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Deciphering the key parameters that influence the rheological properties of concentrated milk protein systems using a multifactorial approach

Francois Martin, Florence Rousseau, Jeehyun Lee, Gaëlle Tanguy, Emeline Gousse, Marie-Hélène Famelart, Romain Jeantet, Cécile Le Floch-Fouéré

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CONTEXT & AIMS

- ✓ Dairy ingredients with high protein content :
 - high value-added products,
 - increasing demand,
 - specific properties,
 - multitude of applications: cheese, bakery, infant formulae, nutritional products for the elderly and athletes...
- ✓ Rheological properties of protein concentrates greatly modulate the spray drying process and final powder quality, so they must be controlled.
- ✓ Aims :
 - identify the key parameters playing a role in viscosity changes
 - understanding molecular mechanisms that affect the viscosity of high protein concentrates during their manufacture.

STRATEGY

- Fresh whey proteins (WP) and casein micelles (CM) concentrates (100 g protein.kg⁻¹) in osmosed water.
- Mixes: Casein (Cas) to WP of 91:9 (Cas 91), 81:19 (Cas 81), 43:57 (Cas 43) and 7:93 (Cas 7).
- 4 different technological schemes (Fig. 1) :
 - **Control**,
 - **HT 10%** (74°C/30 s for Cas91-Cas81; 70°C/30 s for Cas43-Cas77)
 - **HT 20%** (74°C/30 s for Cas91-Cas81; 70°C/30 s for Cas43-Cas77)
 - **2 HT** (74°C/30 s for Cas91-Cas81; 70°C/30 s for Cas43-Cas77)
- Samples = concentrates 200 g protein.kg⁻¹
- Viscosity 40°C: 1-500 s⁻¹

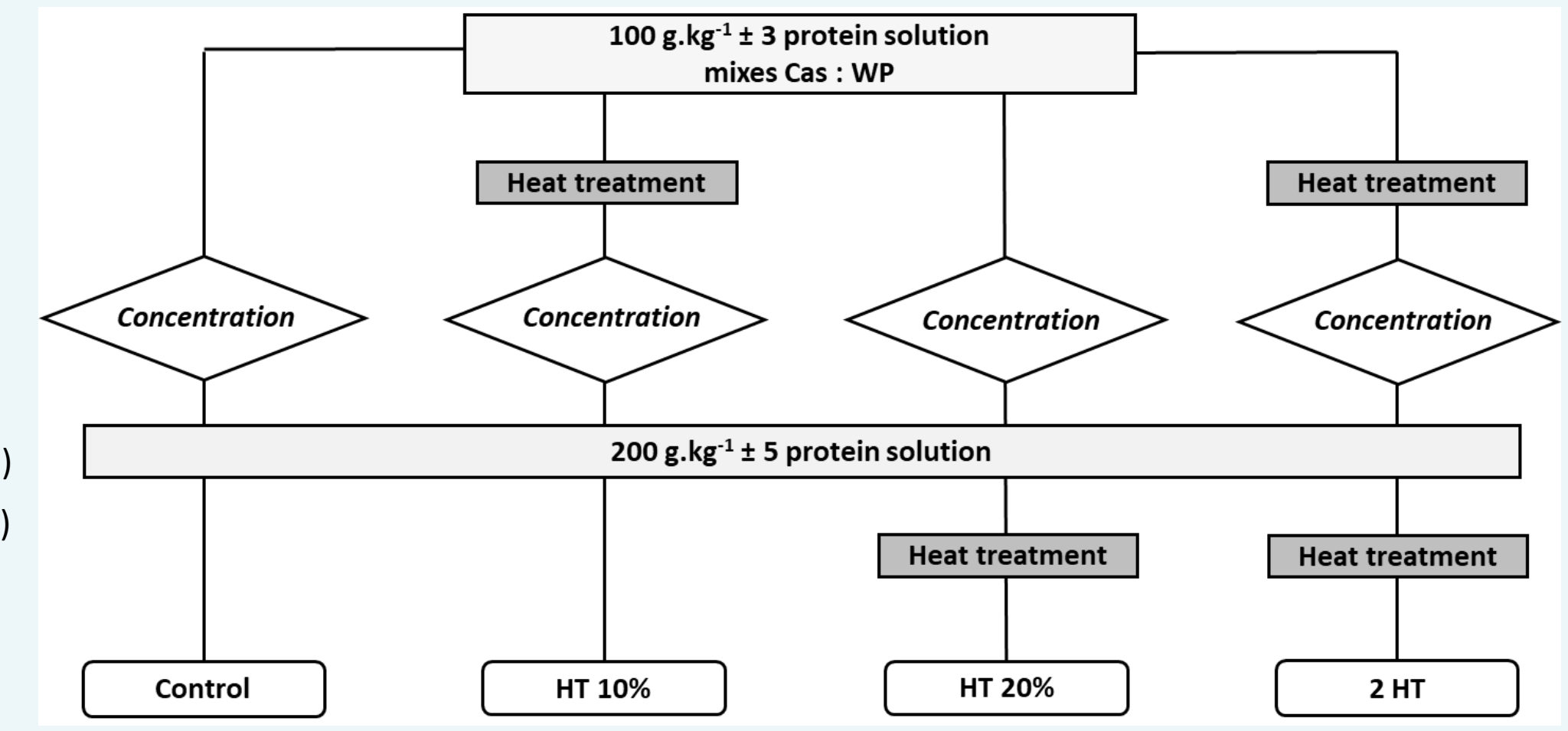
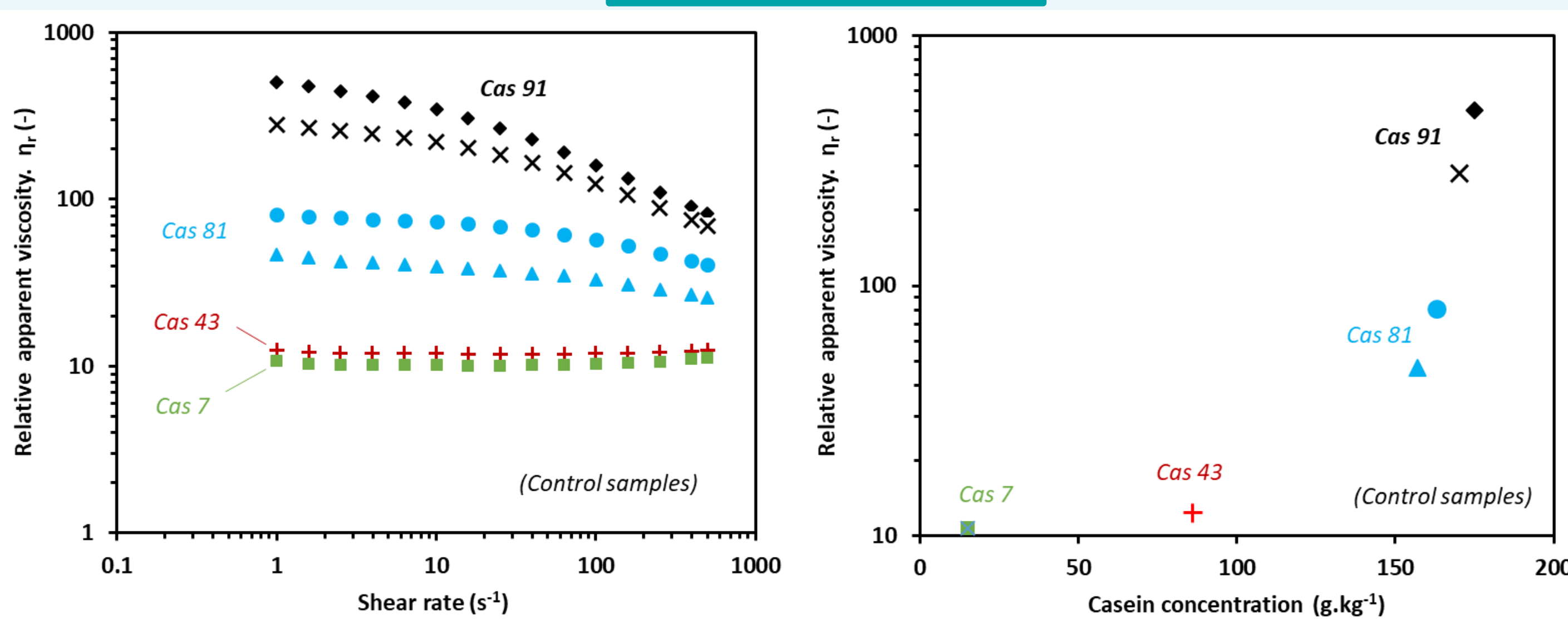


Fig. 1: Different process schemes

RESULTS

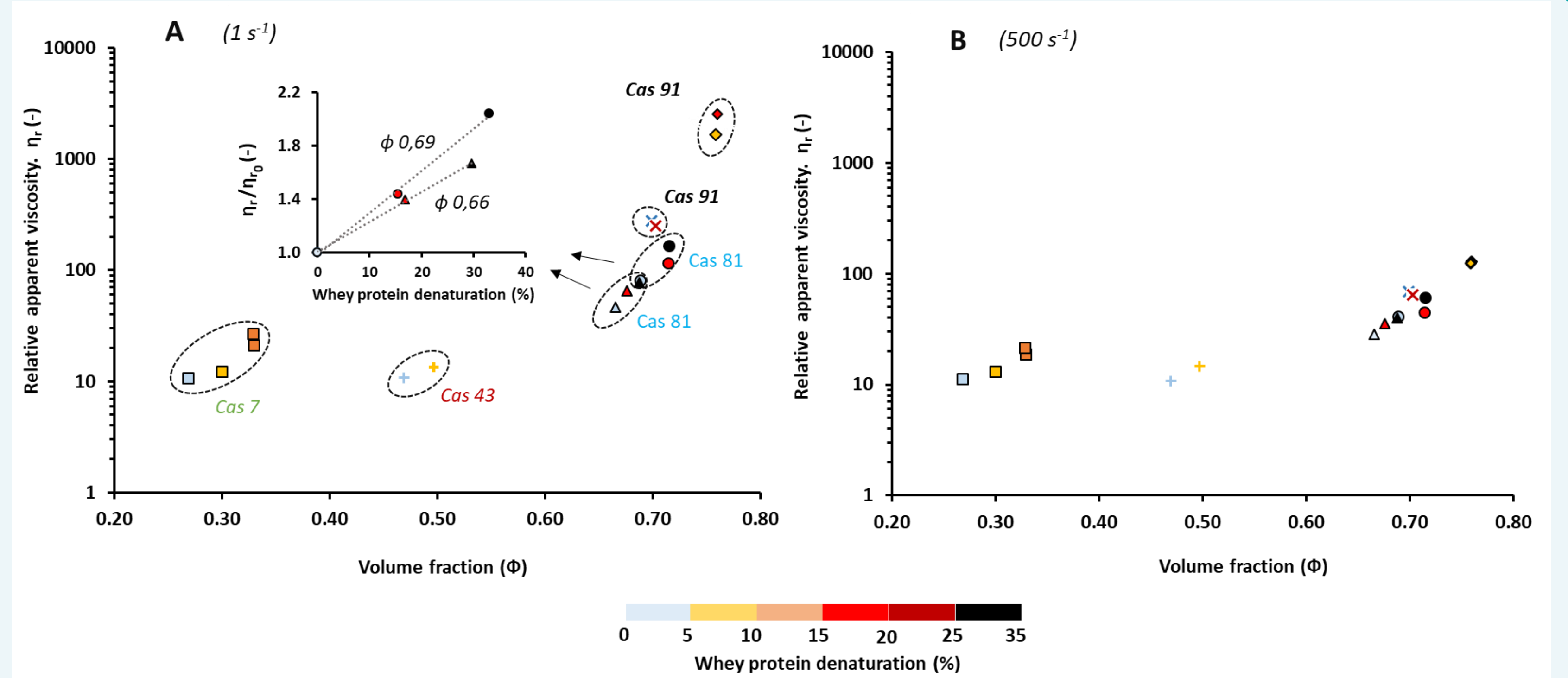
Impact of Cas:WP ratio



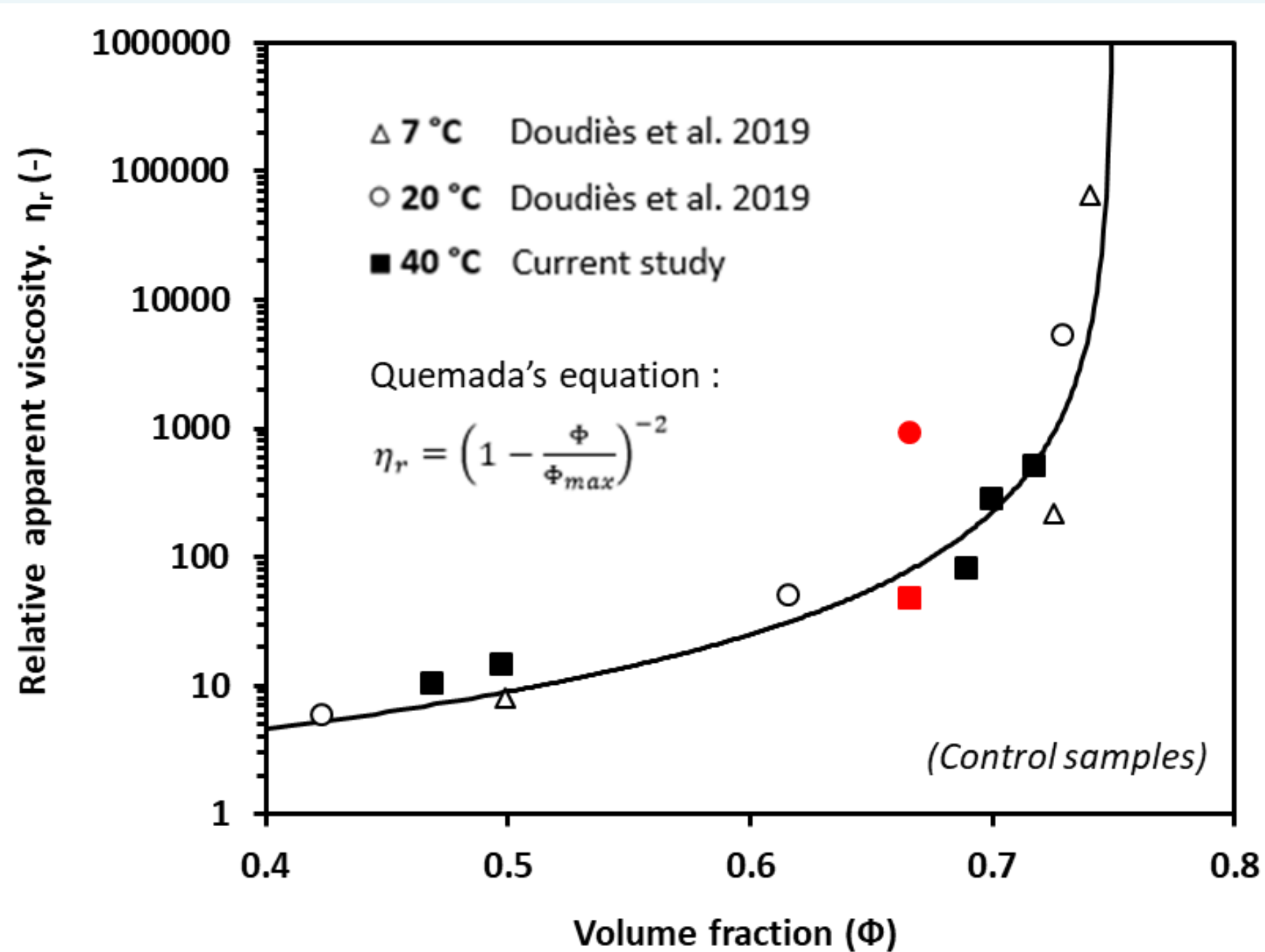
- 1 s⁻¹: $\eta_{r,Cas 91} = 50 \times \eta_{r,Cas 43}$; $\eta_{r,Cas 91} = 8 \times \eta_{r,Cas 81}$
- [CM] ↑ ⇒ inter-micelle distance reduction.
 - increased repulsions between CM
 - hindered flow of CM to keep their inter-distances
- Cas 91 and Cas 81 concentrates : shear-thinning behaviour.
 - hindered flow of solvent across particles (at low shear)
 - less hindered at high shear as CM move too

Impact of WP denaturation level

- Cas 7 : WP denaturation max = 14% ⇒ $\eta_{r,Cas 7 \text{ heat treated}} = 2 \times \eta_{r,Cas 7 \text{ untreated}}$
 - water holding capacity of denatured WP > native WP (A).
- Cas 81 : linear increase of the viscosity with the WP denaturation (inset A).
 - formation of large aggregates with irregular shapes, i.e. CM-WP complexes and soluble aggregates ⇒ ↓ packing density and ↑ viscosity.
- Cas 91 :
 - concentrates with $\Phi=0.70$ ⇒ no viscosity differences between untreated and heat-treated concentrates.
 - $\Phi=0.76$, ↑ (11%) in the WP denaturation level ⇒ ↑ (52%) in viscosity (A).
- The increase in viscosity induced by the heat-treatment was smaller at higher shear rates than at low shear for Cas 81 and Cas 91 (B).



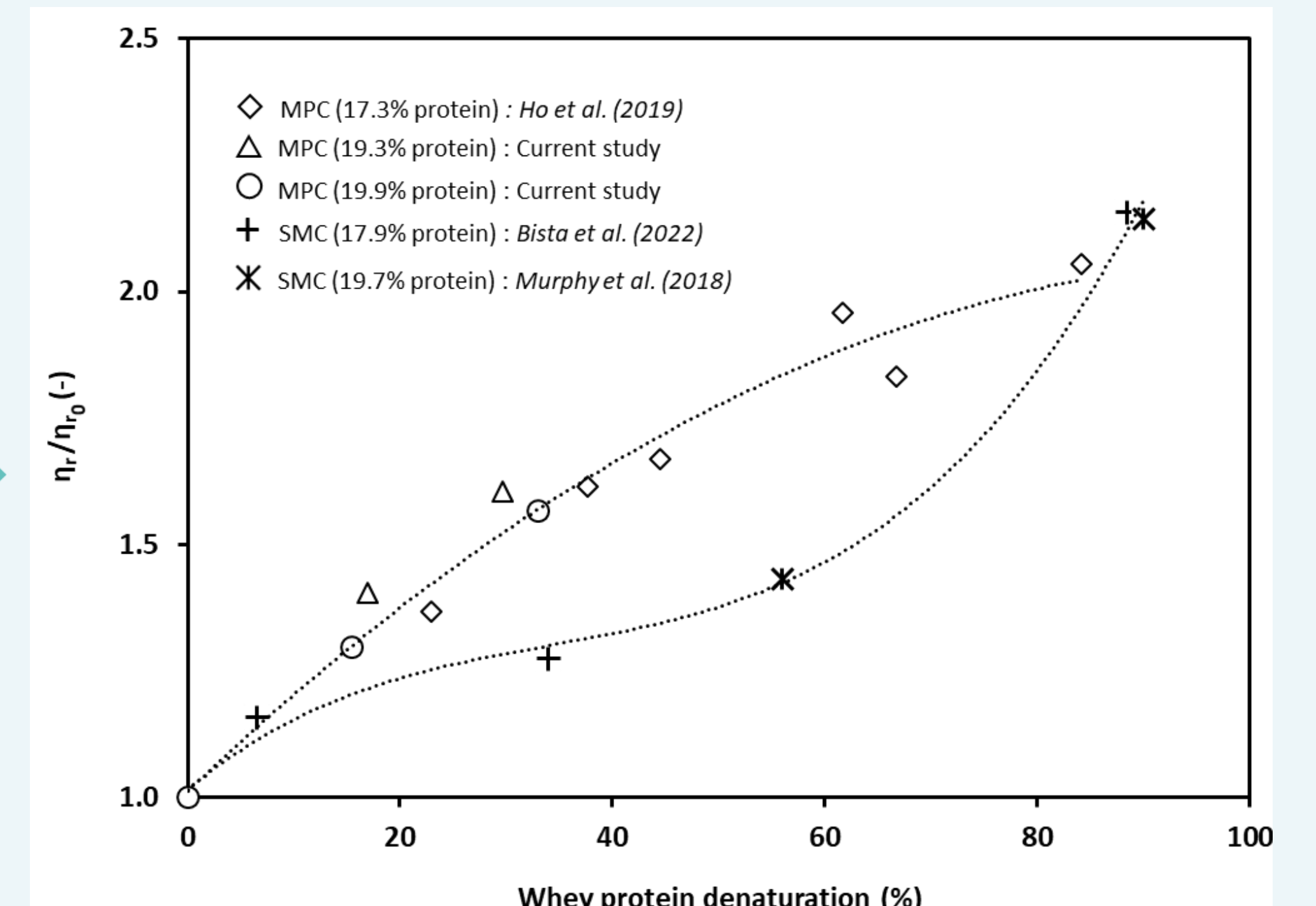
Impact of temperature



- $\eta_r = f(\Phi)$
- $\Phi_{max} = 0.75$ i.e. $[\text{casein}]_{max} = 192 \text{ g.L}^{-1}$
- Same Φ but different η_r (red samples) : Cas:WP ratio? soluble components? mineral content?...

- MPC (milk protein concentrate) ⇒ logarithmic trend
- SMC (skim milk concentrate) ⇒ exponential trend
- Below 85 % of WP denaturation : ratio η_r/η_{r0} ⇒ MPC > SMC
 - MPC : heat treatment at high protein content ≠ SMC : heat treatment at low protein content (milk before evaporation) ⇒ The protein content during a heat treatment is known to affect the type of aggregates formed.

Impact of concentrate type



CONCLUSION & PERSPECTIVES

- This study shows the influence of 3 key parameters, i.e. Cas:WP ratio, WP denaturation level and temperature, on the rheological behavior of dairy protein concentrates at 40°C, a relevant temperature for the spray-drying process (atomization step) :
 - Cas 7 and Cas 43 ⇒ Newtonian behavior / Cas 81 and Cas 91 ⇒ shear-thinning behavior ; Cas 91 ⇒ highest viscosity.
 - Changes in viscosity of concentrates induce by the heat treatment depend of the WP denaturation level, the Cas:WP ratio and the concentrate type.
 - $\eta_r = f(\Phi)$ according to Quemada's equation regardless of the temperature and $\Phi_{max} = 0.75$, nevertheless the Cas:WP ratio (i.e. protein size diversity) seems to modulate this relation.
- Relations between rheological behavior of concentrates and physical properties of powders such as particle size, density... should be investigated in a future work.