Prof. Jaroslav Katona
University of Novi Sad

Jointly elaborated by: Instituto Politécnico do Porto

AGRIMA

Biopolymers obtained by food waste valorization

Funded by the European Union

Erasmus+
Enriching lives, opening minds.

Higher education

erasmus+ PORTUGAL EDUCAÇÃO E FORMAÇÃO

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Agri-food Waste Management for Sustainable bio-economy through Higher Education curricula and upskilling

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Goals

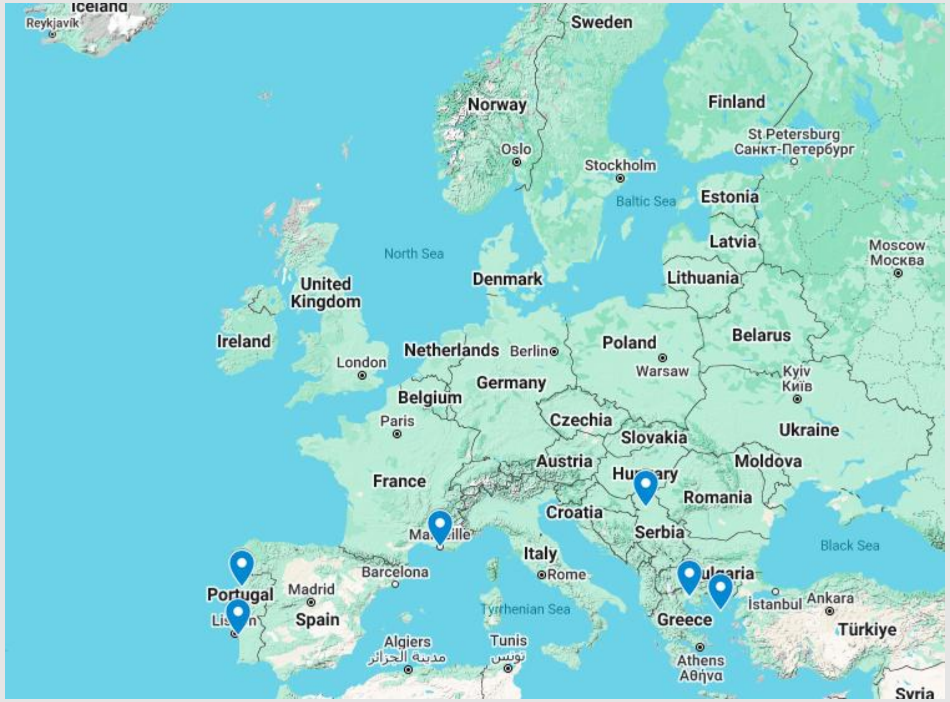
AGRIMA aims to foster universities' **capacity building** for the **green transition** through **innovative practices and higher education curricula updating in agri-food waste management** for the **circular bioeconomy**.

AGRIMA addresses:

1. **Advancing pedagogical methods** for industrial agri-food waste valorisation **based on business-academia synergies**.
2. **Integrating citizen science** in bio-economy-enhanced waste valorisation as a means of **civic engagement and environmental advocacy**.

Partners

AGRIMA



Aix*Marseille université
Socialement engagée

AVIPE
Associação de Viticultores do Concelho de Palmela

P.PORTO

UNIVERSITY OF THE AEGEAN

UNIVERSITAS STUDIORUM NEOPLANTENSIS MCMLX
UNIVERSITY OF NOVI SAD

Web2Learn
Open, social learning

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Outline

- Intro
  - The Team
- Agri-Food Waste Valorization
- (Bio)polymers
- Exampl. 1: Pumkin Seed Oil Cake Valorization
- Exampl. 2: Valorization of Corn proteins

UNIVERSITY OF NOVI SAD
FACULTY OF TECHNOLOGY NOVI SAD

Prof. dr Jaroslav Katona

Coordinates

Department of Applied and Engineering Chemistry

University of Novi Sad, Faculty of Technology Novi Sad

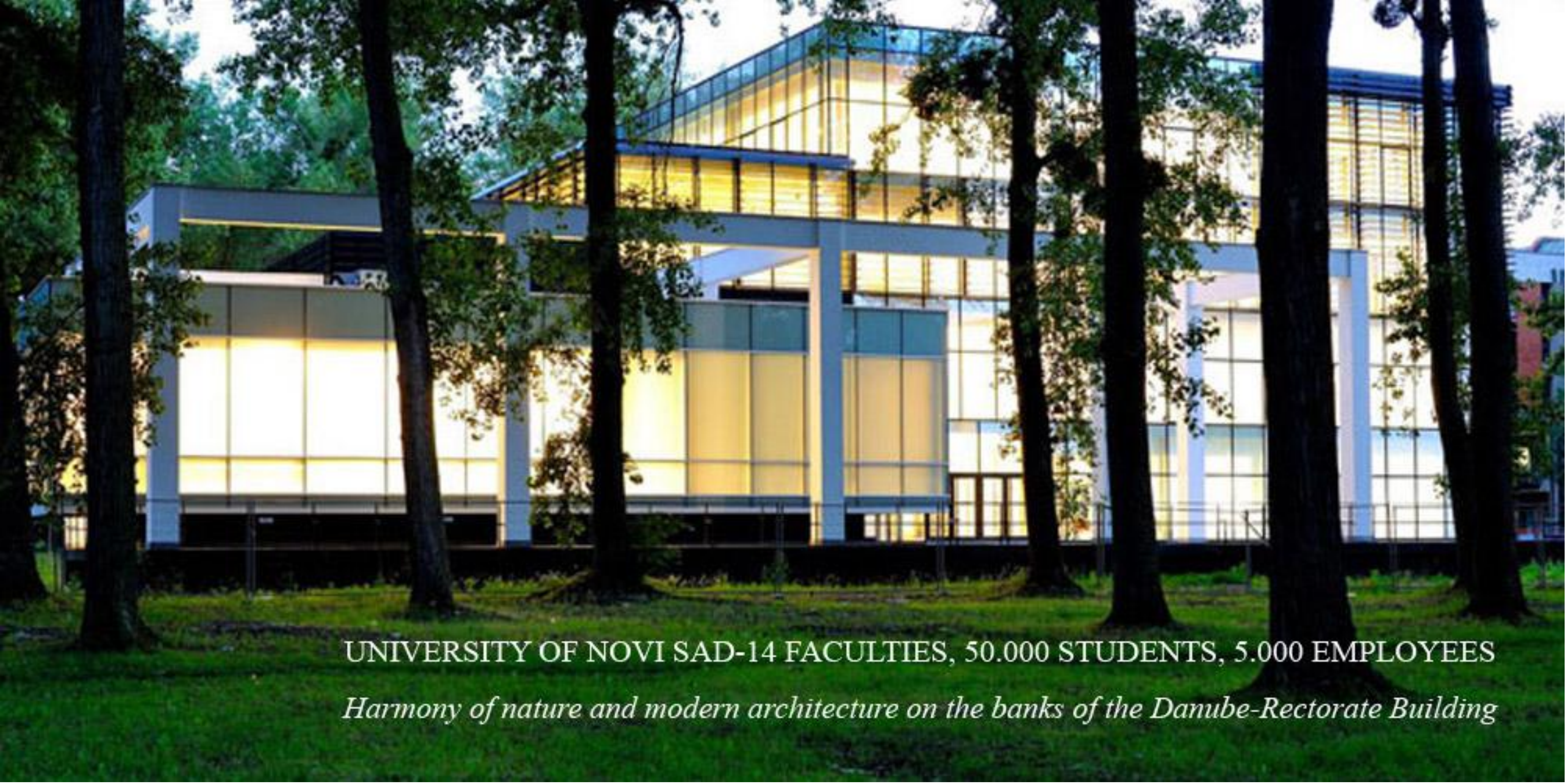
Bul. cara Lazara 1

21000 Novi Sad

Serbia

E: jaroslav.katona@uns.ac.rs

W: https://colloidsns.wordpress.com/



UNIVERSITY OF NOVI SAD-14 FACULTIES, 50.000 STUDENTS, 5.000 EMPLOYEES

Harmony of nature and modern architecture on the banks of the Danube-Rectorate Building

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NIVERSITY OF NOVI SAD-14 FACULTIES, 50.000 STUDE

armony of nature and modern architecture on the banks of the D

Faculty of Technology Novi Sad

- Founded in 1959.
- c.a. 1400 students (BSc, MSc, PhD)
- c.a. 240 employees

  ~150 research staff
    - SCI publications/researcher @ UNS
    - >400 papers/year

COLLOID CHEMISTRY RESEARCH GROUP

https://colloidsns.wordpress.com/

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Design of functional colloids

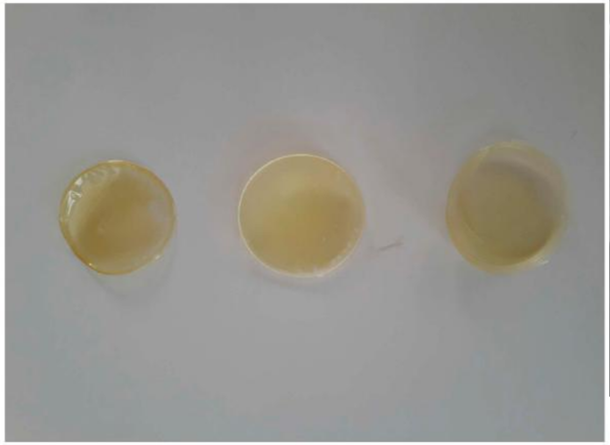
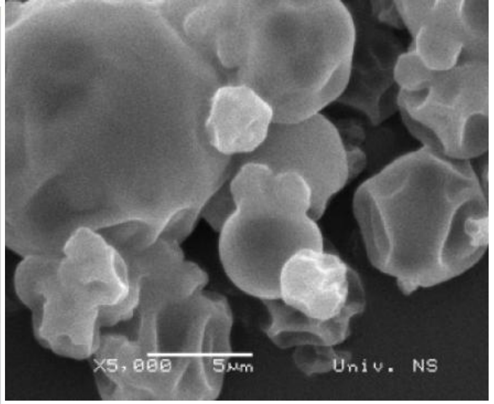
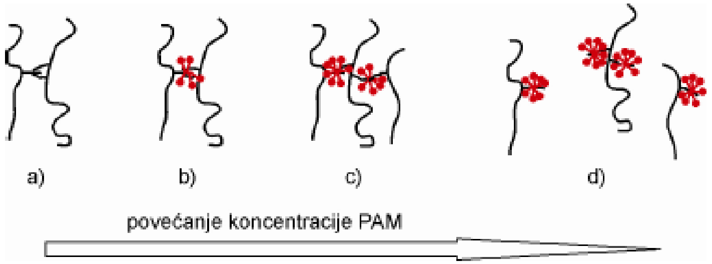


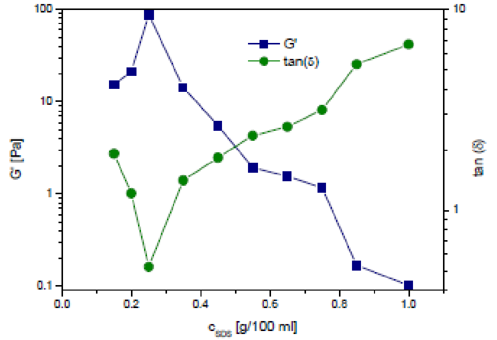
Fig. 3. Photograph of ZS (left), ZD (middle) and ZDPG (right) films



Applications

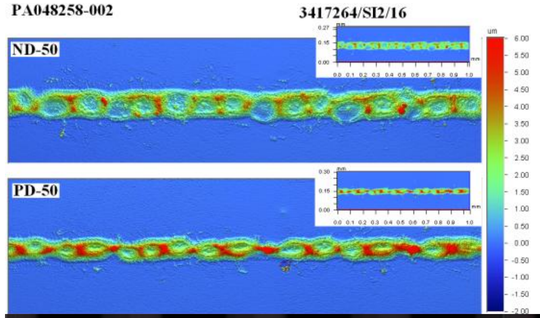
- Food Science Materials by Agri-Food Waste Valorization
- Nano- and Microencapsulation
- Sensors
- Functional Printing Materials
- Free-Surface Flows (inkjet drop formation)

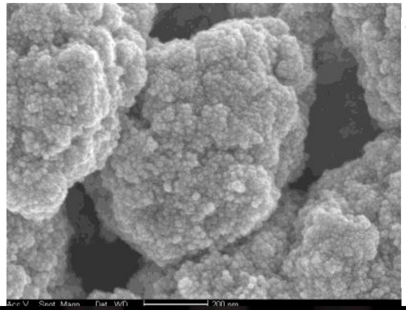


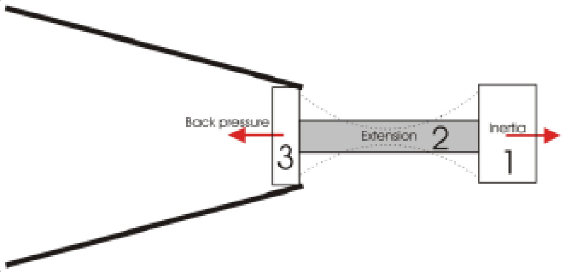


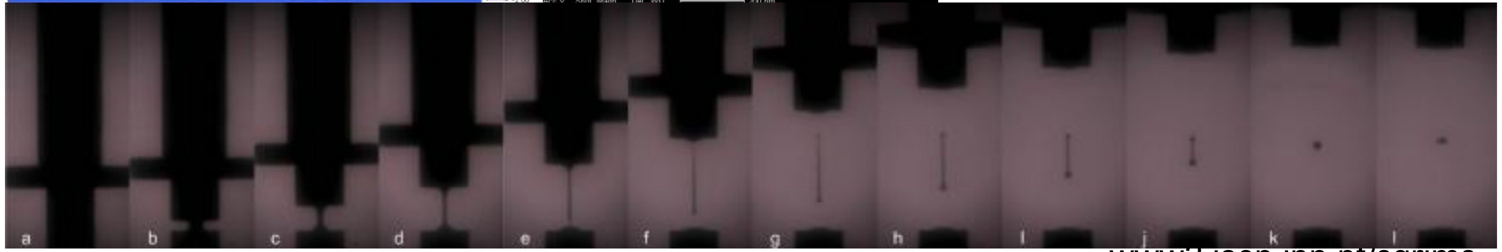
Expertise

- **Colloid & Interface Science**
- Biopolymers
  - Biopolymer nanoparticles
  - Biopolymer films
- Polymer–surfactant interactions
- Emulsions, dispersions
- Rheology
- Formulations









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Applied Colloid Chemistry

Strong track record in industrial partnership

AGFA Agfa

Capsugel®
Now a Lonza Company

Frikom

Alltech®

Biospringer by Lesaffre

Carlsberg Srbija

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Agri-Food Waste Valorization

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Agri-food sector has a massive socio-economic and environmental footprint

- The World will need 50% more food by 2050
  - increasing human population
  - Increase in standard of living
- Highly intensive yet sustainable agri-food industry
  - Precision agriculture, smart farming, circular economy…
- Developed societies are notorious for their inefficient use of food

AGRI-FOOD WASTE

- **20% of all food produced in Europe is eventually wasted**
  - **40% of post-harvested fresh fruits and vegetables**
- **ca. 80% of all freshwater spent by humans is used on crops watering**
- **UN’s 2030 Agenda (12.3 SDG)**
  - **targets to halve per capita food waste at the retail and consumer level by 2030**
- **European Green Deal**
  - **European Farm to Fork strategy targets “Food loss & Waste Prevention” as one of the four main strategy’s pillars**

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High-value valorization of agri-food waste

- Source of valuable biomaterials
  - Nutraceuticals & Functional Food
    - Flavonoids and essential oils from citrus peels
  - Cosmetics & Personal Care
    - Oil from avocado seeds
  - Bio-based Chemicals & Materials
    - Starch from potato peels for biodegradable packaging
  - Pharmaceutical & Biomedical Applications
    - Chitosan in wound dressing

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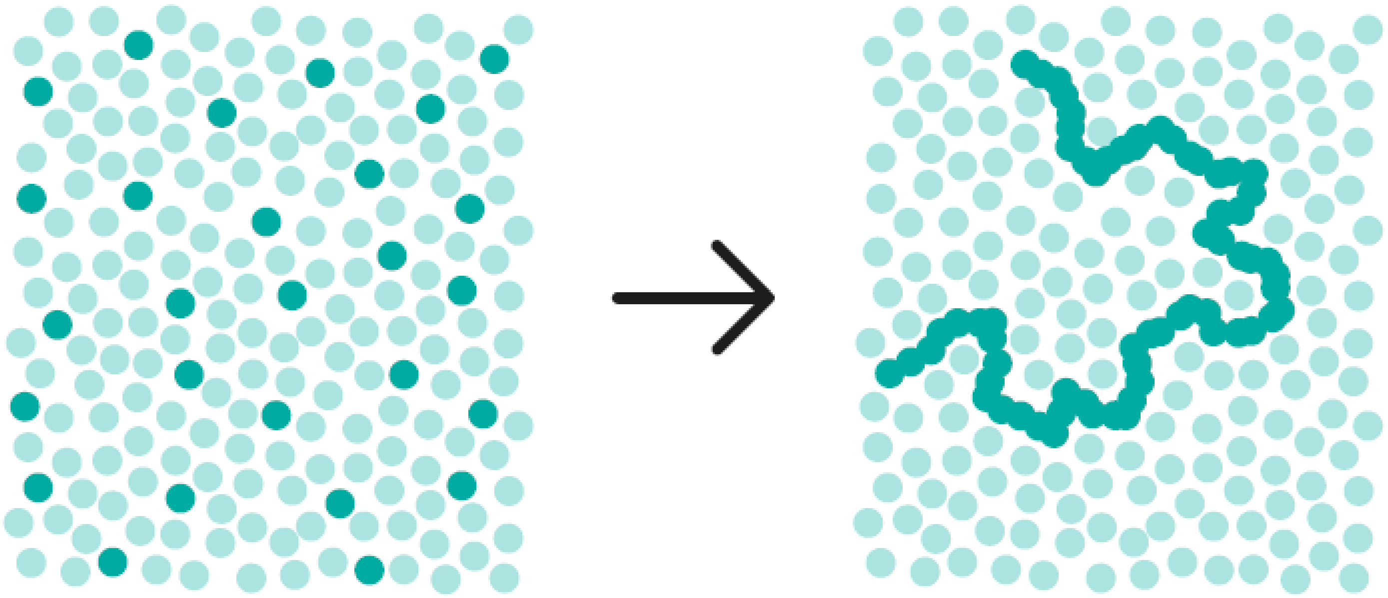
Biopolymers

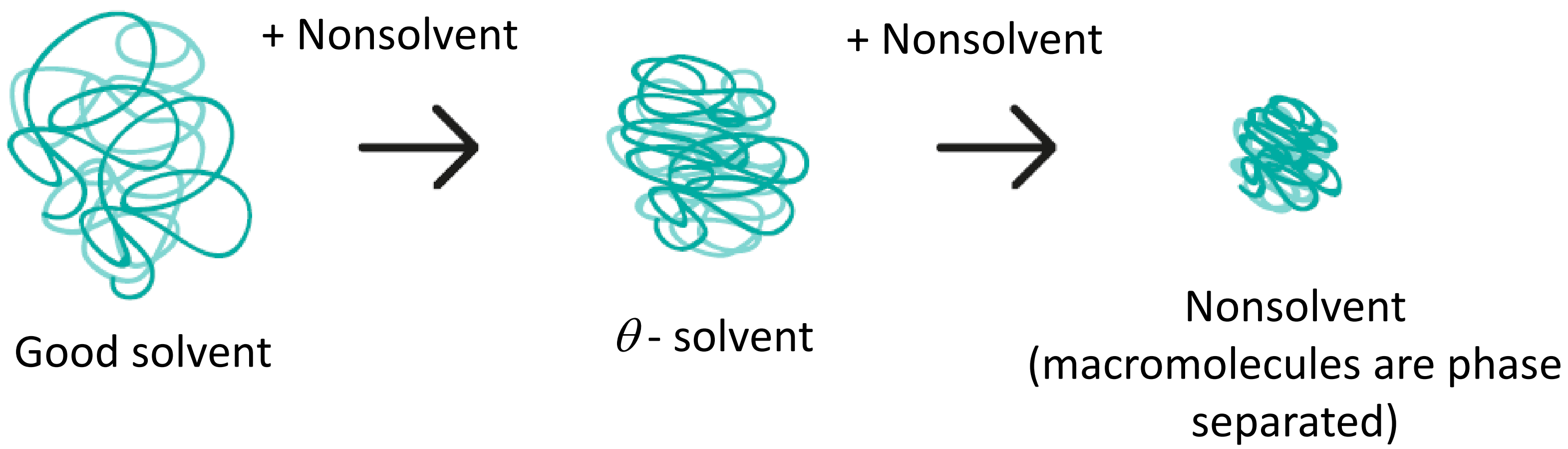
Biopolymers (BP)



- Natural polymers (macromolecules) synthetized by cells of living organisms
  - Polynucleotides
  - **Polysaccharides**
  - **Polypeptides**
  - Polyesters
  - ...
- (Biocompatible polymers)

Biopolymers and solvents

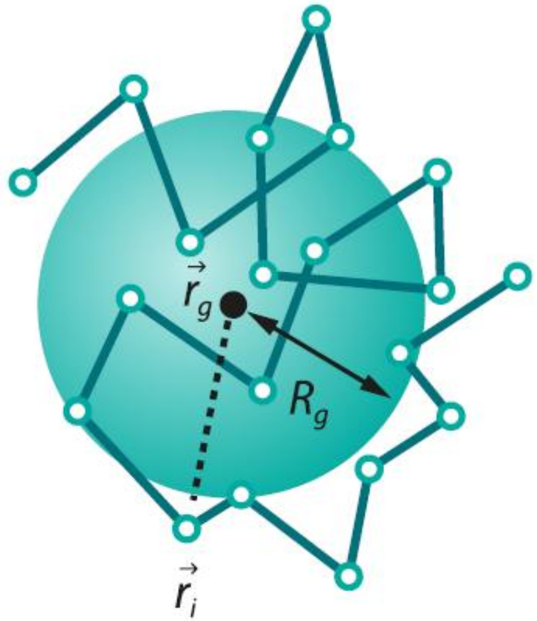
- There are three colloidal states when biopolymers are in equilibrium with solvent molecules
  - Solutions
  - Gels
  - Coacervates

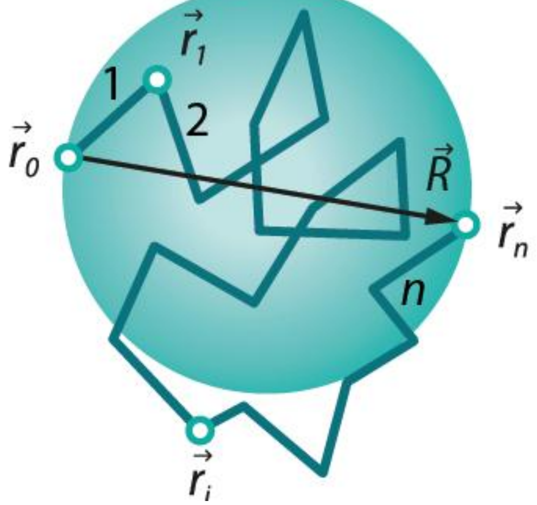


Solutions

- Most biopolymers are soluble in water
  - Polymer chains are well hydrated and expanded
- Not all BP are water soluble
  - Cellulose, Prolamines, Caoutchouc…
- Molecular expansion coefficient

$$\alpha = \frac{R}{R_0} = \frac{R_g}{R_{g0}} \geq 1$$





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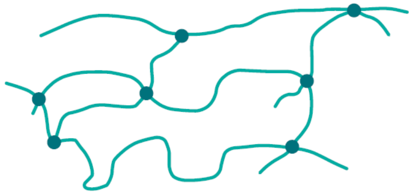
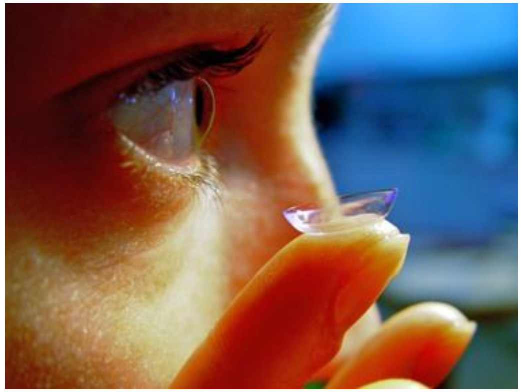
Gels

- Solution concentration c>c*

- BP chains
  - Entangled
  - Networked





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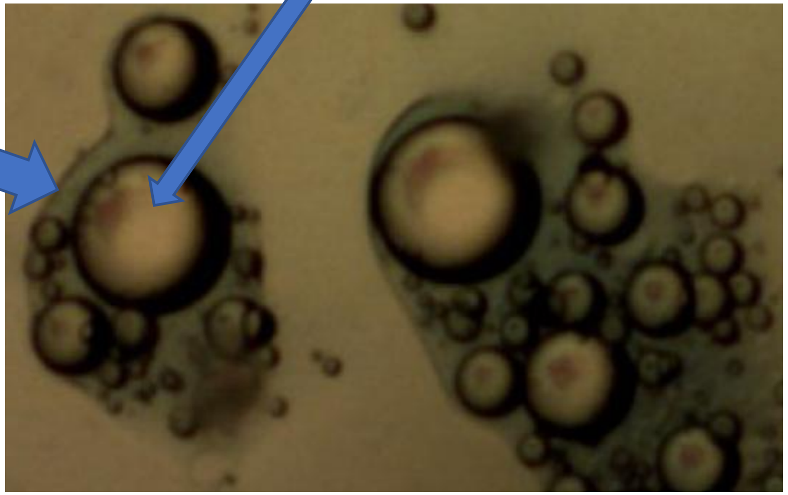
Coacervates

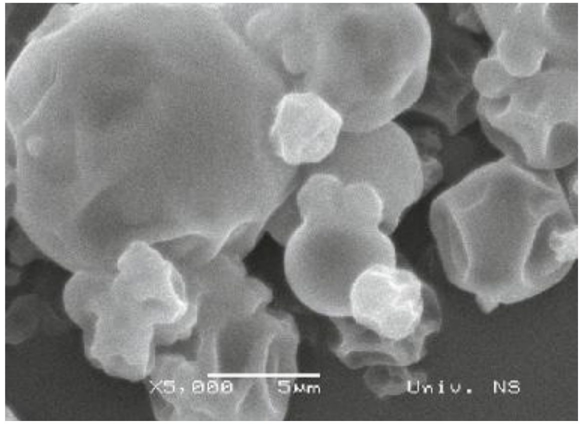
- Coacervate = liquid/gel-like precipitate
  - Simple
  - Complex

Oil

Coacervate

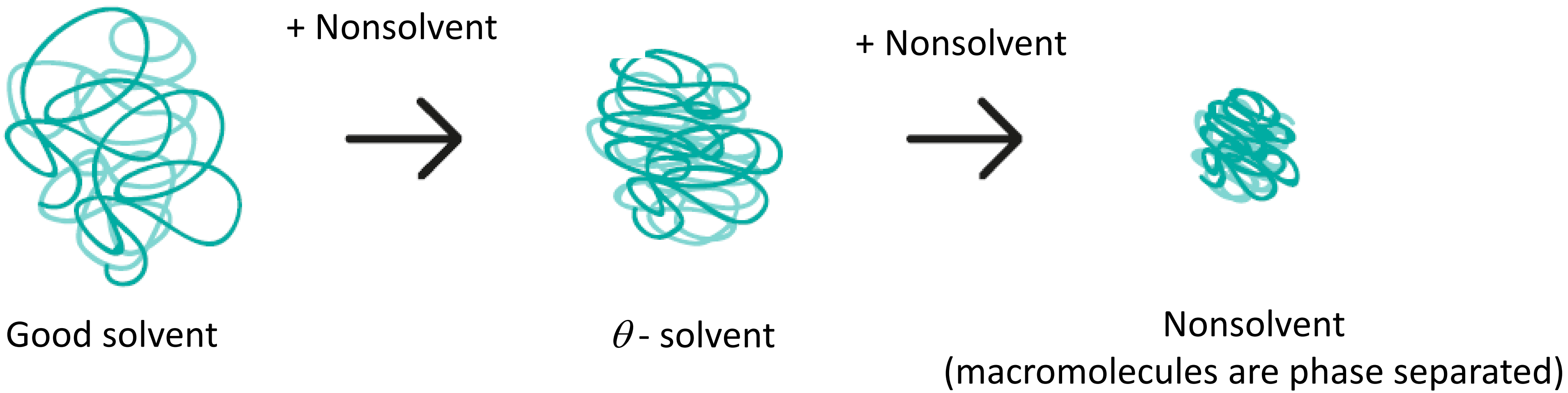


Encapsulation



Precipitation of biopolymers

Phase separation of BP from solution and formation of solid particles



Exam. 1

Oil Cake from pumpkin seed

Pumpkin seeds (*Cucurbita pepo*)

- Pumpkin seeds
- The oil cake – a by product of pumpkin oil production
    - Cold pressed
    - Ca. 65% of the cake are proteins
        - Animal feed
        - Any options for high-value valorization?

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Pumpkin seeds (*Cucurbita pepo*)

- Pumpkin seeds
- The oil cake – a by product of pumpkin oil production
  - Cold pressed
  - Ca. 65% of the cake are proteins
    - Animal feed
    - Any options for high-value valorization?

Colloidal functionality of proteins?

- Adsorption at oil/water interfaces
- Emulsifying properties

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Pumpkin Seed Protein Isolates and Hydrolysates

Oil cake

Alaki extraction

- Defatting
- Dissolution at pH 10
- Slurry Filtration
- Precipitation at pH 5
- Centrifugation and drying

Pumpkin Seed Protein Isolate (**PSPI**)

PSPI

Enzymatic hydrolysis

Pumpkin Seed Protein Hydrolysate (PSPH)

Alcalase → **H1**

Pepsin → **H2**

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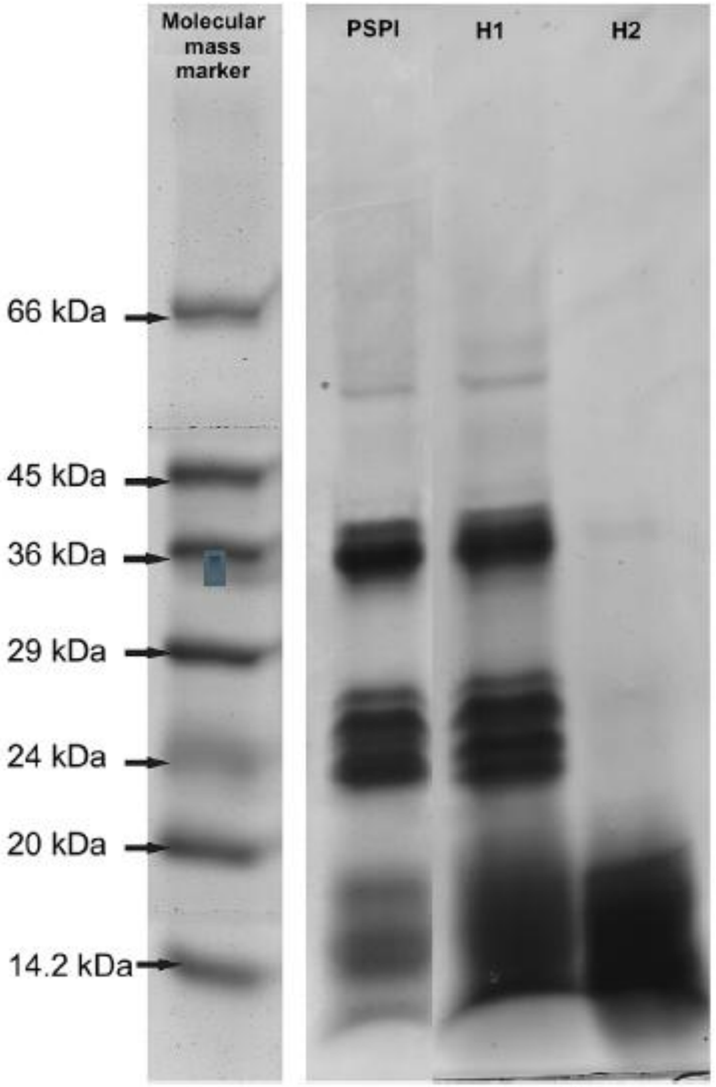

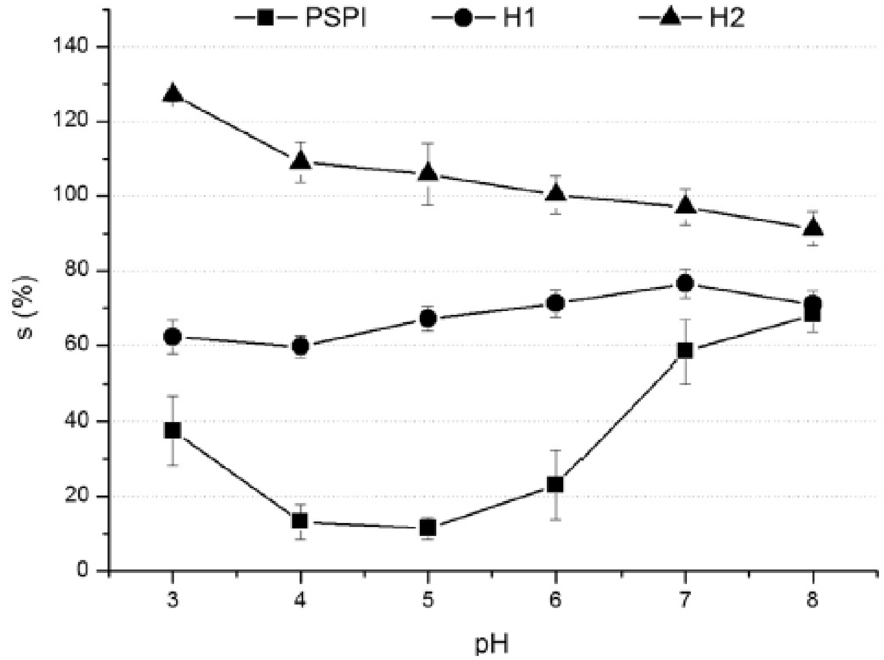

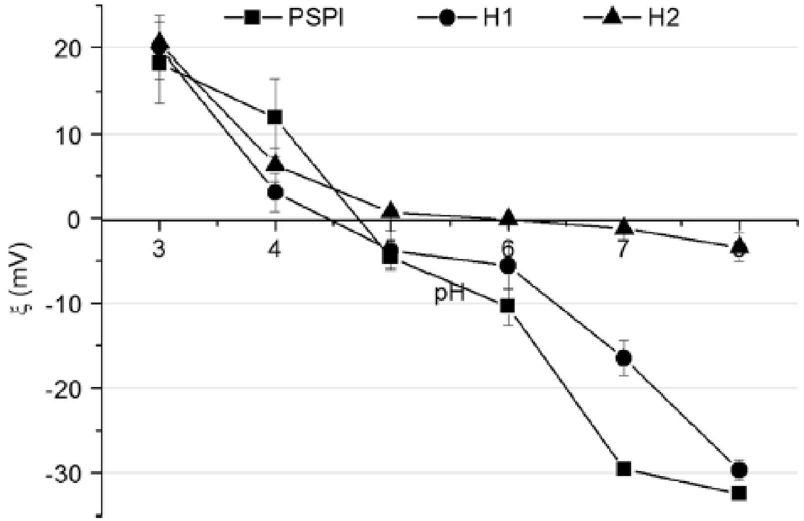

Bučko et a l. (2016) Influence of enzymatic hydrolysis on solubility, interfacial and emulsifying properties of pumpkin (Cucurbita pepo) seed protein isolate, *Food Hydrocolloids* 60, 271-278.

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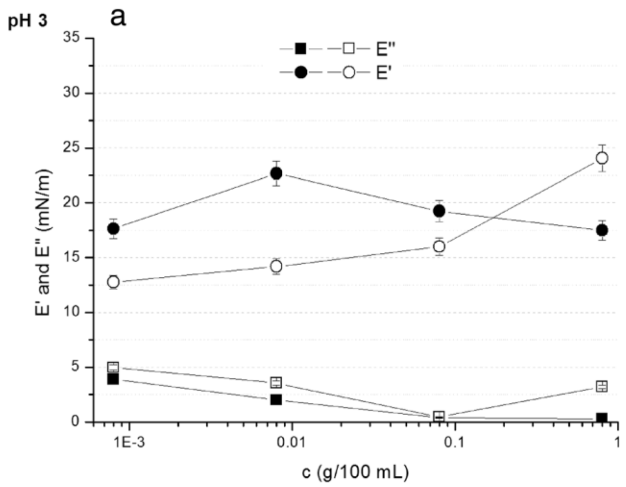
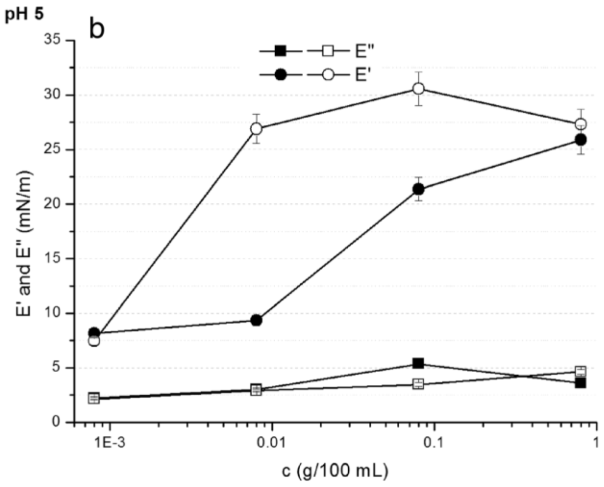
Adsorption at fluid interfaces

Oil –Water Interface

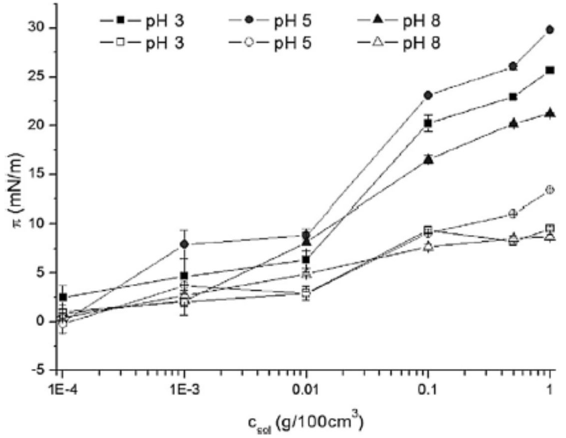
PSPI - filled
H1 -open

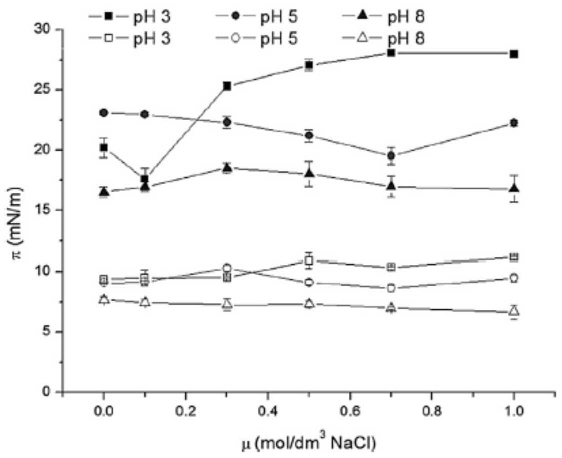




PSPI

Air/Water - filled
Oil/Water -open





Bučko et al. (2015) Investigation on solubility, interfacial and emulsifying properties of pumpkin (*Cucurbita pepo*) seed protein isolate. *LWT– Food Science and Technology* 64, pp. 609-615.
Bučko et al. (2018) The Influence of Enzymatic Hydrolysis on Adsorption and Interfacial Dilatational Properties of Pumkin (*Cucurbita pepo*) Seed Protein Isolate. *Food Biophysics* 13, pp. 217-225

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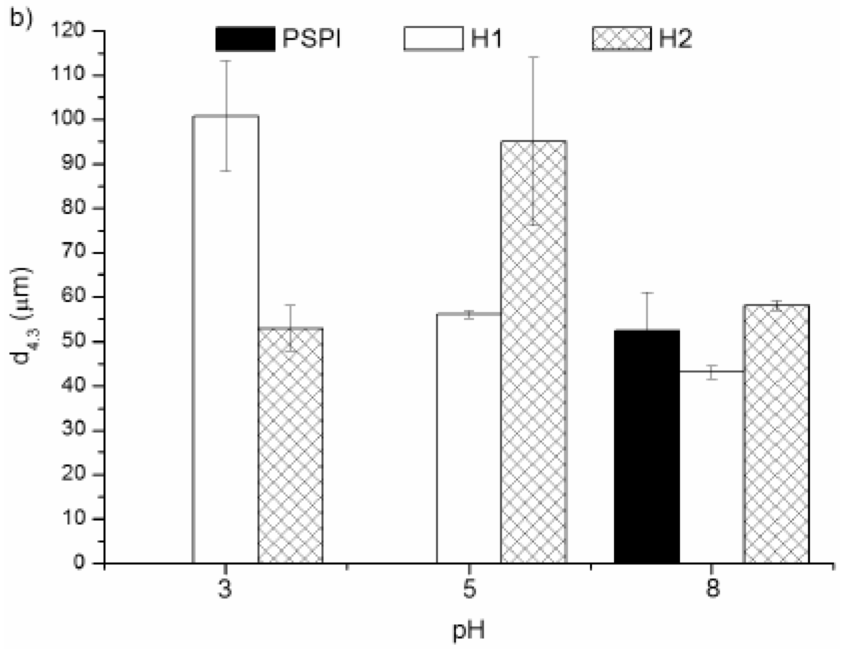
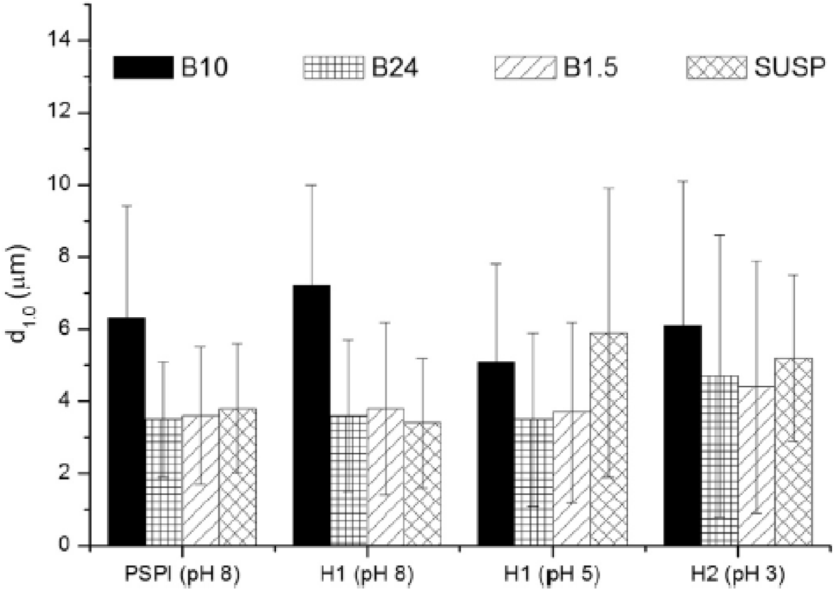
Pumpkin seed (*Cucurbita pepo*) protein isolates and hydrolysates





Bučko et a l. (2016) Influence of enzymatic hydrolysis on solubility, interfacial and emulsifying properties of pumpkin (Cucurbita pepo) seed protein isolate, *Food Hydrocolloids* 60, 271-278.

Exam. 2

Zein – corn protein

by product of starch production

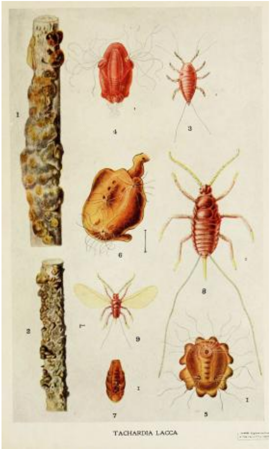
Министарство просвете,
науке и технолошког развоја

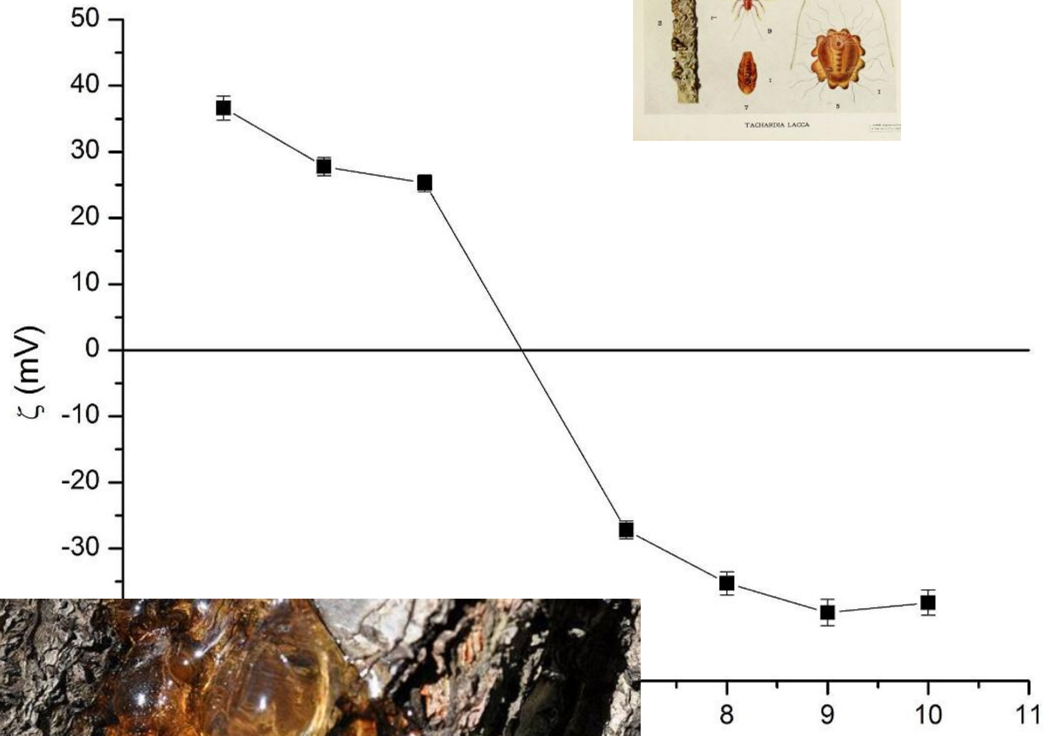
Biopolymers insoluble or weakly soluble in water

- Edible Films, Coatings, and more

Zein

- Main storage protein in corn
    - α–, β–, γ–, δ–
- By product of industrial starch production
- Prolamin i.e. **insoluble in water**
    - Soluble in EtOH/water mixtures when EtOH >60%
    - Suitable for edible films, coatings, packaging…
- Natural resins (soluble in EtOH)
    - Shellac
    - Rosin





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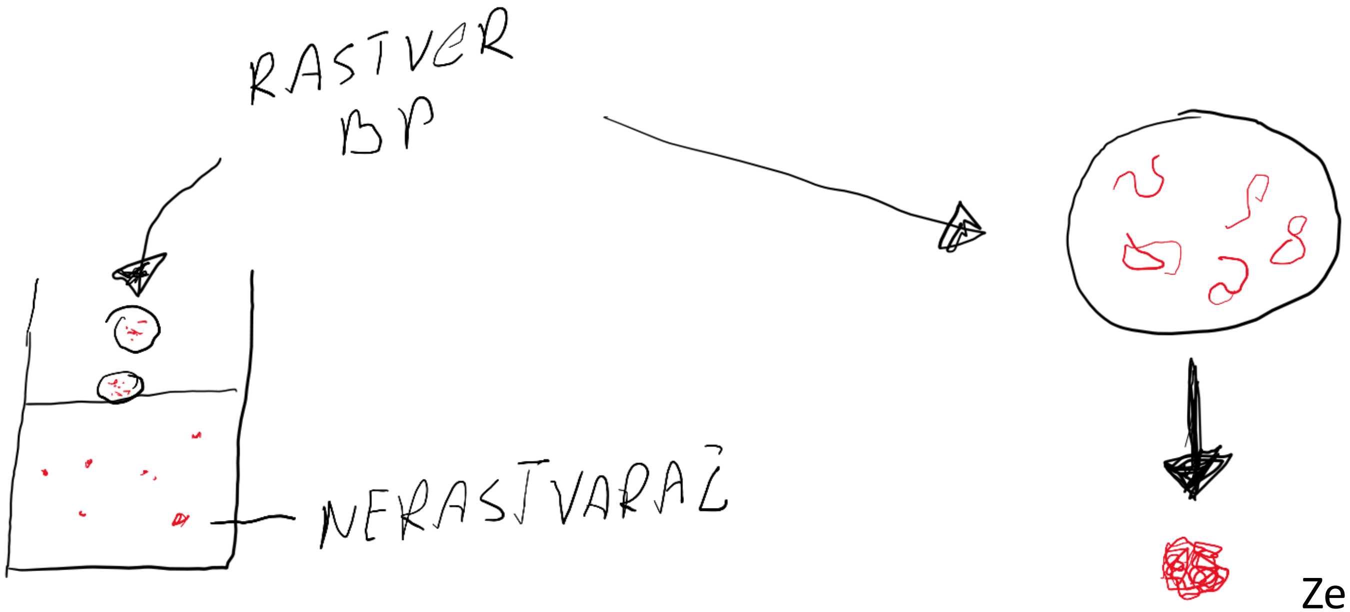
Zein nanoparticles

- Antisolvent precipitation from zein solutions in EtOH/water



Drop of zein solution

Zein nanoparticle

Antisolven precipitation

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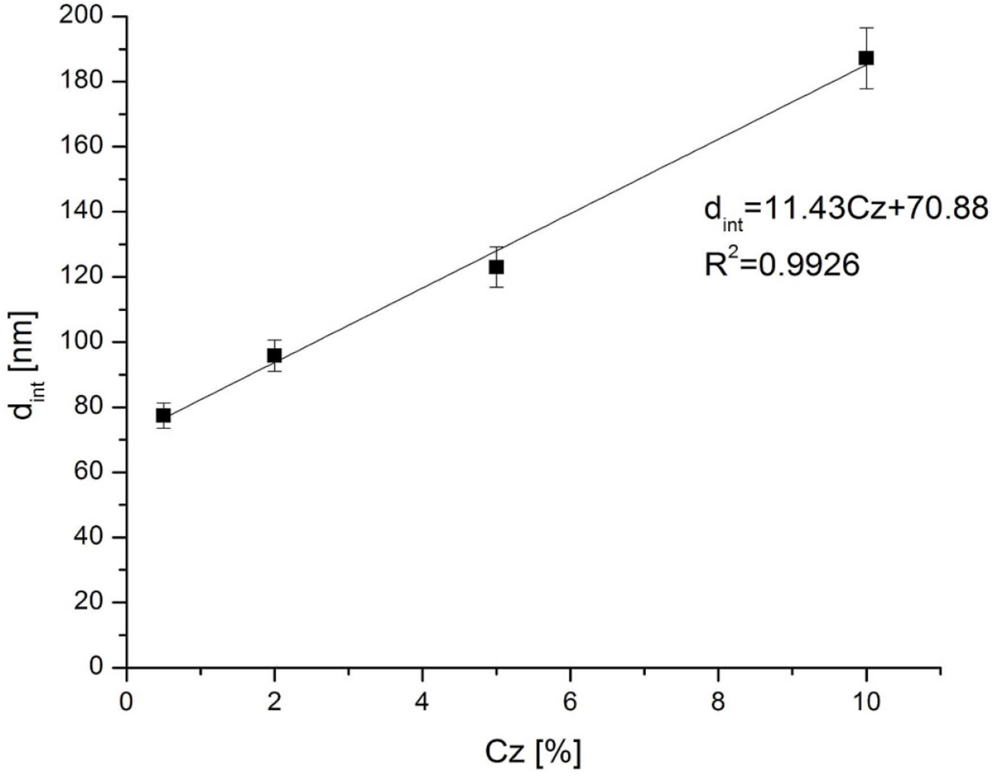
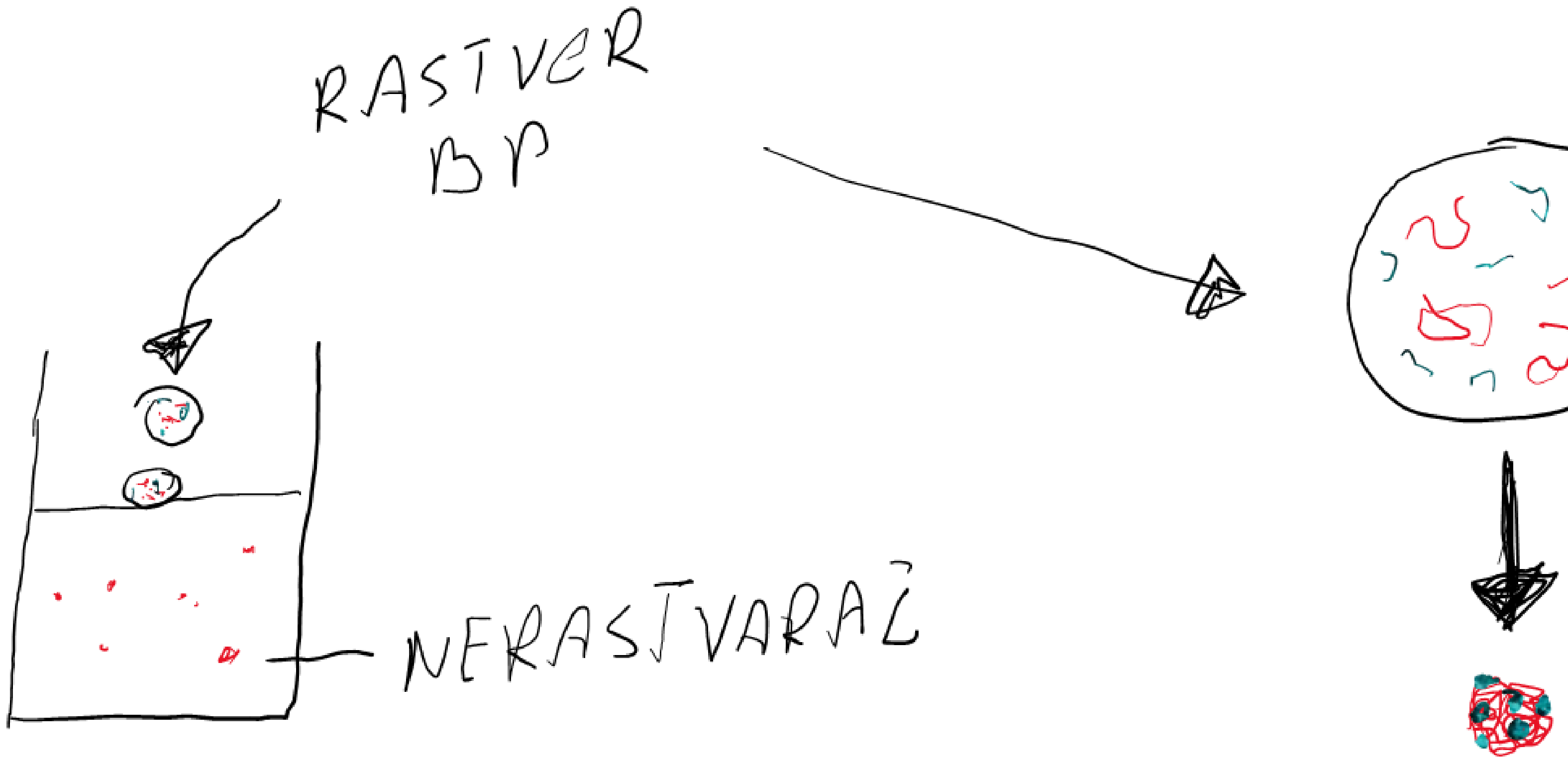
Zein nanoparticles



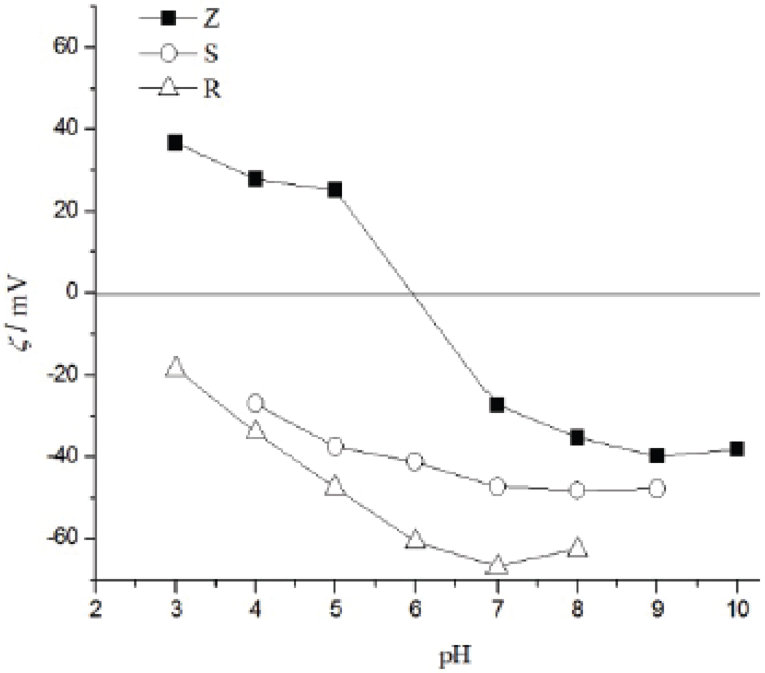
Spasojević et al. (2019) Edible water barrier films prepared from aqueous dispersions of zein nanoparticles, *LWT – Food Science and Technology* 109, 350-358.

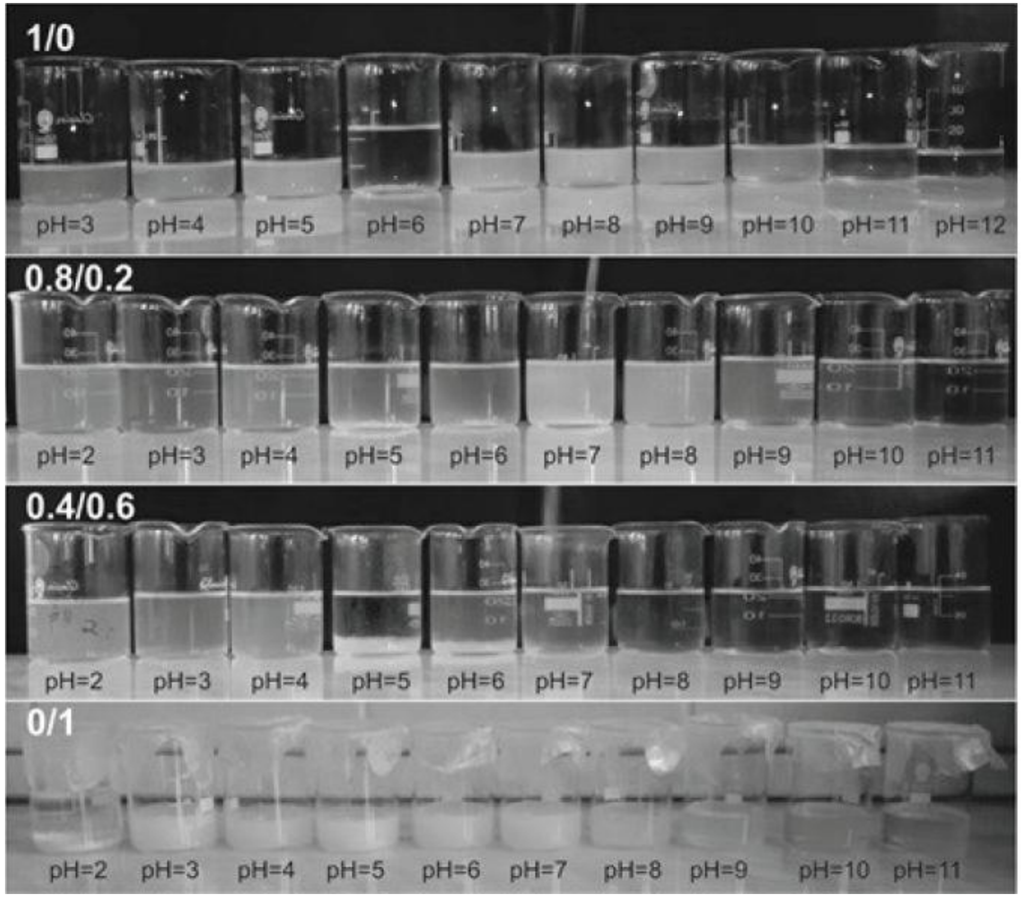
Composite zein/natural resin nanoparticles



Composite zein/natural resin nanoparticles

Fig. 6. Dispersions of composite zein/ /rosin (Z/R) nanoparticles of different Z/R mass ratio (1/0, 0.8/0.2, 0.4/0.6 and 0/1), and of different pH (2–12).





Spasojević et al. (2020) Preparation of composite zein/natural resin nanoparticles, *Journal of Serbian Chemical Society*, 85 (3), 369-380.

Surface modification of (composite)zein nanoparticles

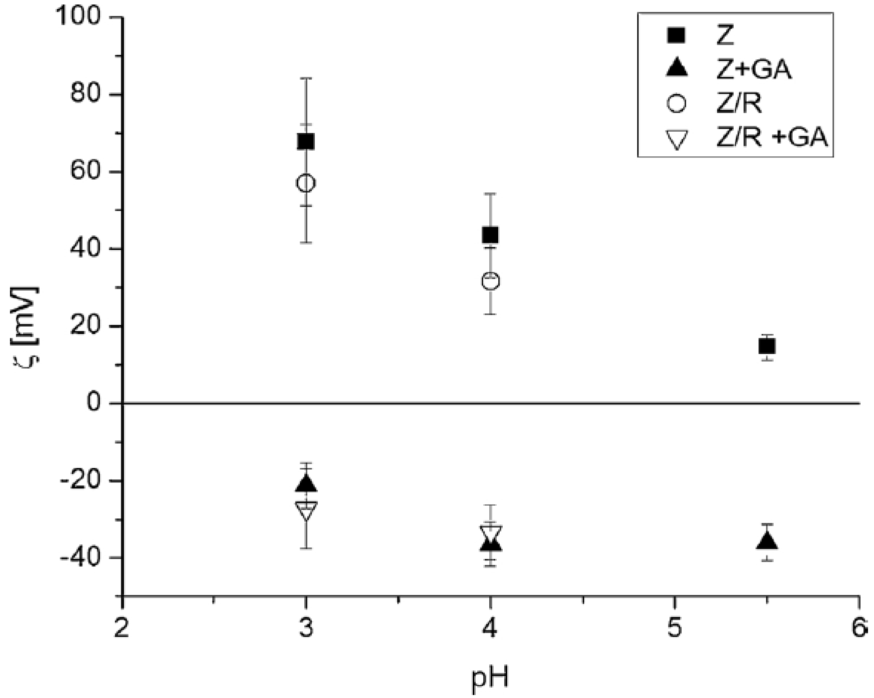
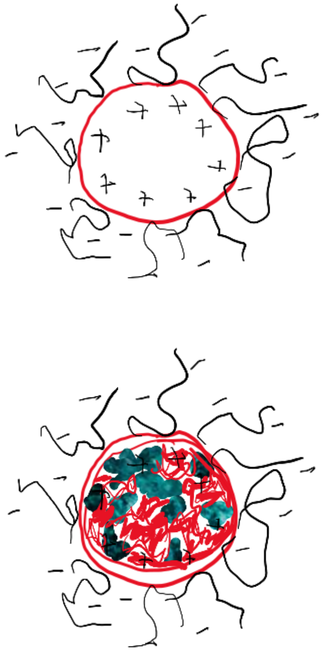
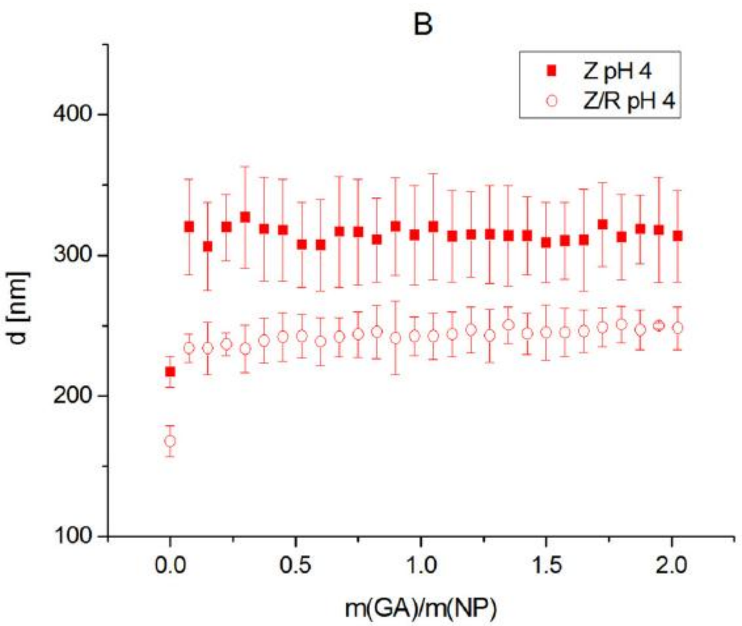


Fig. 2. Influence of pH on zeta potential of Z and Z/R NPs, before and after addition of GA solution to the NPs' suspensions (GA/NP mass ratio is 1).



Spasojević et al. (2020) Interactions of zein and zein/rosin nanoparticles with natural polyanion gum arabic, *Colloids and Surfaces B: Biointerfaces* 196, 111289.

Surface modification of (composite)zein nanoparticles



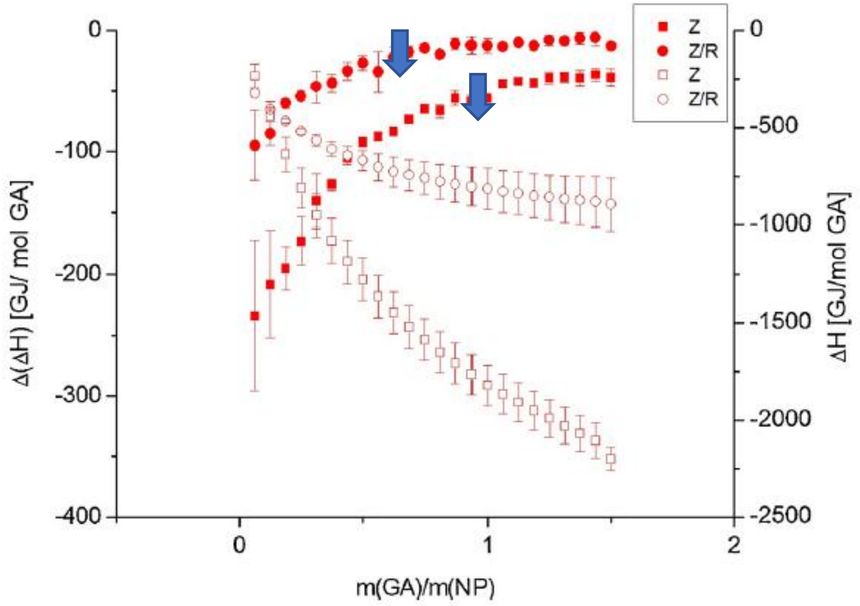
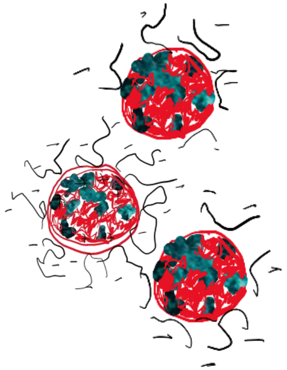
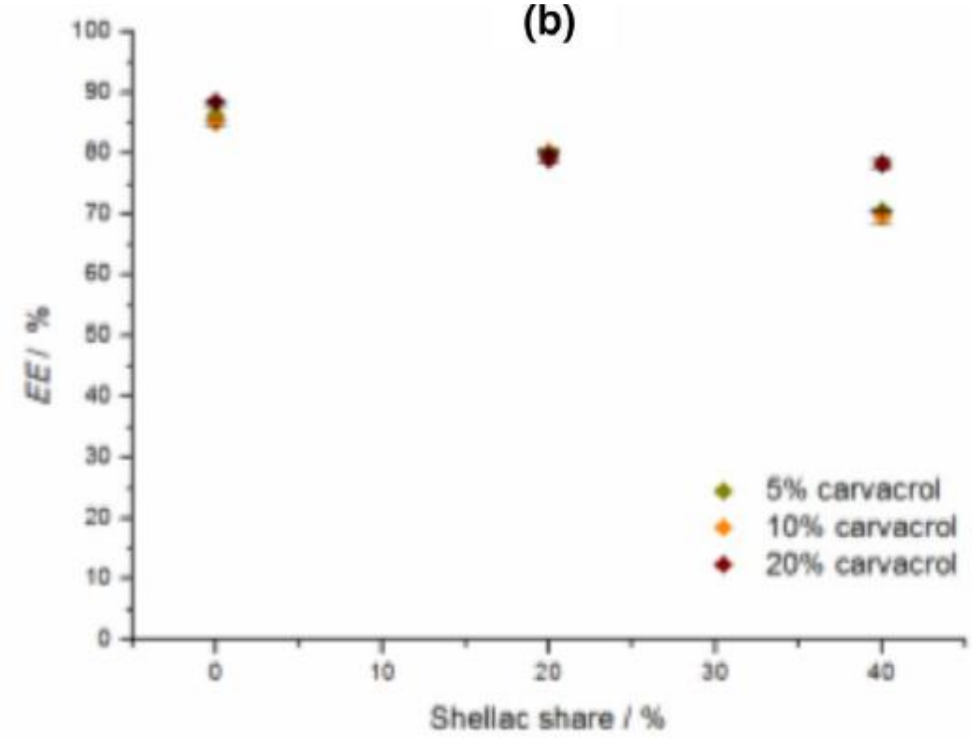


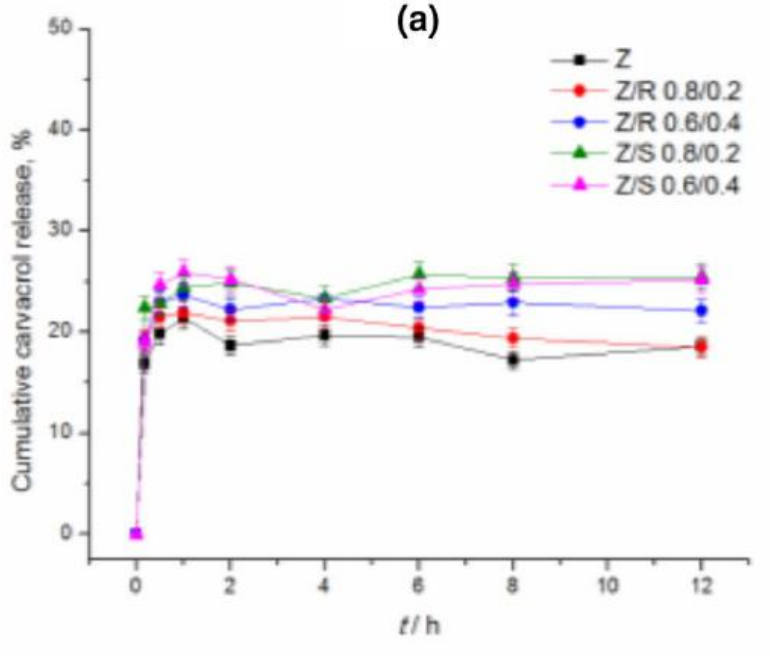
Fig. 6. Influence of GA/NP mass ratio on enthalpy change per aliquot of GA (filled symbols) and the total enthalpy of reaction (open symbols) between Z NPs and GA (squares) and between Z/R NPs (circles), at pH = 4.



Spasojević et al. (**2020**) Interactions of zein and zein/rosin nanoparticles with natural polyanion gum arabic, *Colloids and Surfaces B: Biointerfaces* 196, 111289.

Encapsulation of carvacrol in zein nanoparticles



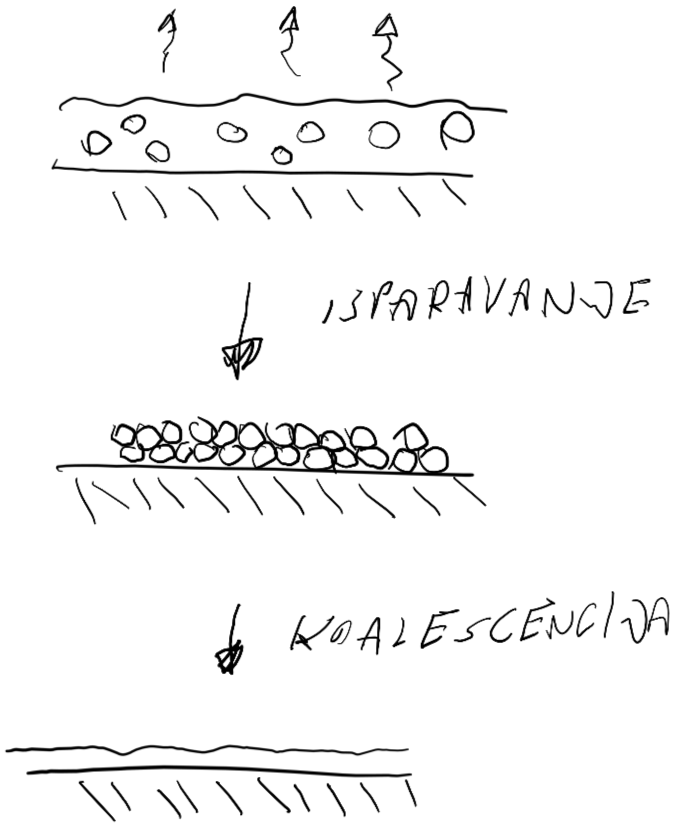


Rajić et al. (2021) Zein–resin composite nanoparticles with coencapsulated carvacrol, *Journal of Food Processing and Preservation*, https://doi.org/10.1111/jfpp.15741. IF (2020) 2,190; Food Science & Technology 90/144.

Water-insoluble Biopolymer films and coatings

- Coatings for Extending shelf life of post harvested perishable fruits and vegetables
    - Water soluble biopolymers or resins (+lipids and waxes)
- Biodegradable/edible packaging
- Sensors
- ….

Zein (pseudo)latex films



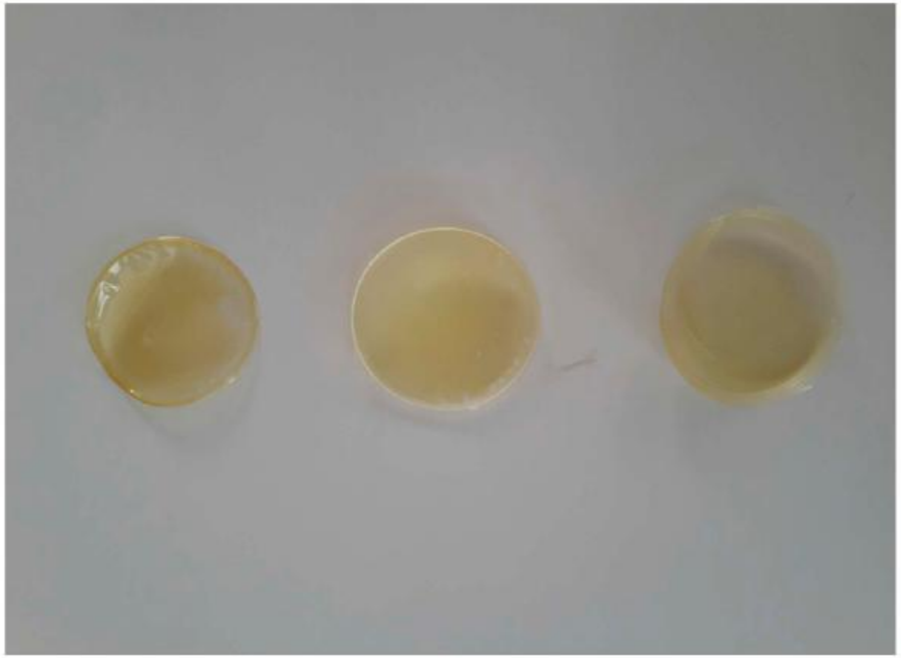


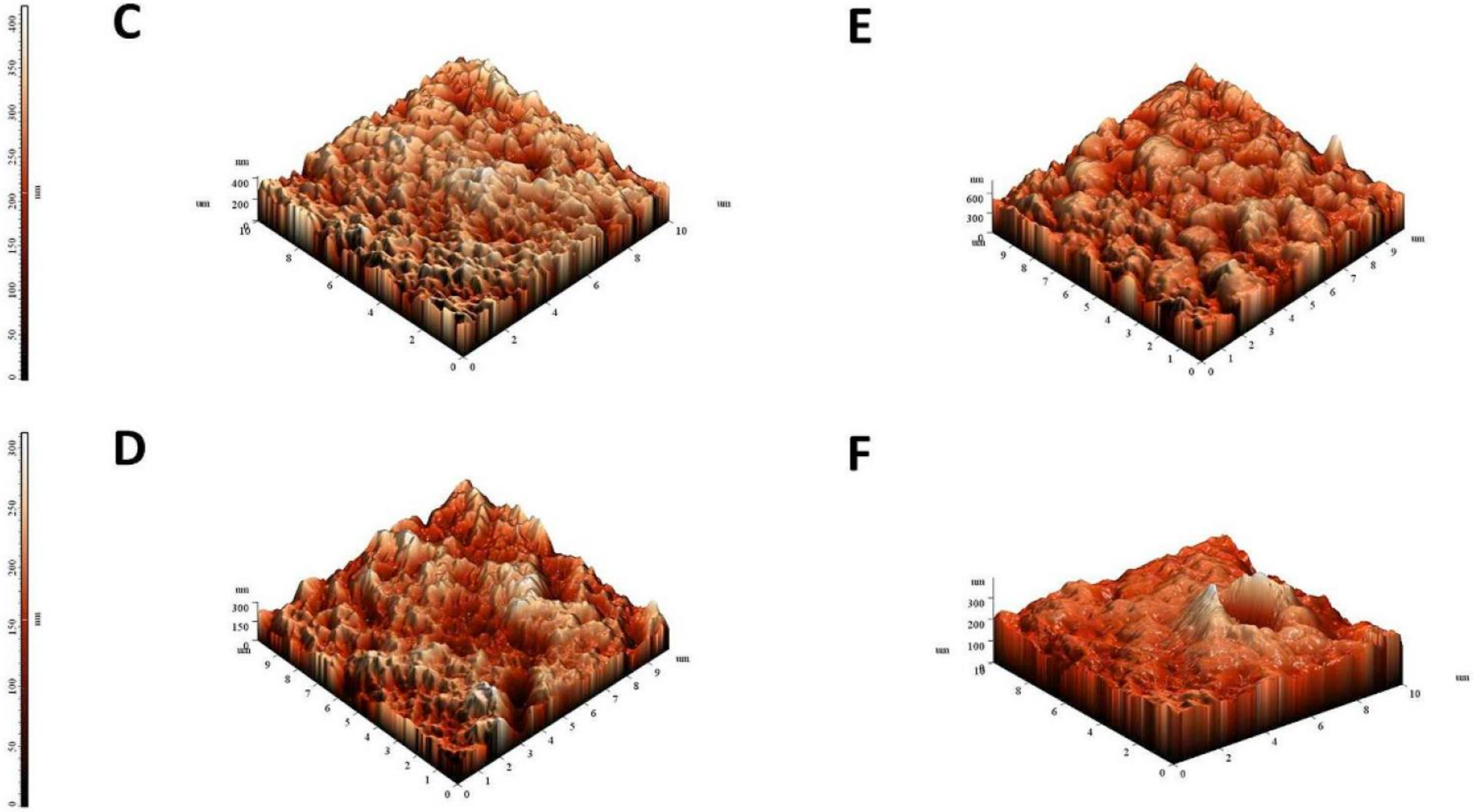
Fig. 3. Photograph of ZS (left), ZD (middle) and ZDPG (right) films.

Spasojević et al. (**2019**) Edible water barrier films prepared from aqueous dispersions of zein nanoparticles, *LWT – Food Science and Technology* 109, 350-358.

Morphology of zein films

90 nm

180 nm



Spasojević et al. (**2019**) Edible water barrier films prepared from aqueous dispersions of zein nanoparticles, *LWT – Food Science and Technology* 109, 350-358.

Antimicrobial pseudolatex zein films with encapsulated carvacrol

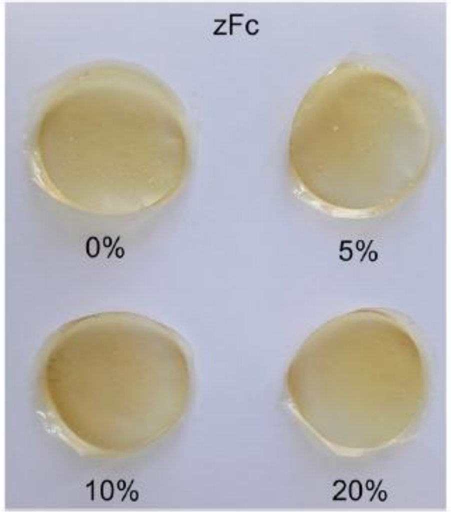


Fig. 4. Photograph of zFc with different carvacrol concentrations.

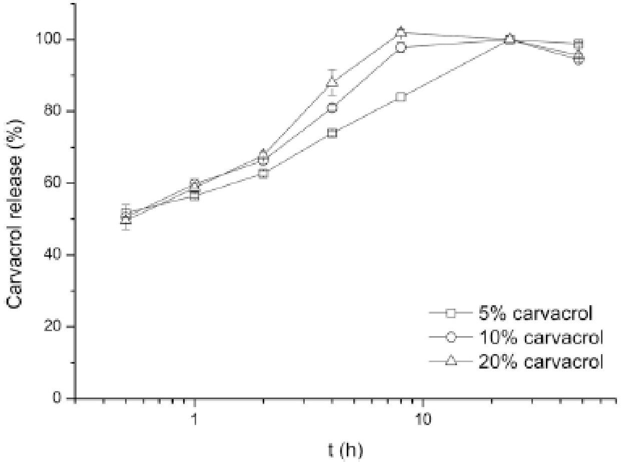


Fig. 5. Carvacrol release curves from zFc with 5%, 10%, and 20% of carvacrol.

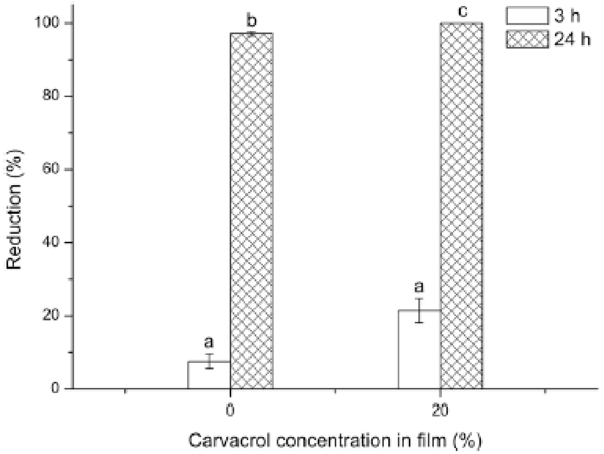


Fig. 6. Antimicrobial activity of zFc with 0% and 20% of carvacrol, shown as the reduction percent of number of MO in suspension. Different letters on the graph represent significant differences ($p < 0.05$) as obtained by ANOVA and Tukey's HSD test.

Babayev et al., Antimicrobial pseudolatex zein films with encapsulated carvacrol for sustainable food packaging, *Food Packaging and Shelf Life* 37 (2023) 101076.

THANK YOU FOR YOUR ATTENTION!

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