Contribution of starch and protein to the mechanical properties of plant-based food

Zhihong Lyu, Guido Sala, Elke Scholten

Physics and Physical Chemistry of Foods, Wageningen University,

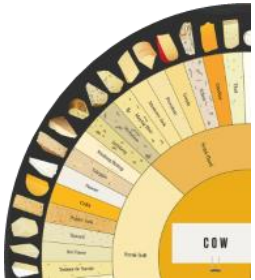
4th of Nov, 2021

WAGENINGEN
UNIVERSITY & RESEARCH

Background

Vegan cheese

Oil content: 20-22%
Starch content: 21-26%
Protein content: 0-3 %



Hardness

Brittleness

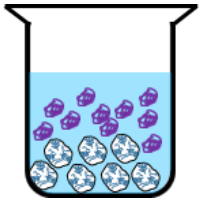
Stiffness

Emulsion-filled starch protein gel

Aim: to study the relative contribution of starch and protein to the gel texture

WAGENINGEN
UNIVERSITY & RESEARCH

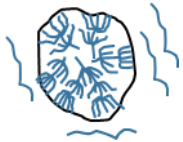
Gel formation induced by heat treatment



Before heating

Starch granules

0.8 g water/g MS



After heating

Swollen starch granule

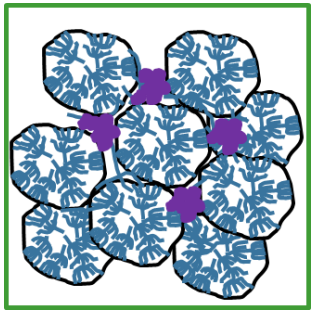
7.0 g water/g MS

Protein powders

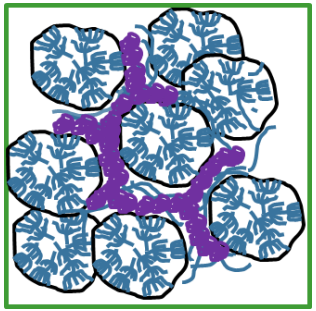
6.6 g water/g PPI

Unfolded protein

4.8 g water/g PPI



Filled gel

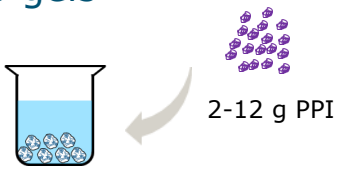


Bicontinuous gel

Water availability in composite gels

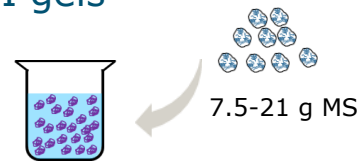
Maize starch (MS) Pea protein isolate (PPI)

MS gels



12 g MS
88 g Water

PPI gels

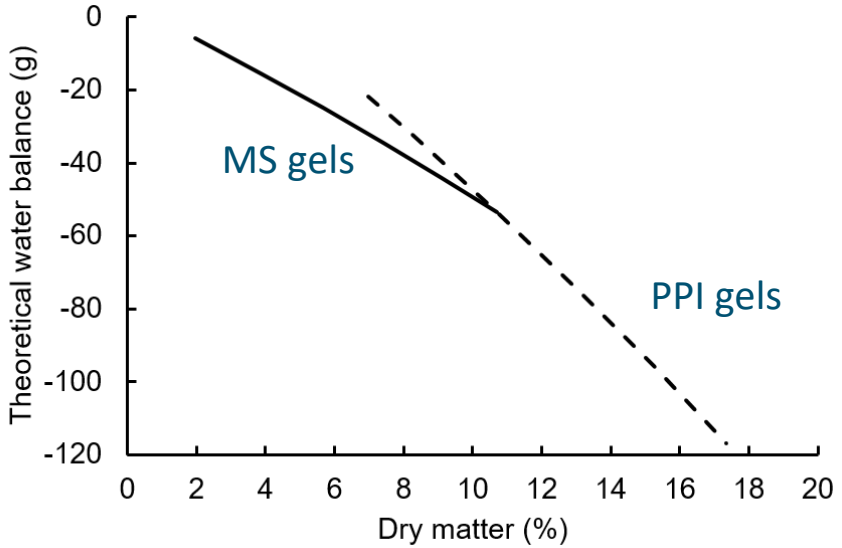


12 g PPI
88 g Water

WHC of MS & PPI

Theoretical water balance

= Water available - Water for MS - Water for PPI



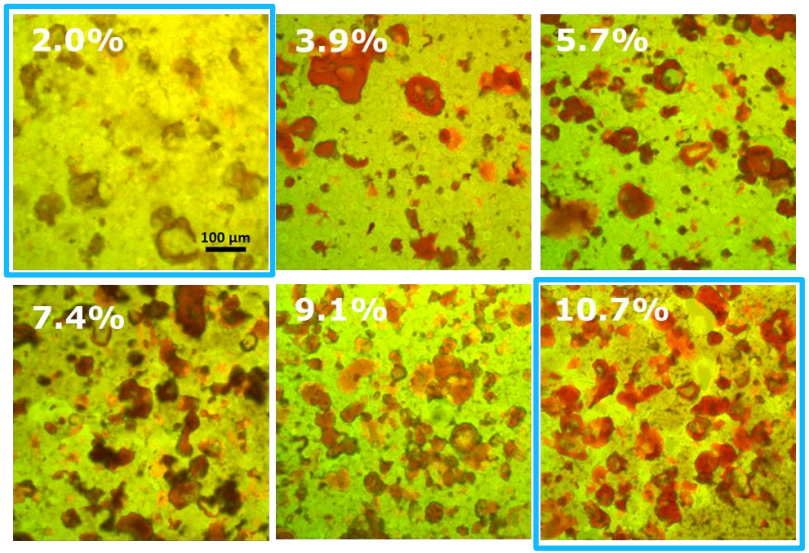
- Water is insufficient in all the starch-protein composite gels.

WAGENINGEN
UNIVERSITY & RESEARCH

Microstructure of MS gels and PPI gels

MS gels

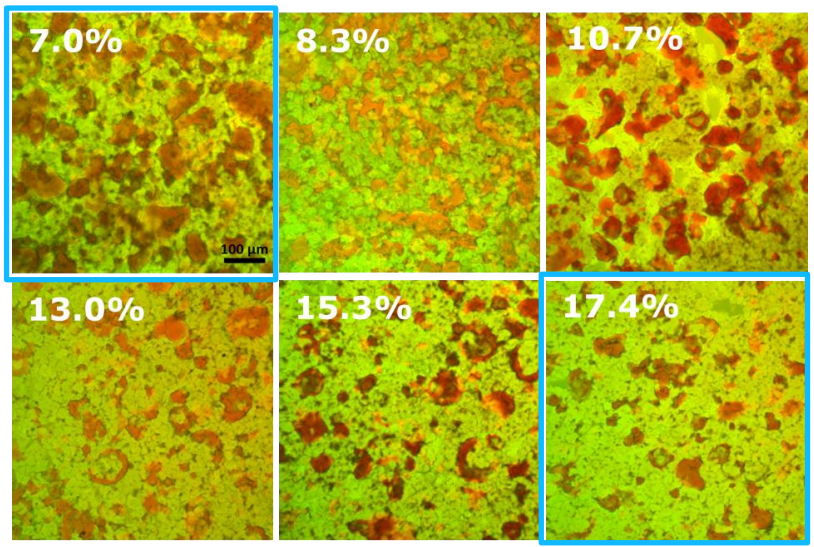
Filled gel



Starch in green; Protein in red.

PPI gels

Bicontinuous gel

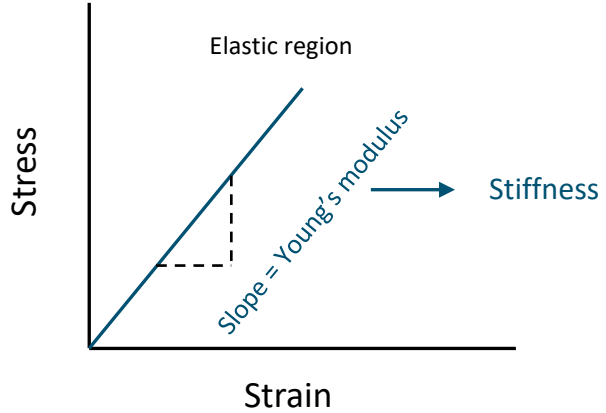


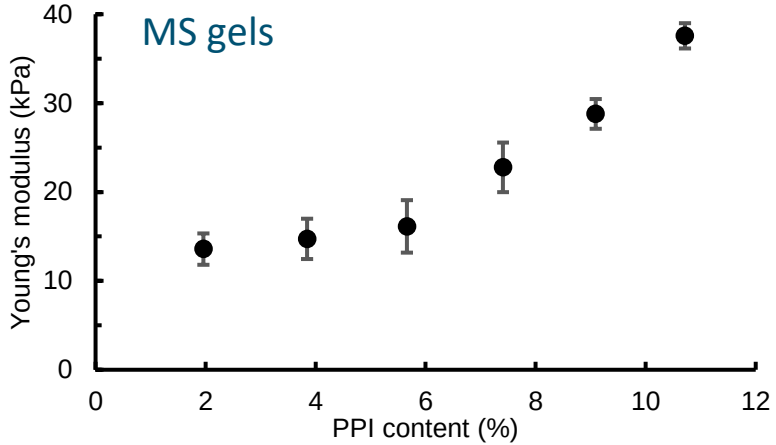
Filled gel

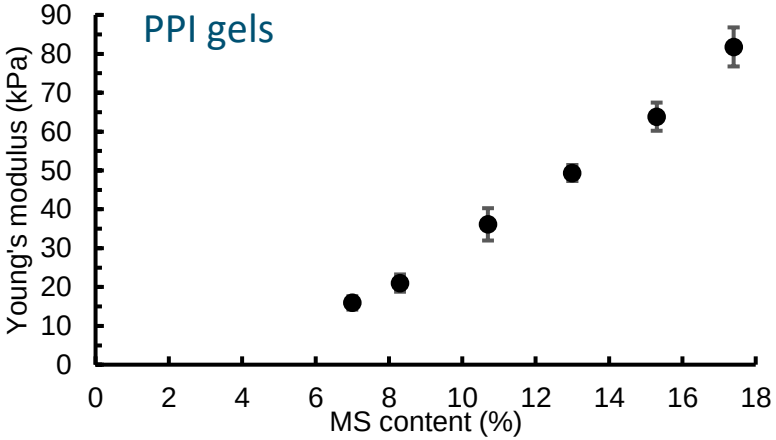
WAGENINGEN
UNIVERSITY & RESEARCH

Mechanical properties of the gels

Compression test



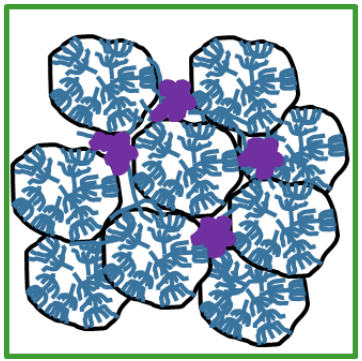




WAGENINGEN
UNIVERSITY & RESEARCH

Mathematical models for different gel structure

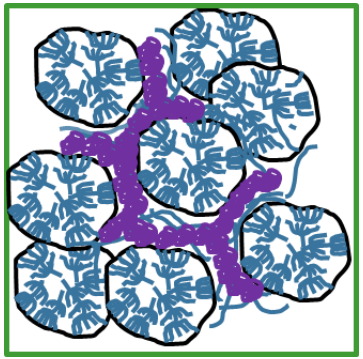
Filled gel



MS

PPI

Bicontinuous gel



Volume fraction
Modulus
(MS and PPI phases)

Smith model

$$G' = \frac{3M + 4.5 + (10.5M - 10.5)\varphi}{3M + 4.5 - (3M - 3)\varphi} G'_m$$

M: Ratio between the storage modulus of the filler and the gel matrix
φ: volume fraction of the fillers
G'_m: Modulus of gel matrix

Davies model

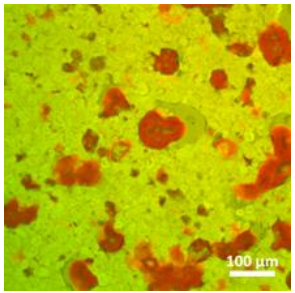
$$G'^{1/5} = \varphi_s G_s'^{1/5} + \varphi_p G_p'^{1/5}$$

G'_s: Modulus of starch phase;
G'_P: Modulus of protein phase;
φ_s: Volume fraction of starch phase;
φ_P: Volume fraction of protein phase;

$$E = 3G'$$

WAGENINGEN
UNIVERSITY & RESEARCH

Volume fractions estimated by CLSM image analysis



ImageJ

Red (PPI) area (µm²)

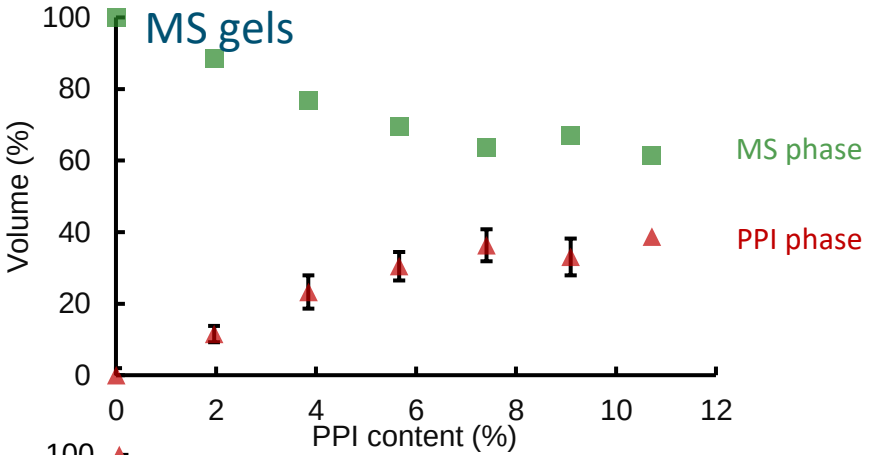
Image area

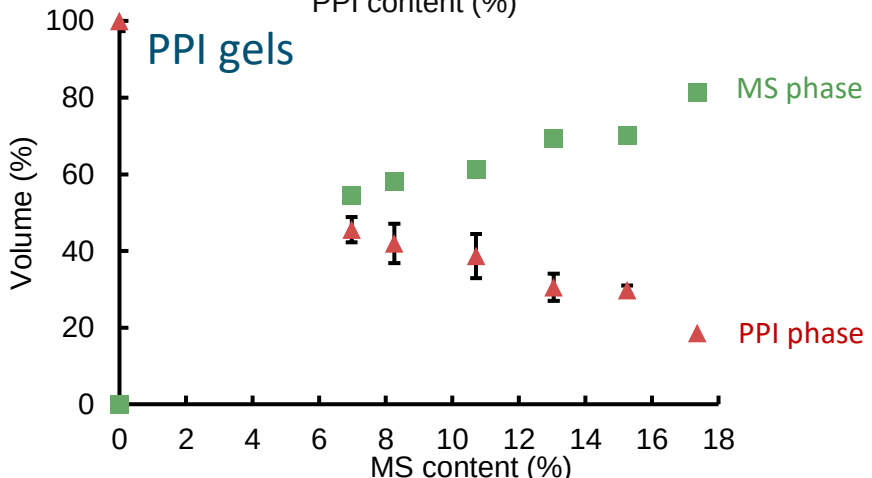
Red fraction in image

5 images

Volume fraction of PPI

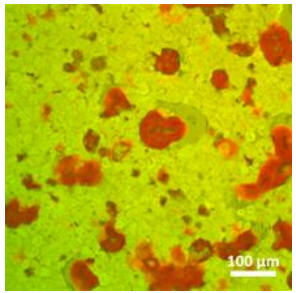
φ_{PPI} (%) → φ_{MS} (%)





WAGENINGEN
UNIVERSITY & RESEARCH

Effective MS or PPI concentrations in their corresponding phases



φ_{PPI} (%)

φ_{MS} (%)

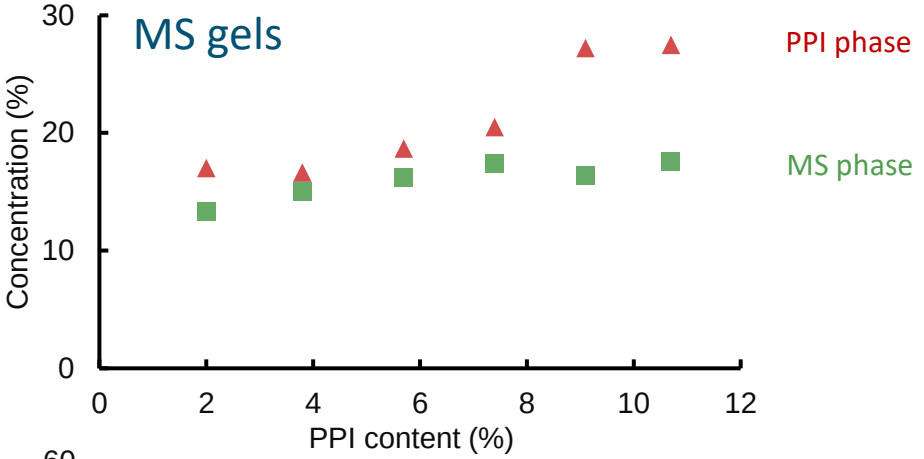
Before heating

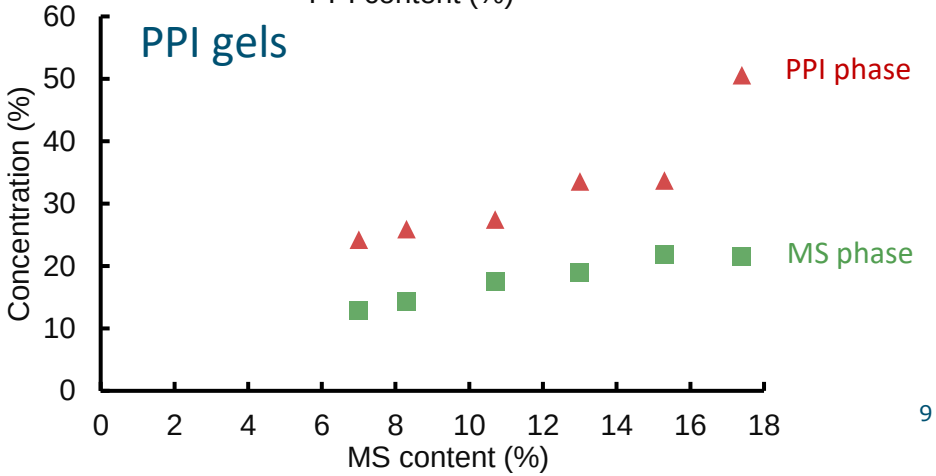
$m_{PPI\ powder}$ —ρ→ $\varphi_{PPI\ powder}$

$\varphi_{PPI\ phase}$ ↓

After heating

$C_{PPI\ in\ PPI\ phase}$ ← $\varphi_{water\ in\ PPI\ phase}$

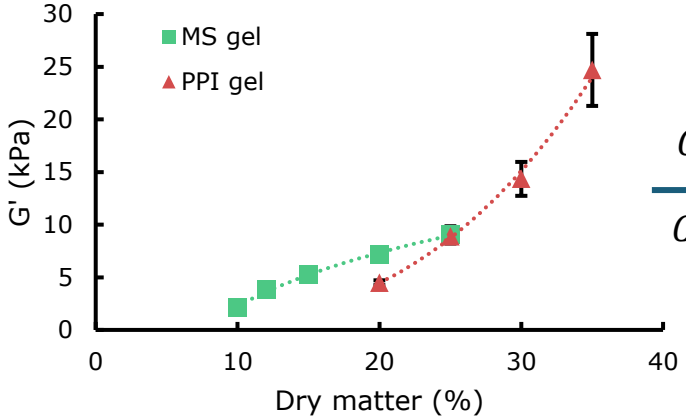




WAGENINGEN UNIVERSITY & RESEARCH

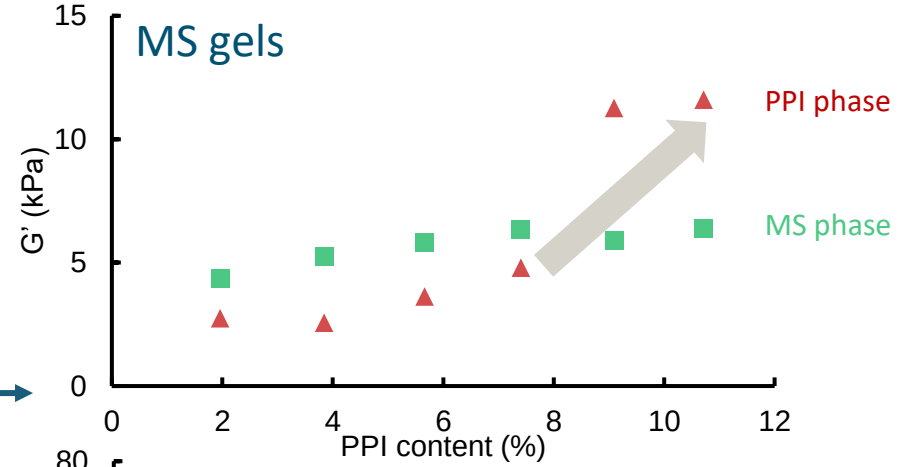
Moduli of individual MS and PPI phases in the composite gels

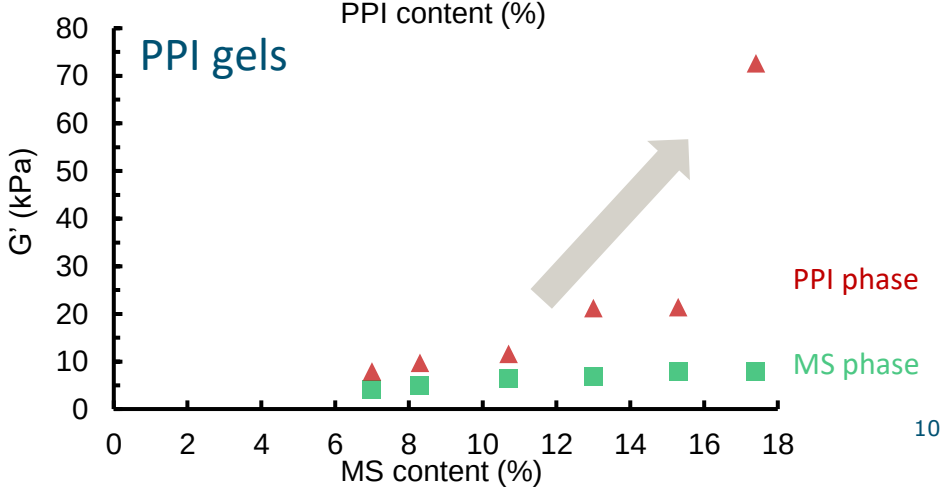
Calibration curves of single component gels



$C_{MS\ in\ MS\ phase}$

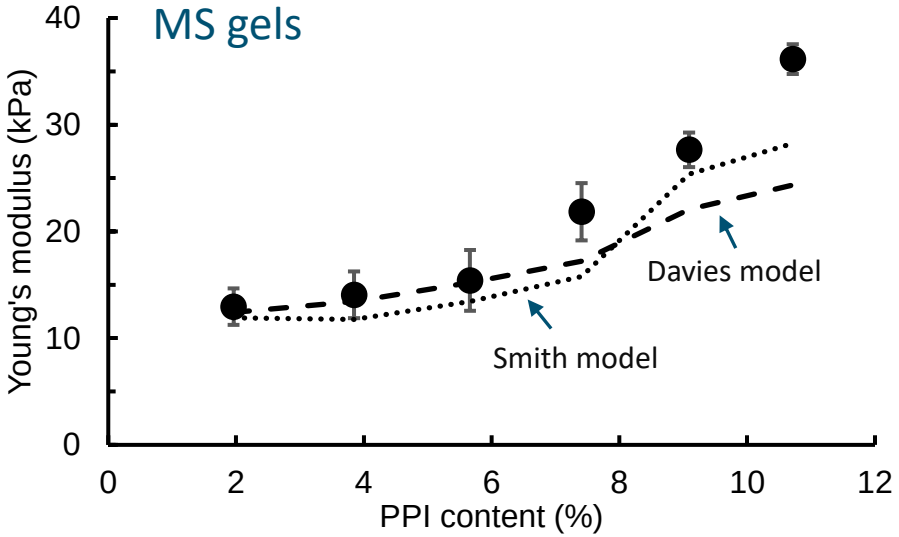
$C_{PPI\ in\ PPI\ phase}$

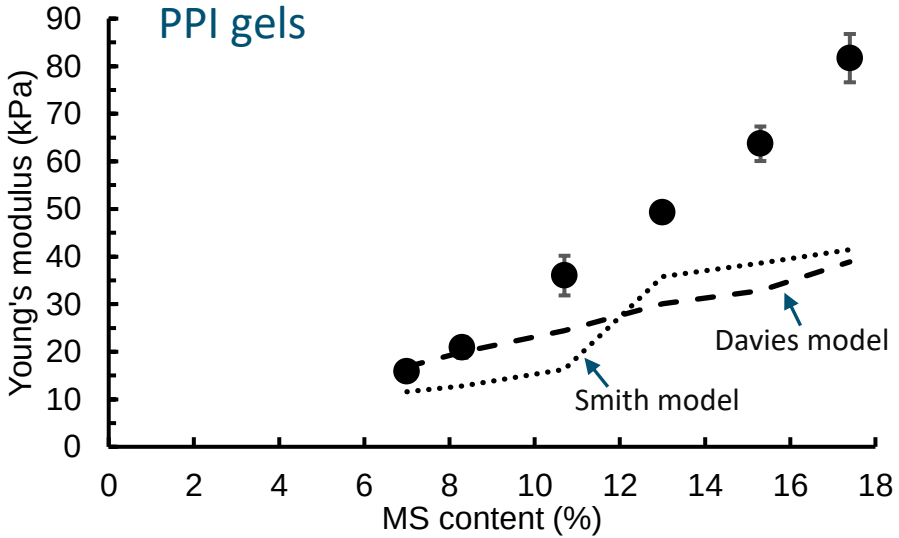




WAGENINGEN
UNIVERSITY & RESEARCH

Comparison between estimated data and measured data

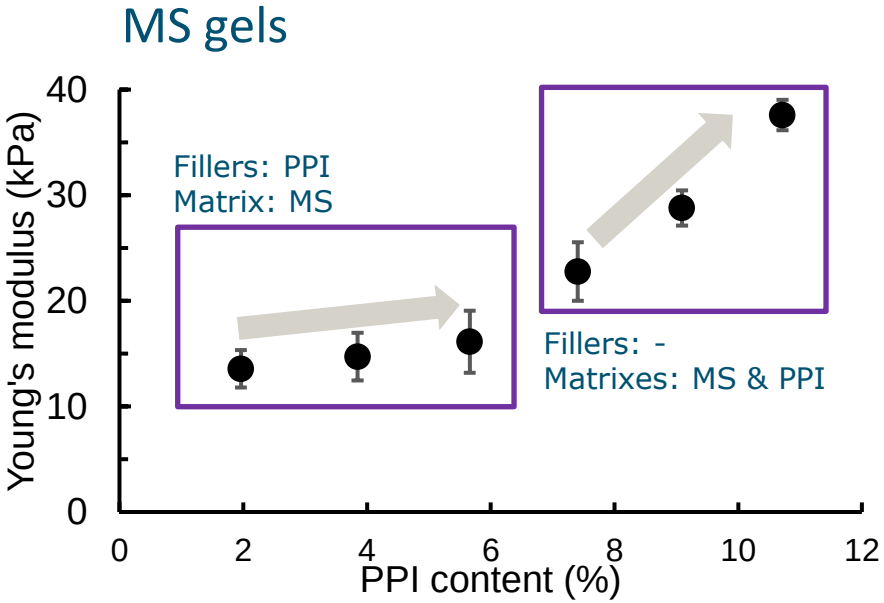


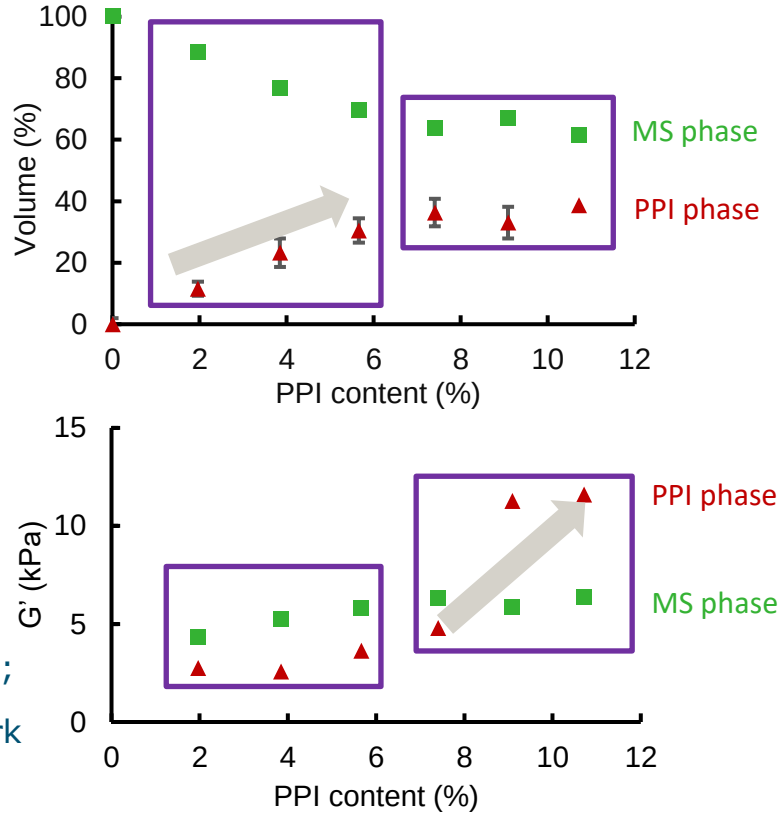


- Smith and Davies models are not sensitive to the structure of our studied gels;
- Models are more dependent on the volume fractions and moduli of the starch and protein phases.

WAGENINGEN
UNIVERSITY & RESEARCH

Relative contributions of MS and PPI to gel stiffness

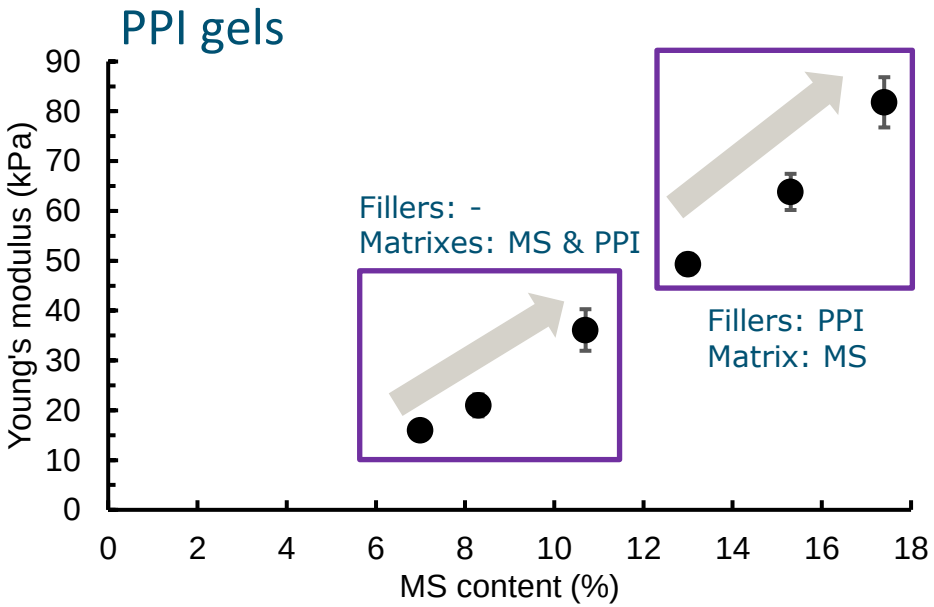




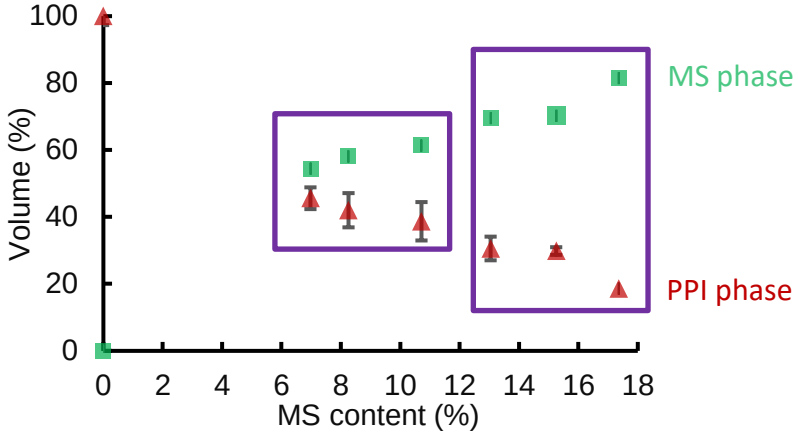
- In filled gels, PPI fillers have limited effects on the gel stiffness;
- In bicontinuous gels, gel stiffness depends more on the network with the higher strength.

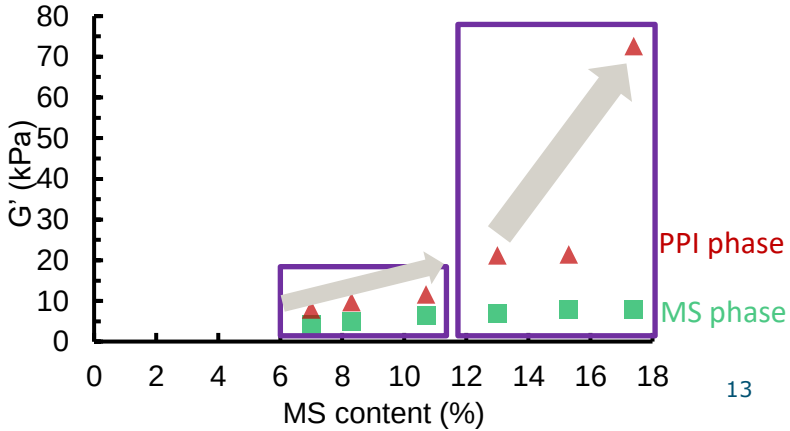
WAGENINGEN
UNIVERSITY & RESEARCH

Relative contributions of MS and PPI to gel stiffness



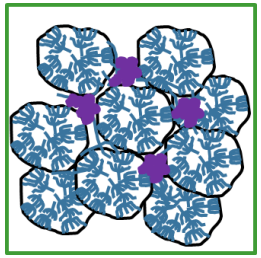
- In bicontinuous gels, gel stiffness depends more on the network with the higher strength;
- PPI fillers dominate gel stiffness when their moduli are substantially higher than starch matrix.



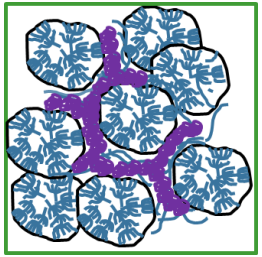


WAGENINGEN
UNIVERSITY & RESEARCH

Conclusions



- Starch matrix dominates the gel stiffness;
- $G'_{Fillers} \gg G'_{Matrix}$, Protein fillers dominate the gel stiffness;



- Gel stiffness depends on the network with the higher modulus.

Thank you for listening!

WAGENINGEN
UNIVERSITY & RESEARCH

PLANT4
TEXTURE

CHINA SCHOLARSHIP COUNCIL