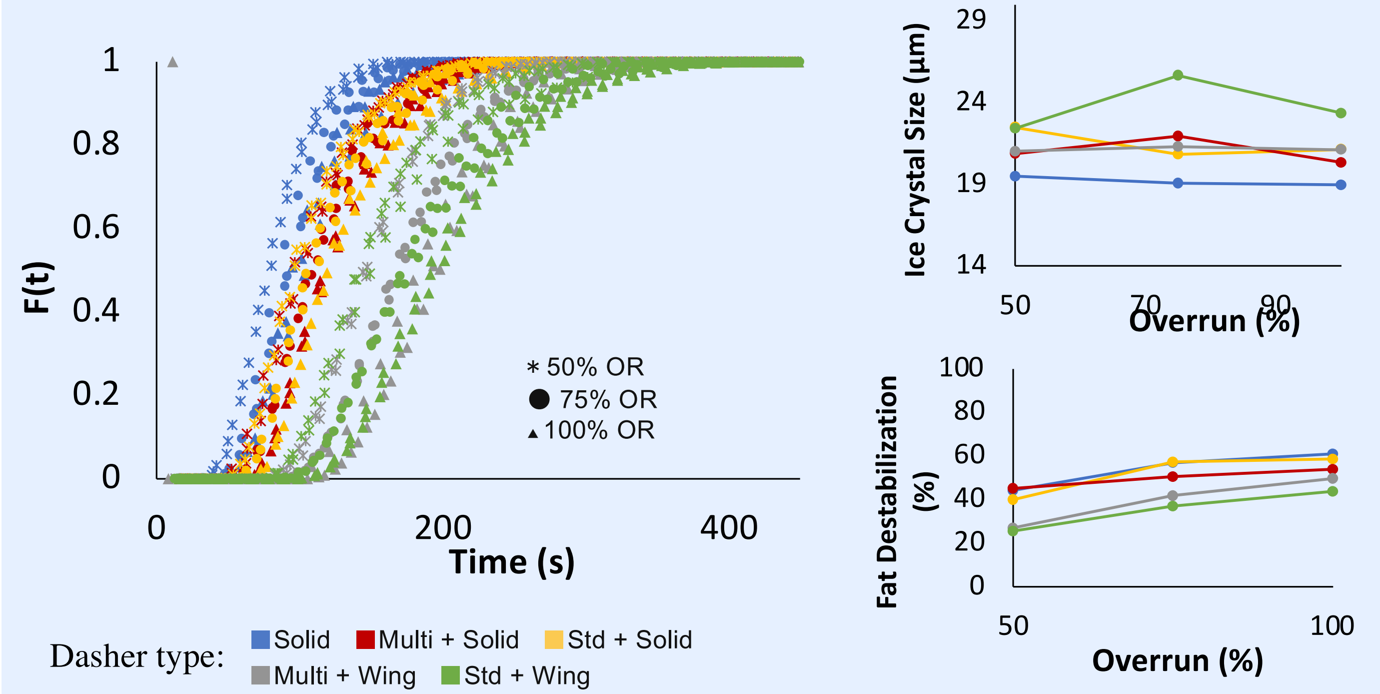
Arellano et al., 2013

Measure RTD for 5 different dasher designs at different operating conditions to correlate against development of structures

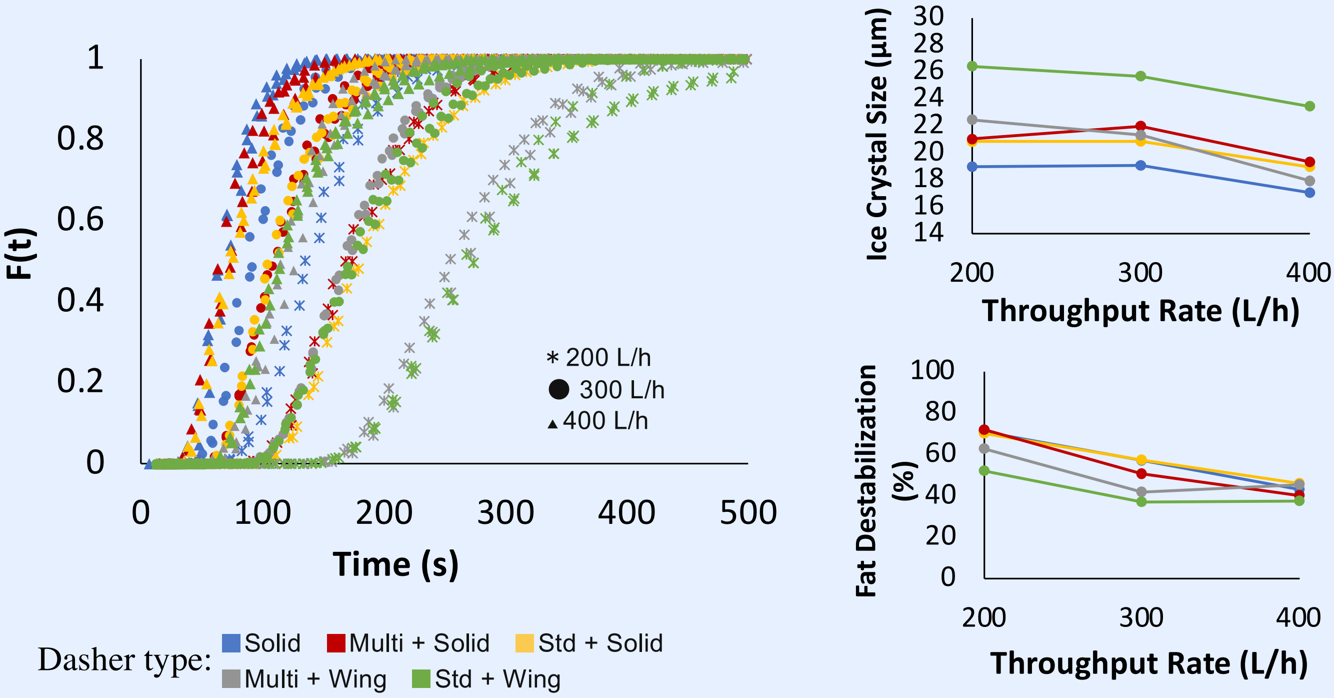
Dasher Speed



Overrun



Throughput Rate



New/Recent Directions Structures/Melt Down

- "No melt" ice cream based on addition of polyphenols
  - *CJ Wicks*
- Rheological properties of continuous phase
- Phase separation of protein/hydrocolloids
  - *Dr. Jasmine Wu*

No-Melt Ice Cream?

- Japanese ”no-melt” ice cream
  - Strawberry extract
- After 2 hours, all the ice is melted, these ice creams just don’t collapse

  “no-collapse” ice cream
- Must be related to the structures
  - Fat globules, protein

After 30 mins

“Polyphenol liquid has properties to make it difficult for water and oil to separate so that a popsicle containing it will be able to retain the original shape of the cream for a longer time than usual and be hard to melt”

Tomihisa Ota
Professor Emeritus of Pharmacy at Kanazawa University,
Co-Developer of Ice Cream

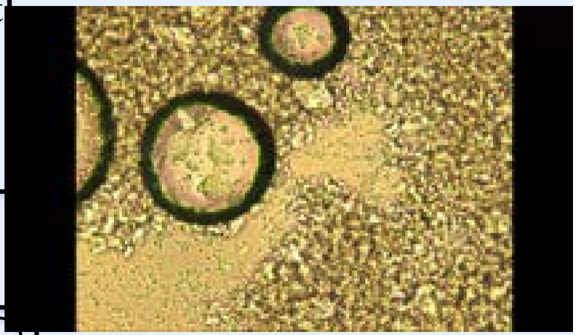
Ice Cream Melting

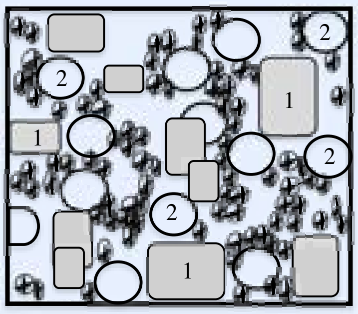
- Not all ice creams are created equal – or melt in the same way
- Drip-through test – slabs on mesh, measure drip through weight and height change

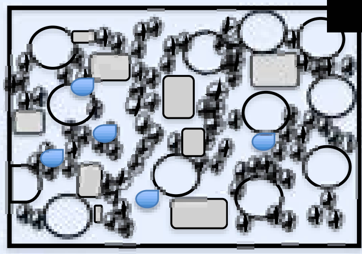
Which is better? That’s up to you and what the manufacturer wants

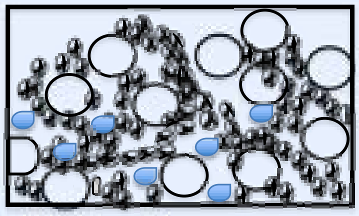
High Fat Destabilization
Minimal Collapse

1 - Ice crystals
-Free water
-Serum phase
- Fat/destabilized fat
2 - Air cells





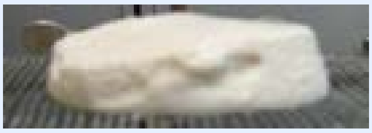




t = 0 minutes

t = 60 minutes

t = 120 minutes



Objective 1

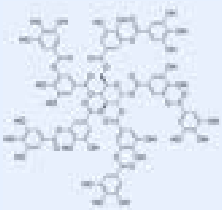
Do polyphenols affect partial coalescence of fat or is the primary mechanism protein mediated?

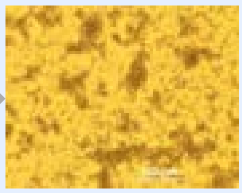
Tannic Acid

Microstructure

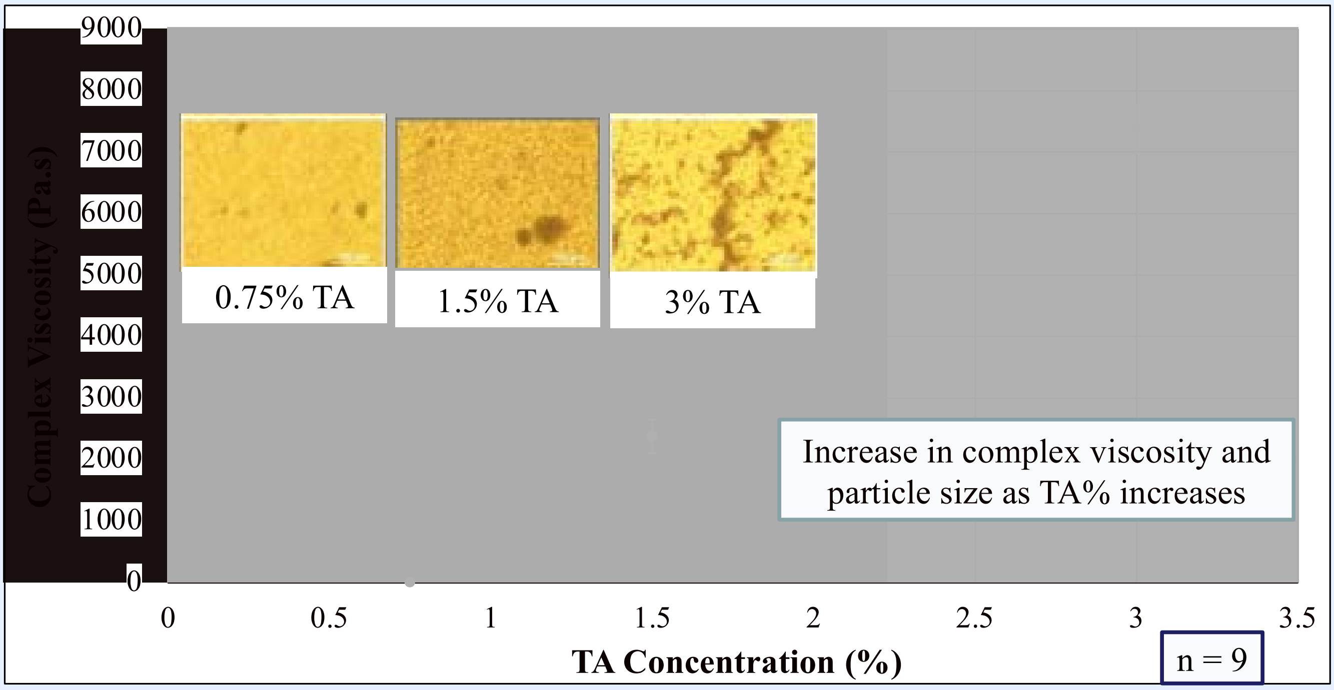
Gelation

Melting Rate



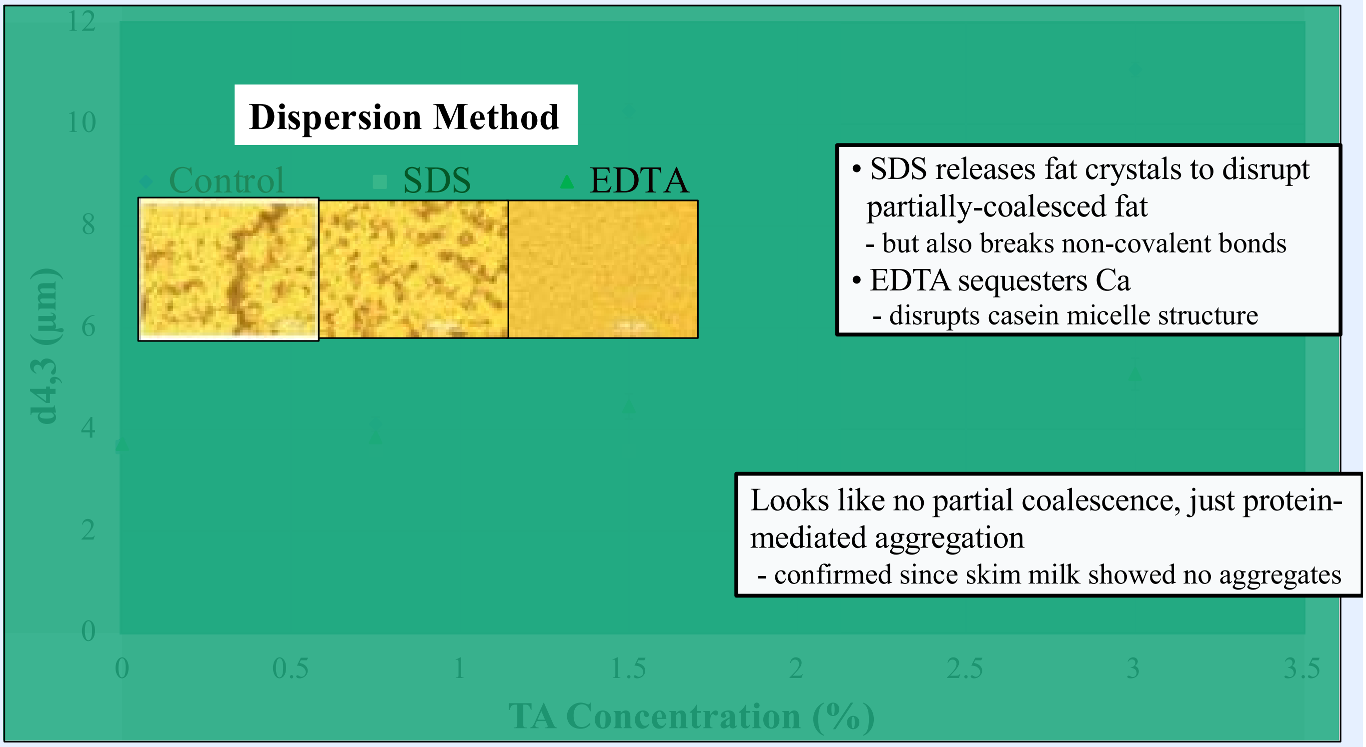


Complex Viscosity



Wicks et al., 2023

Mean Particle Size



Wicks et al., 2023

Objective 3

Evaluate logical target PPs and/or extracts for further study in frozen dessert systems.

Experimental Design:

Fat %	10	13	16
Protein %	2	3.5	5
PP %	0	3	

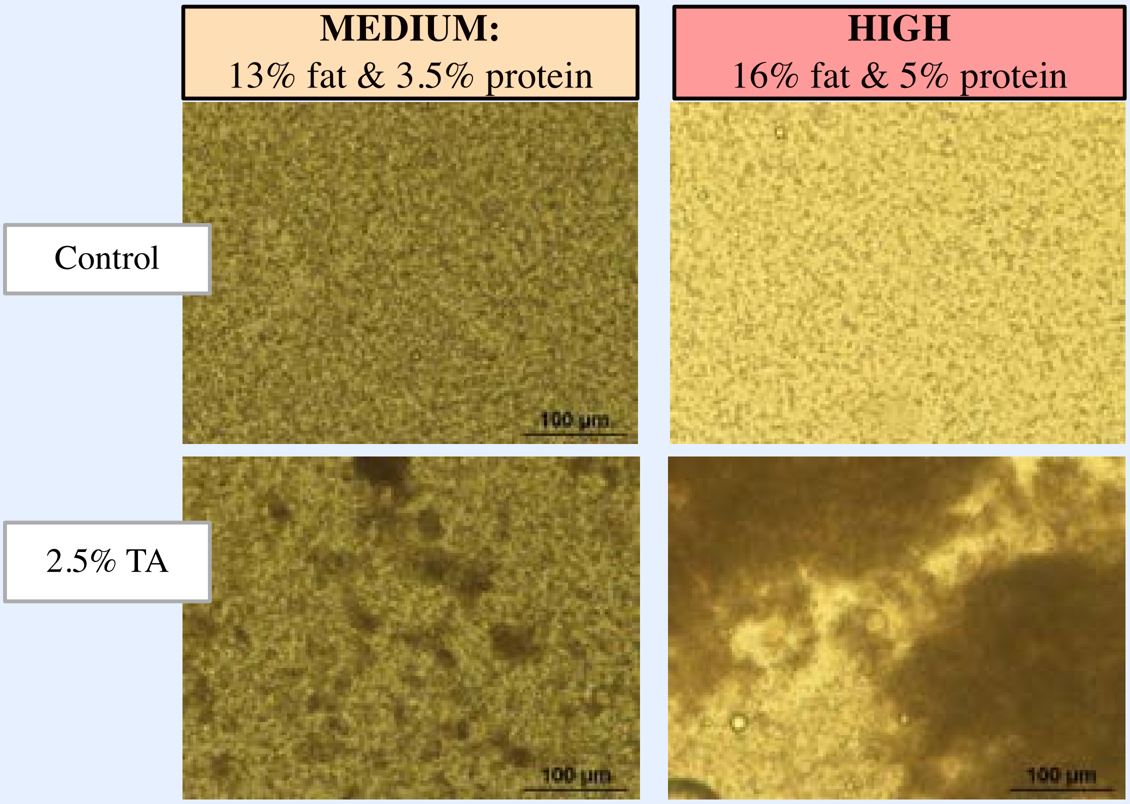
Methods:

- Mix Preparation with polyphenol
- Particle Size Distribution
- Microscope Images
- pH of mix
- Overrun
- Rheology
- Melting Rate
- Ice Crystals

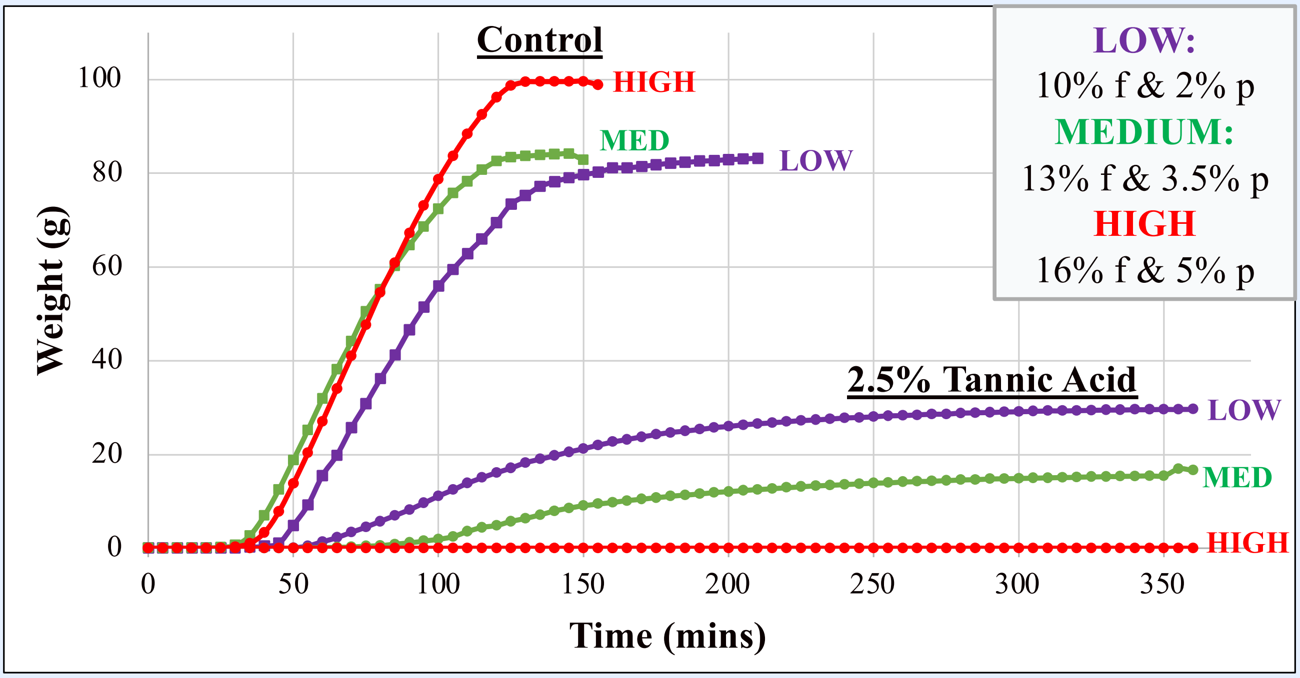
Mix and Ice Cream Preparation

Ingredient
Cream
Non-Fat Dry Milk
Milk Protein Concentrate (80%)
Sugar
Tannic Acid
Water
Mono and Diglycerides (0.12%)
Stabilizers (0.2%)

Microscope Images



Drip Weight



Future Work

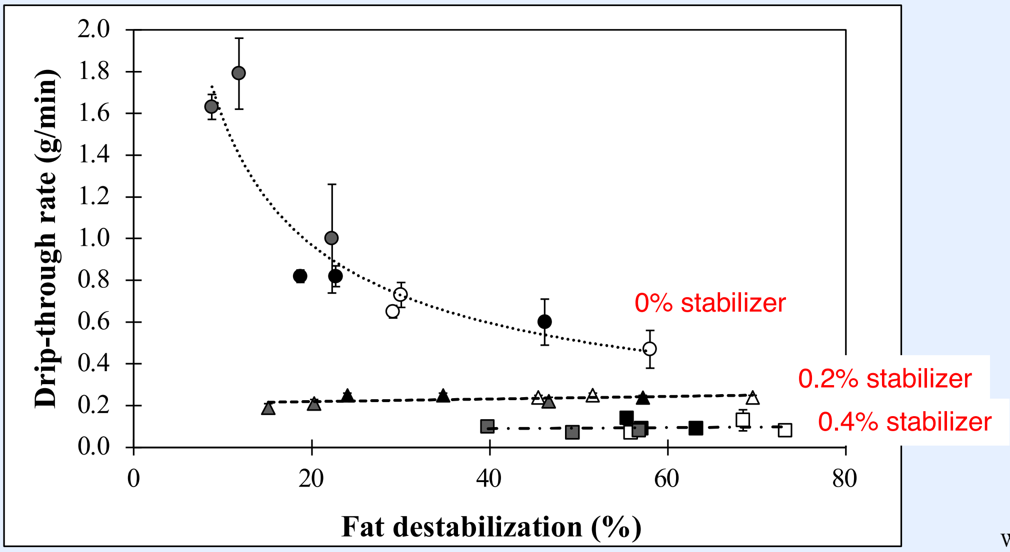
- Evaluate TA level on melt properties
  - Correlate to structure development through microscopy and rheology
- Evaluate various extracts and other delivery formats as developed from Objective 2
- Can extracts modulate melting properties of frozen desserts?
  - Non-dairy products?

https://youtu.be/sA-lc6ZnWLo

Funding acknowledgment: USDA NIFA (WIS03038 GRANT 12905866)

Rheological Effects

- Previous work has shown that viscosity of the mix had the most important effect on melt-down
  - Overrun and partial coalescence were only important at the lowest level of stabilizer addition



Wu et al., 2019

Rheological Effects

- Phase 2. The effect of rheological properties on meltdown behavior of non-aerated frozen sucrose system
- Phase 3. The effect of rheological properties on meltdown behavior of aerated frozen sucrose system
- Phase 4. The effect of protein-polysaccharides interaction on meltdown behavior of aerated frozen sucrose system

Wu J., Understanding the meltdown behavior of frozen dessert:
from ice cream to model system, PhD Dissertation, UW-Madison (2023)

Phase 2. Rheology on non-aerated system

Hypothesis: The effect of rheological properties on melting and dripping is caused by either apparent viscosity or shear-thinning behavior in the non-aerated frozen sucrose system.

- ➢Apparent mix viscosity (at 5 s^{-1} shear rate)
- ➢Shear-thinning behavior
  - Flow rate index (power law model) $\sigma = \eta\dot{\gamma}^{n}$

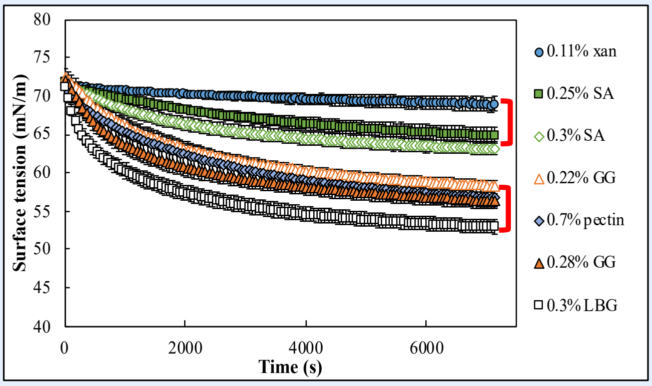
Experimental design

Same flow index (0.74)	Apparent viscosity at 5 s^{-1}
0.22% guar gum (GG)	0.10±0.00[a]
0.3% locust bean gum (LBG)	0.15±0.00[b]
0.3% sodium alginate (SA)	0.26±0.00[c]

Same viscosity at 5 s^{-1} (0.20)	Flow index
0.11% xanthan	0.47±0.01[a]
0.28% guar gum (GG)	0.66±0.00[b]
0.25% sodium alginate (SA)	0.76±0.00[c]
0.7% pectin	0.86±0.01[d]

Phase 2. Rheology on non-aerated system

Surface tension



*Filled: same apparent viscosity; hollow: same flow rate index

Same flow rate index*	
0.22% GG	58.4 ± 0.8[b]
0.3% LBG	54.0 ± 0.6[c]
0.3% SA	63.2 ± 0.9[a]
Same apparent viscosity*	
0.11% XAN	69.0 ± 1.0[a]
0.28% GG	56.4 ± 1.0[c]
0.25% SA	64.9 ± 1.0[b]
0.7% PEC	56.8 ± 1.2[c]

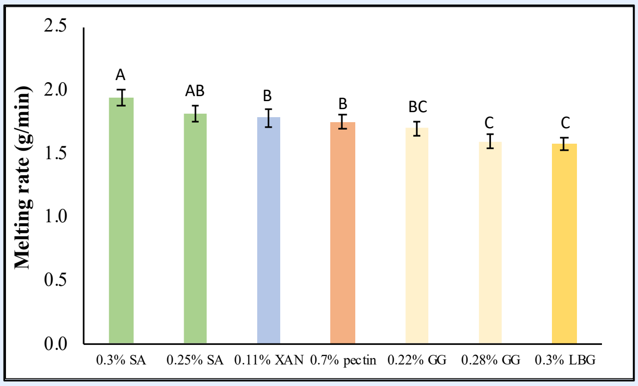
- Polysaccharides reduce surface tension
- The surface tension is related to the natures of polysaccharide
- Surface-active property results in air incorporation

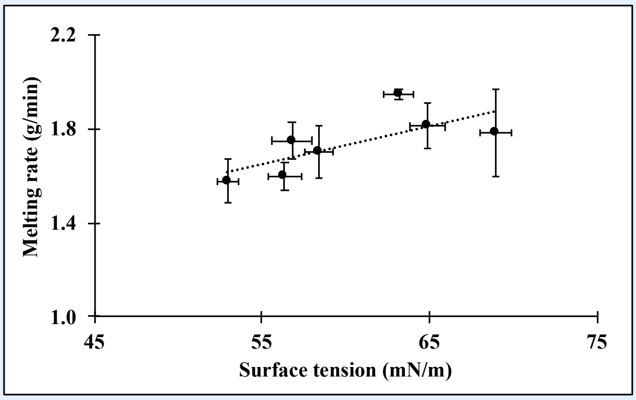
Overrun (%)

Same flow rate index*	
0.22% GG	17.5 ± 1.4[a]
0.3% LBG	13.7 ± 1.0[b]
0.3% SA	11.9 ± 2.9[b]
Same apparent viscosity*	
0.11% XAN	12.4 ± 0.7[b]
0.28% GG	16.1 ± 0.8[a]
0.25% SA	9.2 ± 1.5[c]
0.7% PEC	9.8 ± 1.4[c]

Phase 2. Rheology on non-aerated system

Meltdown





Key conclusions:

- No significant difference was found in induction time
- The nature of polysaccharide affected the melting rate.
- Anionic polysaccharide showed a faster melting rate than galactomannan

0.7% pectin

0.3% locust bean gum

Phase 3. Rheology on aerated system

Hypothesis: The effect of rheological properties on melting and dripping is caused by either apparent viscosity or shear-thinning behavior in the aerated frozen sucrose system.

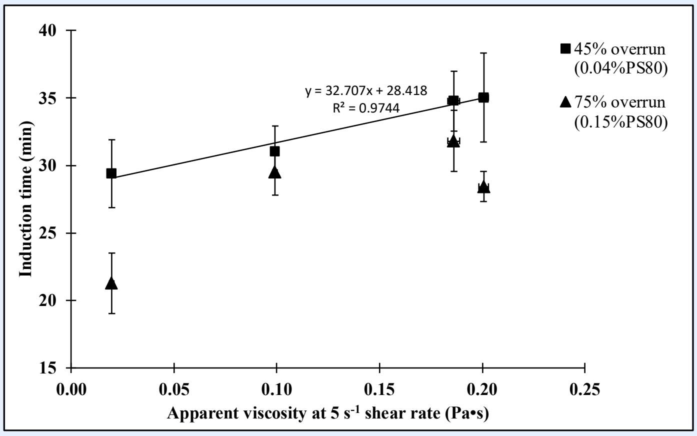
Polysorbate 80		Overrun
0.04%	→	45%
0.15%	→	75%

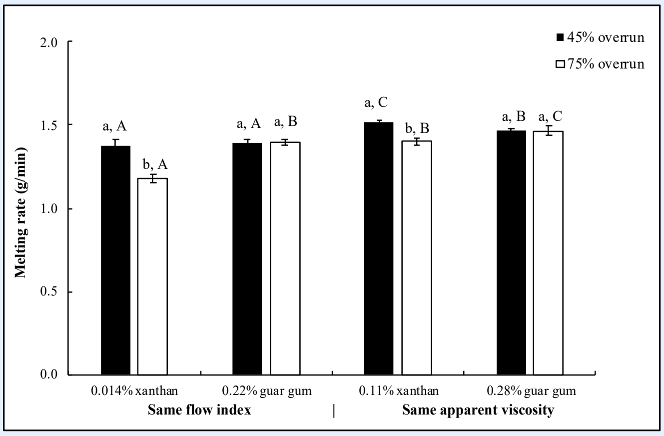
Experimental design

	Sample	Target overrun	Flow rate index	Apparent viscosity at 5 s^{-1} shear rate
Same flow rate index	0.014% xanthan	45%	0.76 ± 0.01	0.02 ± 0.00
		75%		
	0.22% guar gum	45%	0.74 ± 0.00	0.10 ± 0.00
		75%		
Same apparent viscosity	0.11% xanthan	45%	0.47 ± 0.00	0.20 ± 0.00
		75%		
	0.28% guar gum	45%	0.69 ± 0.00	0.19 ±0.00
		75%		

Phase 3. Rheology on aerated system

Meltdown



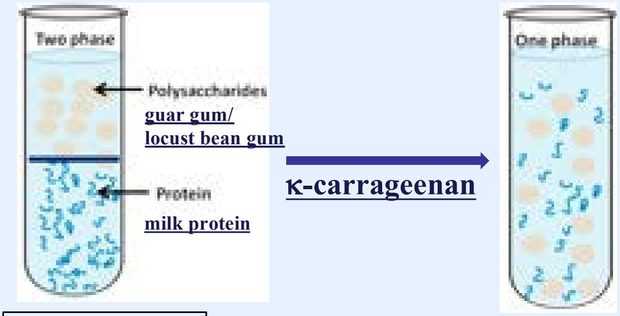


- A strong correlation was found between apparent viscosity and induction time, but not between the flow rate index and induction time
- The effect of overrun was only seen in xanthan, where increase in overrun decreased melting rate.

Phase 4. Phase separation on meltdown

Hypothesis: The protein-polysaccharide phase separation in serum results in a slow meltdown behavior due to the interaction between two immiscible phases.

Background



Phase separation

No phase separation

Experimental design

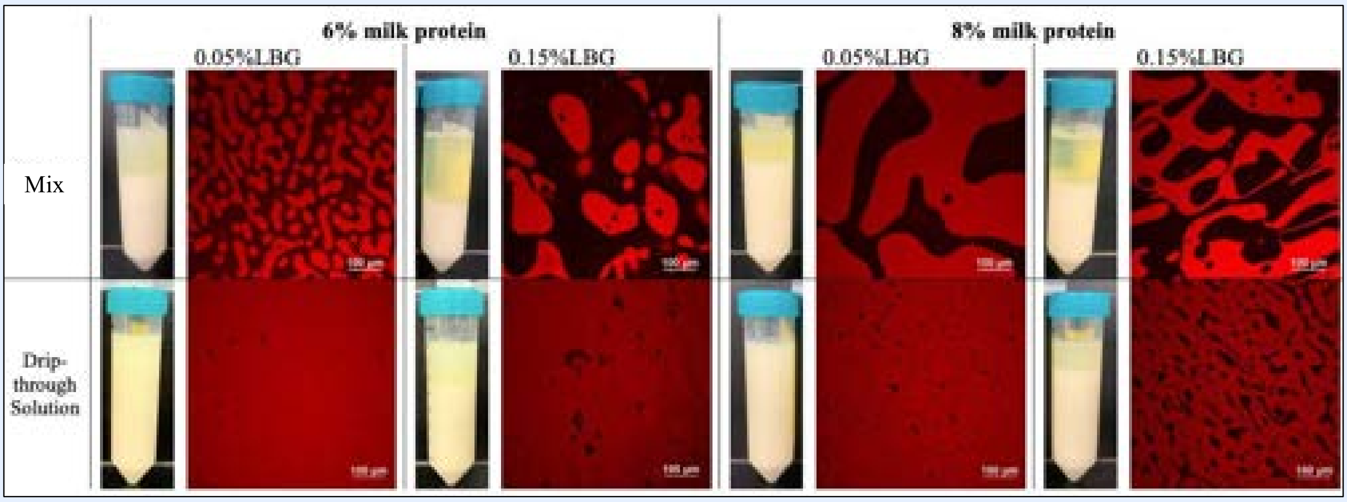
Protein (NFDM*)	Locust bean gum	Guar gum	κ-carrageenan
4%	0.05%	0.05%	0%
6%	0.15%	0.15%	0.015%
8%			

*NFDM: non-fat dry milk

Phase 4. Phase separation on meltdown

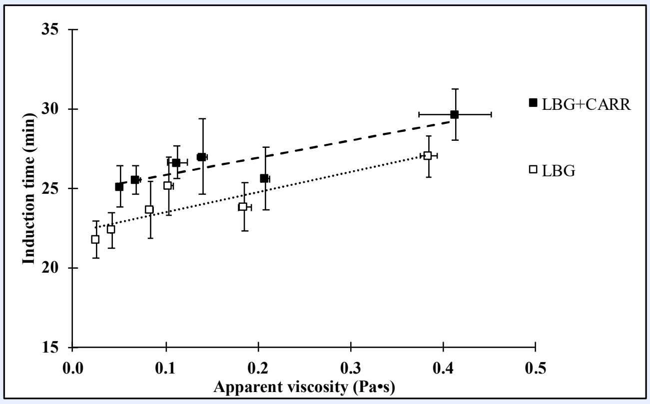
Phase separation

- CLSM provided additional information on phase separation
- Freezing prevented phase separation on LBG system



Phase 4. Phase separation on meltdown

Meltdown



6% protein

6% protein

0.05%LBG

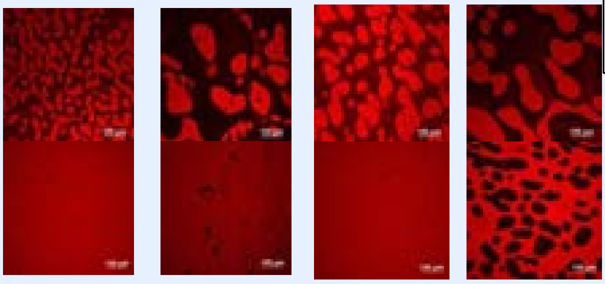
0.15%LBG

0.05%GG

0.15%GG

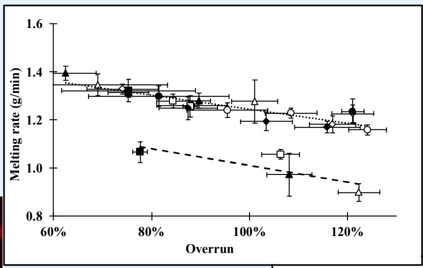
Mix

Drip-through solution

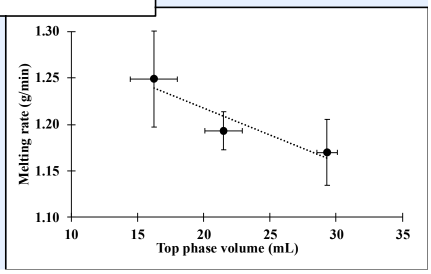


Key conclusions:

- Correlation between rheology and induction time only seen in LBG.
- Protein affected meltdown by achieving different overrun
- The more phase separation in the drip-through solution, the slower the melting rate (carrageenan+GG).



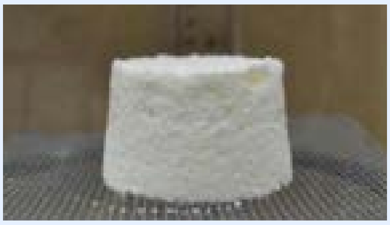
Wu, 2023



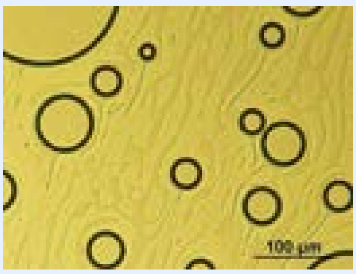
Phase 4. Phase separation on meltdown

Meltdown behavior

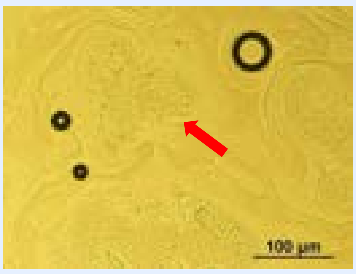
NFDM+LBG/GG



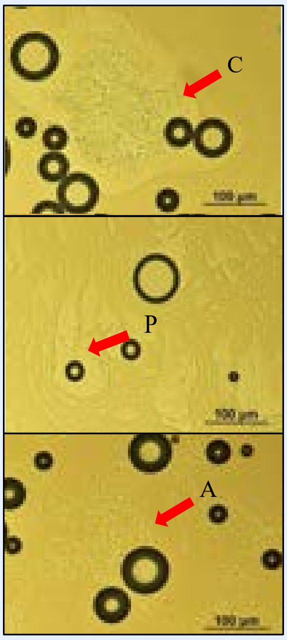
Guar



Locust bean



Melted samples observed under microscope.



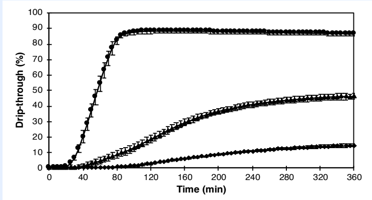
C: cryo-gel

P: protein layer

A: κ-carrageenan and protein aggregate

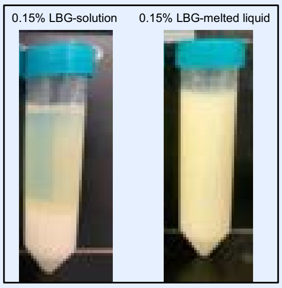
Conclusions

- Connection between melt-down and rheological properties still remains unclear
- Locust bean gum in general slows down the meltdown process through cryo-gel formation
- Freezing prevented phase separation in the locust bean gum system



Future recommendations

- The types of polysaccharide influence meltdown in the ice cream system
- Local viscosity vs. bulk viscosity in phase separation system
- The structure in the serum phase changes during freezing-melting process



Ice cream is complex and there is still so much we don’t understand

Thanks to all the students who have contributed to these studies