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Unraveling particle breakage in high-pressure homogenization: a novel focus on suspensions

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Introduction and methodology

Dehulled White Lupin flour (LF)

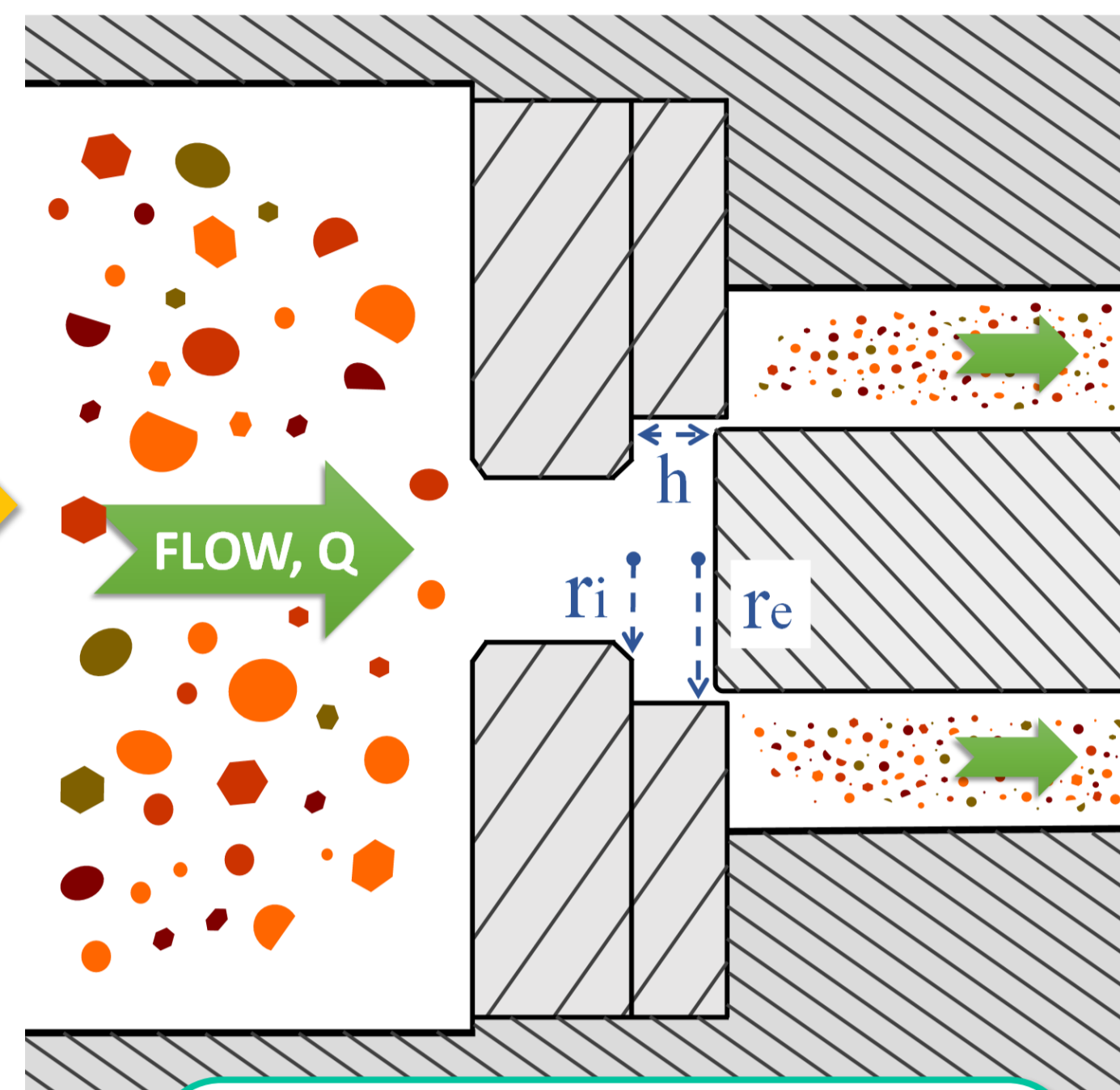
Agronomical and nutritional advantages

Particle sizes up to ~ 900µm

Unstable suspensions



- 40% protein
- 34% fiber
- 11% fats
- 4% glucides
- 11% others



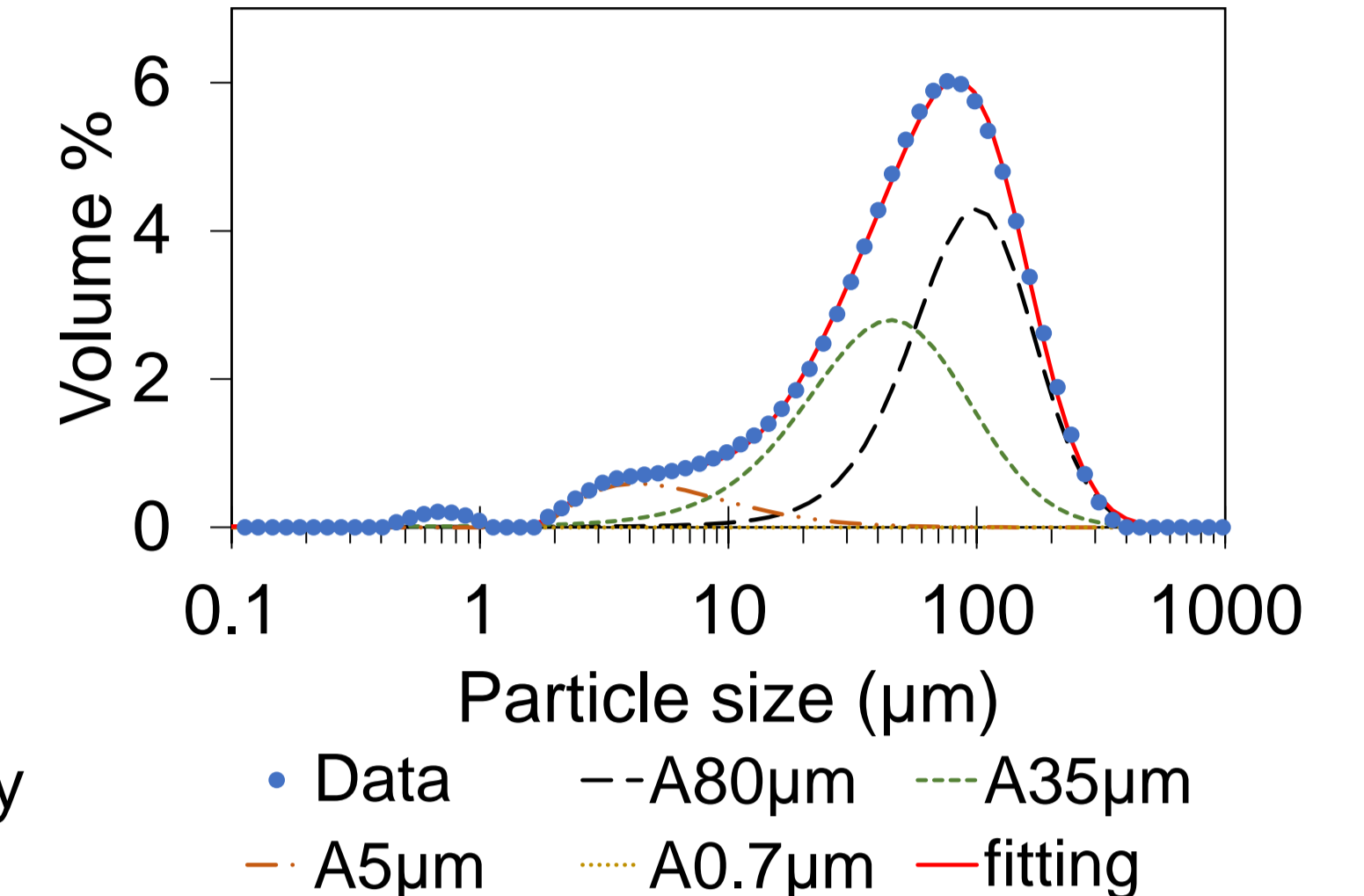
High-Pressure Homogenization (HPH)

- Proven effectiveness in stabilization of other legume-based suspensions
- Low energy consumption.
- Enhances functional properties.



- Stability
- Texture
- Viscosity

Ex: Deconvolution of the PSD of a LF suspension processed by HPH (30 MPa)



Phenomenological description via deconvolution and analysis of particle size distributions

Operating Conditions

Pressure drop (ΔP)
Number of passes (N)
Temperature (T)

Disruption Phenomena^{1,2}

Comparison of experimental relationships of max. particle size surviving processing (~D_{v,90}) vs ΔP, against theoretical scaling relations, based on:

$$\Delta P = \frac{\rho}{4} \left[\frac{Q}{2\pi r_i h} \right]^2 + \frac{6\mu Q}{\pi h^3} \ln \left(\frac{r_e}{r_i} \right) + \frac{\rho}{2} \left[\frac{Q}{2\pi r_e h} \right]^2$$

(for Re < 500)

$$\varepsilon \propto Q^{5/3} \mu^{-4/3} \Delta P^{4/3} \quad G \propto Q^{1/3} \mu^{-2/3} \Delta P^{2/3} \quad h \propto D_{v,90}$$

Lack of models that predict the **disruption phenomena** and the **breakage mechanisms** in complex suspensions

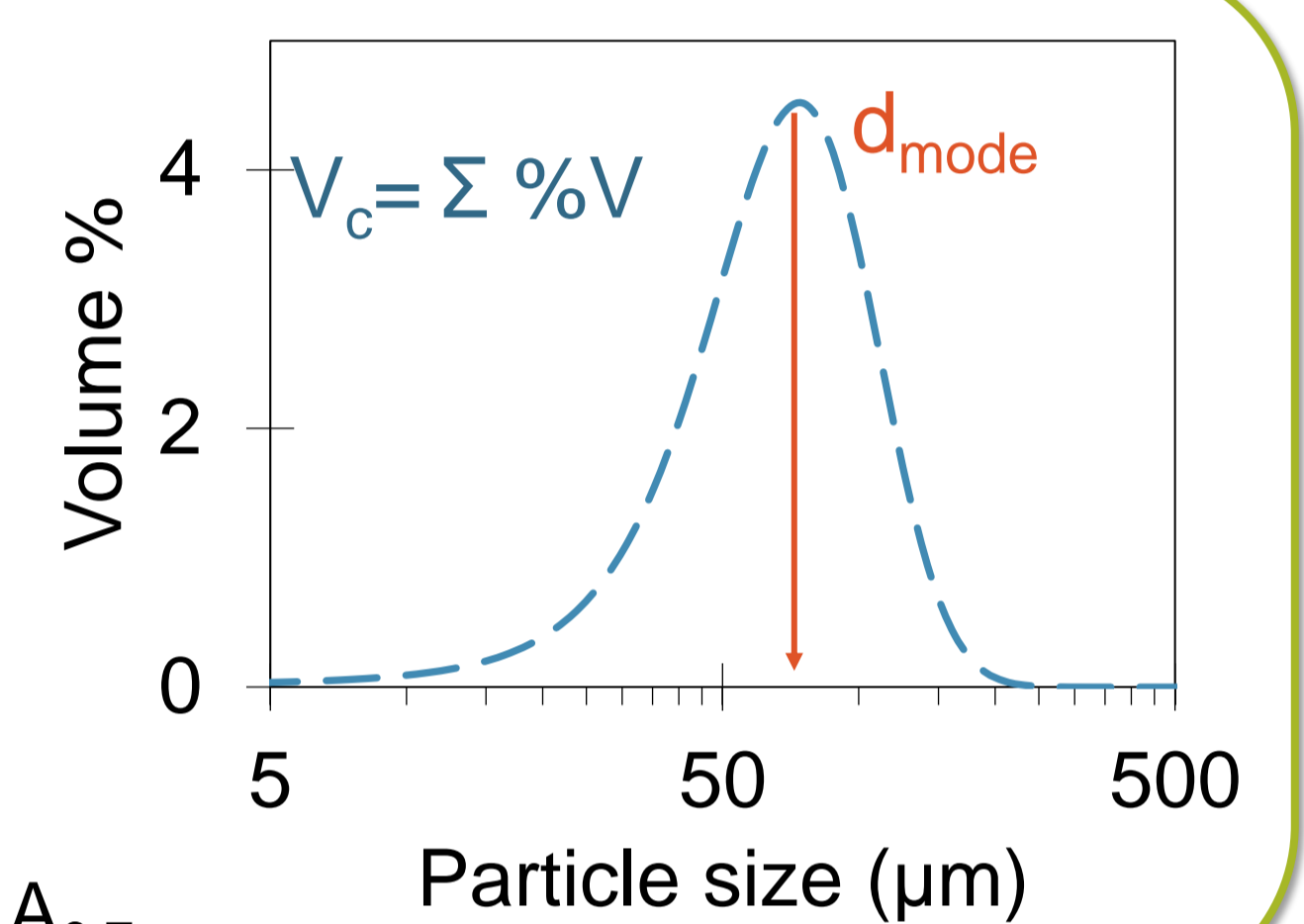
Breakage Mechanisms

Tracking of cumulated volume (V_c) and particle size mode (d_{mode}) as a function of ΔP

- Fragmentation: V_c ↓ ↓
- Erosion: d_{mode} ↓

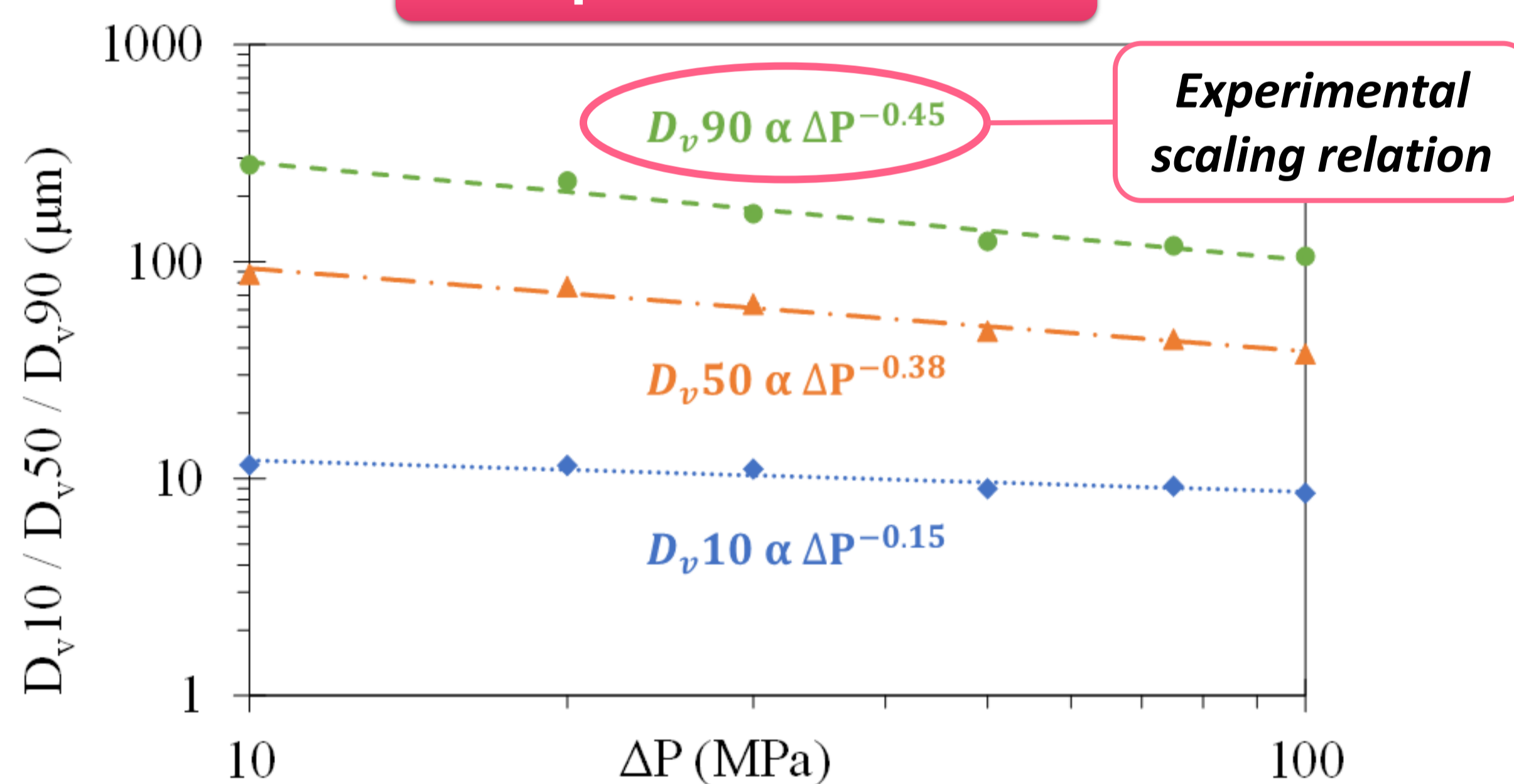
Identified populations:

A_{320µm}, A_{80µm}, A_{35µm}, A_{5µm}, and A_{0.7µm}

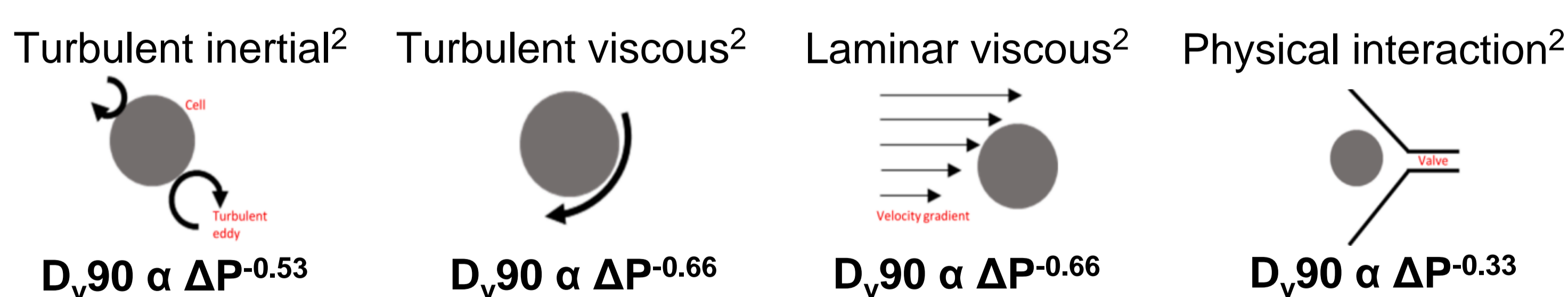


Results and Analysis

Disruption Phenomena

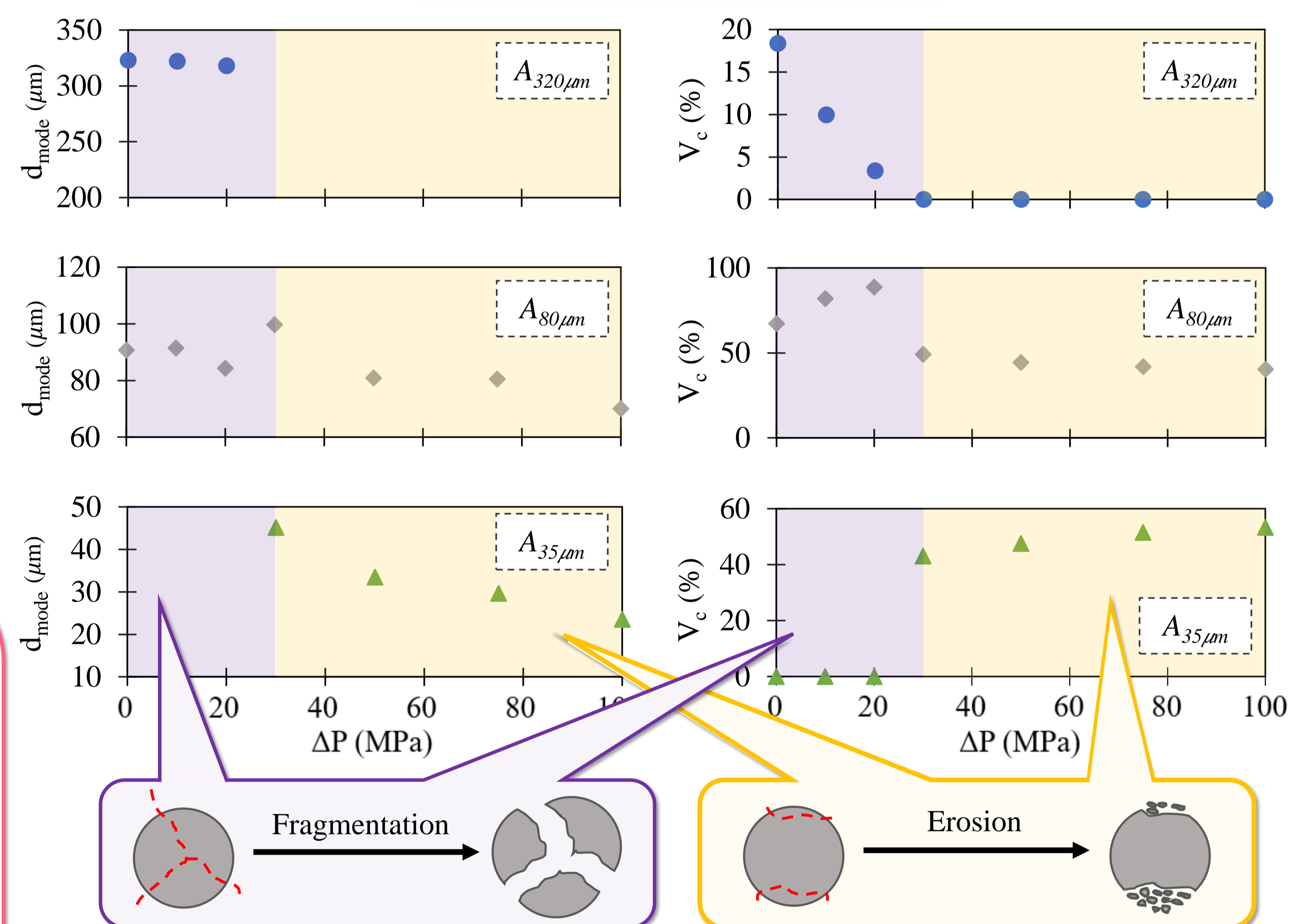


Theoretical scaling relations



The experimental exponent (-0.45) lies within predicted values, suggesting the presence of **physical interaction** (-0.33) in combination with at least one of the other proposed phenomena: laminar viscous (-0.66), turbulent viscous (-0.66), or turbulent inertial (-0.53).

Breakage Mechanisms



- At low ΔP (<30 MPa) → only fragmentation on population A_{320µm}
- At ΔP = 30 MPa → A_{320µm} and part of A_{80µm} populations are fragmented
- At high ΔP (>30 MPa) → fragmentation + erosion increases

Conclusions

- The findings indicate that physical interaction plays an important role in the particle breakup of lupin flour dispersions. This differs fundamentally from the disruption phenomena reported in the literature for emulsions (turbulent phenomena) and yeast cell suspensions (viscous shear phenomenon).
- The identified breakage mechanisms at play were found to depend on pressure drop; fragmentation dominates at low ΔP, and erosion appears at ΔP over 30MPa. This may lead to a decrease in energy efficiency above ΔP of 30MPa, as fragmentation is a more energetically efficient breakage mechanism than erosion.
- This work provides a phenomenological framework that can be used to connect HPH operating conditions with particle-size-dependent product functionalities, contributing to the development of sustainable food processing strategies and products with reduced dependence on refined ingredients.

References

- 1 Phipps, L. W. (1975). The fragmentation of oil drops in emulsions by a high-pressure homogenizer. *Journal of Physics*
- 2 Innings, F., Alameri, M., Koppmaier, U. H., & Håkansson, A. (2020). A mechanistic investigation of cell breakup in tomato juice homogenization. *Journal of Food Engineering*

Acknowledgments

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