Evaluation of the physicochemical and textural properties of binary protein-polysaccharide hydrogels

Adonis Hilal; Anna Florowska; Małgorzata Wroniak

Institute of Food Science, Department of Food Technology and Assessment, Warsaw University of Life Sciences-SGGW

Foods 2022

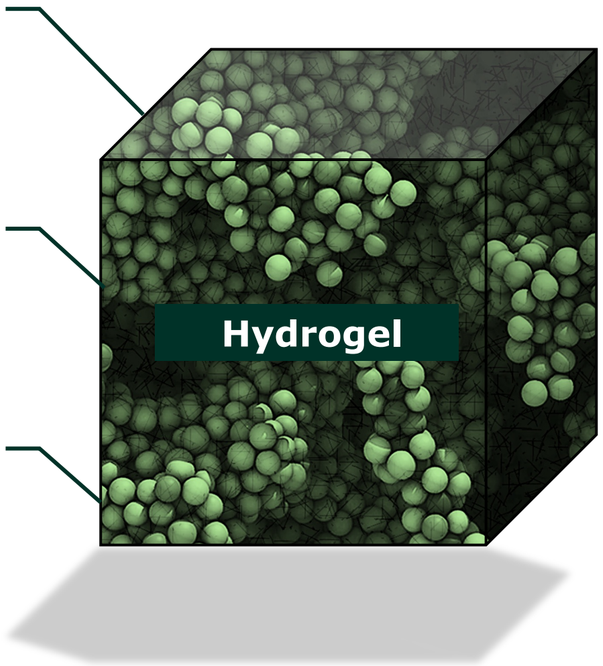
WARSAW UNIVERSITY OF LIFE SCIENCES

Introduction

3D structure made of hydrophilic polymers

High water content

Viscoelastic properties



The European plant-based food sector has expanded rapidly (49%) over the past two years, mainly due to the pandemic COVID-19, which has accelerated this growth, as consumers have become increasingly conscious of their health and natural environment.

Due to the increasing interest in providing enough nutritious food for everyone while protecting natural resources. Plant-based foods, as well as hybrid food products (from animal and plant sources), are a new growing trend that can help with this sustainability challenges.

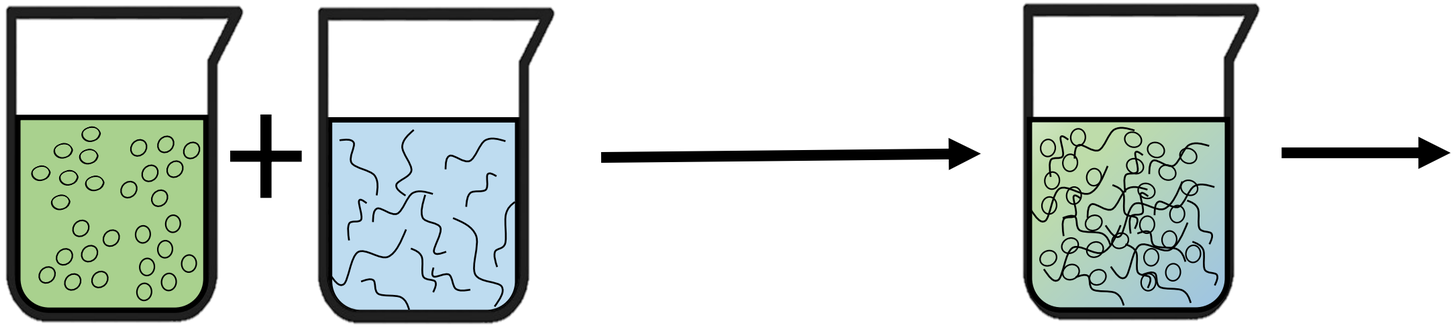
Food-grade hydrogel's building blocks are naturally sourced biopolymers:
- **Proteins,**
- **Polysaccharides.**

WARSAW UNIVERSITY OF LIFE SCIENCES

References
- Peschel, A. O., Kazemi, S., Liebichová, M., Sarraf, S. C. M., & Aschemann-Witzel, J. (2019). Consumers' associative networks of plant-based food product communications. *Food Quality and Preference*, *75*, 145–156. https://doi.org/10.1016/j.foodqual.2019.02.015
- EU-funded retail scanning data Nielsen. (2020). EU-funded SMART PROTEIN project -Plant-based foods in Europe: How big is the market? www.smartproteinproject.eu
- Tuorila, H., & Hartmann, C. (2020). Consumer responses to novel and unfamiliar foods. Current Opinion in Food Science, 33, 1–8. https://doi.org/10.1016/j.cofs.2019.09.004
- Zhang, H., Zhang, F., & Yuan, R. (2020). Applications of natural polymer-based hydrogels in the food industry. In Hydrogels Based on Natural Polymers (pp. 357–410). Elsevier. https://doi.org/10.1016/B978-0-12-816421-1.00015-X

Introduction

Protein-polysaccharide binary hydrogels can help in the development of these food products by acting as a structural matrix that can help modulate the texture and mouthfeel of the product while also providing a way to protect and deliver bioactive compounds (used for the fortification of these food systems).



Protein water dispersion

Polysaccharide water dispersion

Protein-polysaccharide binary hydrogel

Innovative health-promoting plant-based food products:

- **Food quality and nutrition improvement,**
- **Calorie and texture modulation,**
- **Bioactive compounds protection,**
- **Targeted delivery systems.**

WARSAW UNIVERSITY OF LIFE SCIENCES

References

- Li, J., Jia, X., & Yin, L. (2021). Hydrogel: Diversity of Structures and Applications in Food Science. Food Reviews International, 37(3), 313–372. https://doi.org/10.1080/87559129.2020.1858313
- Zhang, H., Zhang, F., & Yuan, R. (2020). Applications of natural polymer-based hydrogels in the food industry. In *Hydrogels Based on Natural Polymers* (pp. 357–410). Elsevier. https://doi.org/10.1016/B978-0-12-816421-1.00015-X
- Liu, Z., Smart, J. D., & Pannala, A. S. (2020). Recent developments in formulation design for improving oral bioavailability of curcumin: A review. In Journal of Drug Delivery Science and Technology (Vol. 60). Editions de Sante. https://doi.org/10.1016/j.jddst.2020.102082
- Klein, M., & Poverenov, E. (2020). Natural biopolymer-based hydrogels for use in food and agriculture. Journal of the Science of Food and Agriculture, 100(6), 2337–2347. https://doi.org/10.1002/jsfa.10274

Introduction

This research objective was to evaluate the physicochemical and textural properties of the binary hydrogels obtained using plant-based protein and prebiotic polysaccharide.

The scope of this research included:

- **Designing the experiment using DOE statistical tool (pea protein concentration ranging from 10 to 15% and psyllium husk concentration ranging from 1.5 to 2%),**
- **Obtaining 10 hydrogel combinations (variants) using the thermo-mechanical induction technique,**
- **Analyzing the obtained hydrogels in terms of their volumetric gelling index, water holding capacity, microrheology, texture, and color parameters.**

WARSAW
UNIVERSITY
OF LIFE SCIENCES

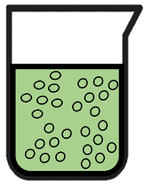
Materials and methods

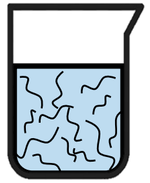
Materials

- Pea protein NUTRALYS® F85F (**PP**, protein content 84%) provided by Roquette Frères (Lestrem, France),
- Psyllium Husk Powder (**PS**, type 10351, purity: 95%, particle size: 60 mesh) provided by C.E. Roeper GmbH (Hamburg, Germany).

Sample preparation was conducted in two stages:

Stage 1
Preparation of the dispersions

Pea protein (PP) + Water → **Mixing** **30 min. 80°C** →  **Pea protein (PP) water dispersion**

Psyllium (PS) + Water → **Mixing** **30 min. 80°C** →  **Psyllium (PS) water dispersion**

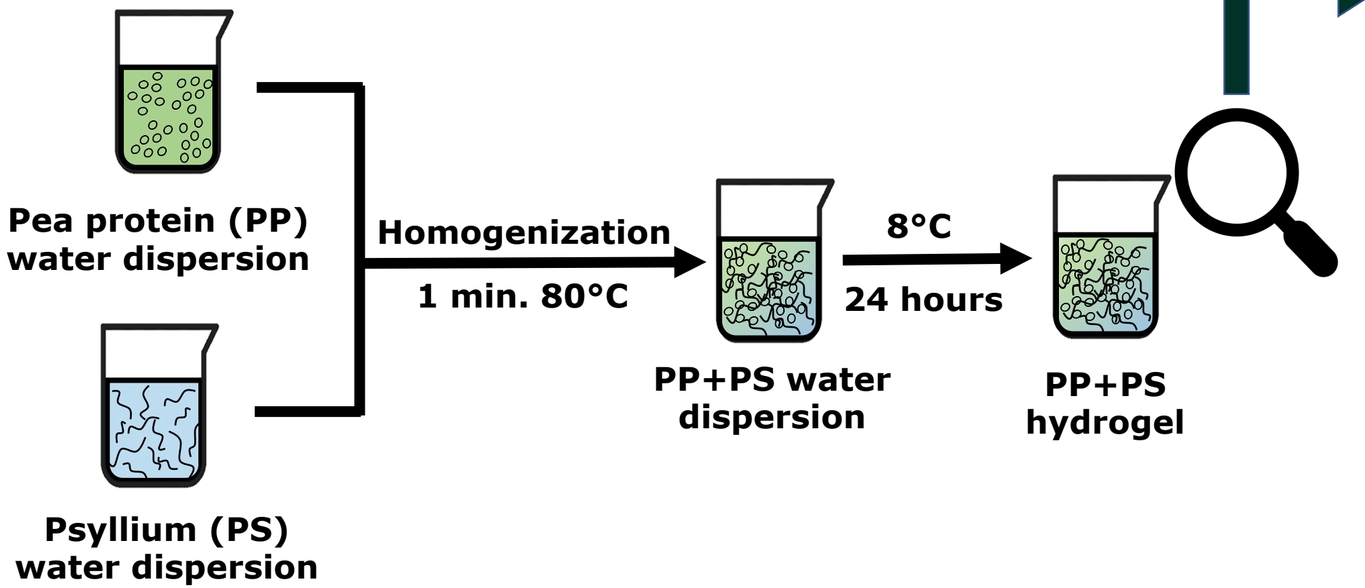
Experimental combinations of pea protein (PP) and psyllium husk (PS)

Combination	Variables	
	PP [%]	PS [%]
C1	10	1.5
C2	10	1.75
C3	10	2
C4	12.5	1.5
C5	12.5	1.75
C6 (c)	12.5	1.75
C7	12.5	2
C8	15	1.5
C9	15	1.75
C10	15	2

WARSAW UNIVERSITY OF LIFE SCIENCES

Materials and methods

Stage 2
Preparation of the hydrogel



Methods

1) Volumetric gelling index (VGI) and water holding capacity (WHC)

2) Microrheological properties - Rheolaser Master device (Formulaction, L'Union, France)

3) Textural Properties - texture analyzer (TA.XT Plus, Stable Micro Mixtures, Surrey, UK)

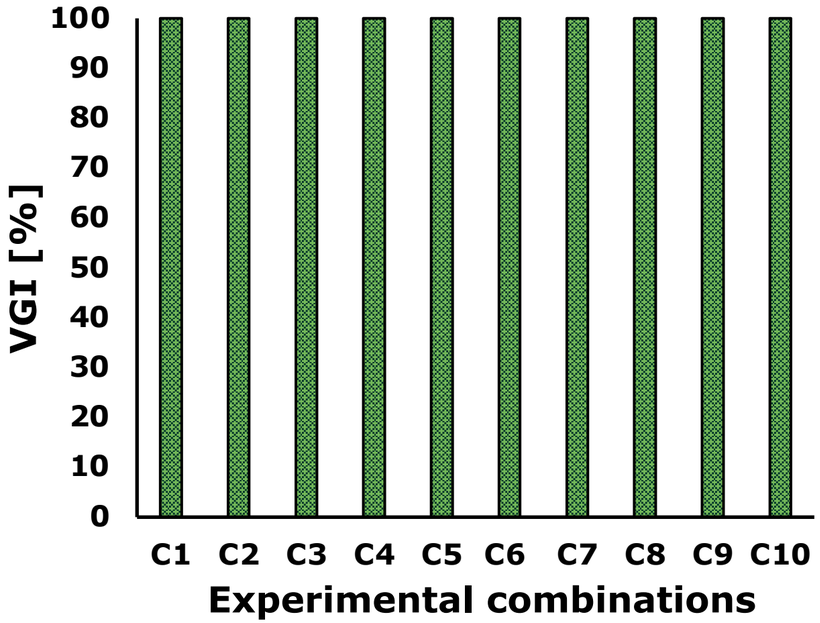
4) Color parameters in the CIE system (L*, a*, b*) – Minolta CR-200 colorimeter (Minolta, Japan)

5) statistical analysis – one-way ANOVA, PCA and HCA (Statistica 13.3, TIBCO Software Inc., Palo Alto, CA, USA)

* Measurements were made in triplicate for each sample

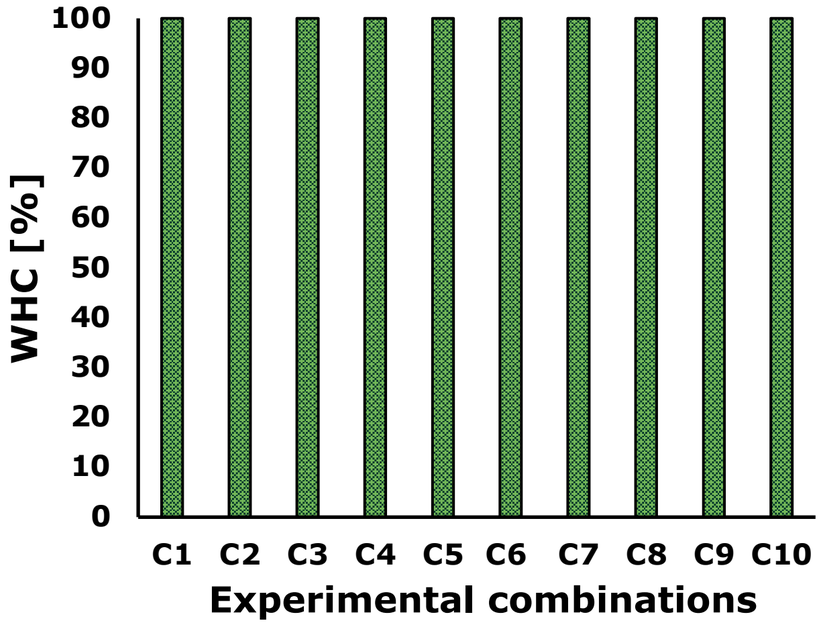
Results

1) Volumetric gelling index (VGI) and water holding capacity (WHC)



- VGI is a parameter that expresses a gel structure's capacity to develop. VGI is equivalent to 0% when the gel structure is not formed, and it is equal to 100% when the sample is entirely gelled.

Example of an inverted vial containing the experimental combination C5 (12.5% PP and 1.75% PS)



- WHC is a parameter that showcase the capacity of a hydrogel to hold water (after subjecting the hydrogel to a centrifugal force). The hydrogel's water holding capacity is related to its physical stability.

WARSAW UNIVERSITY OF LIFE SCIENCES

References

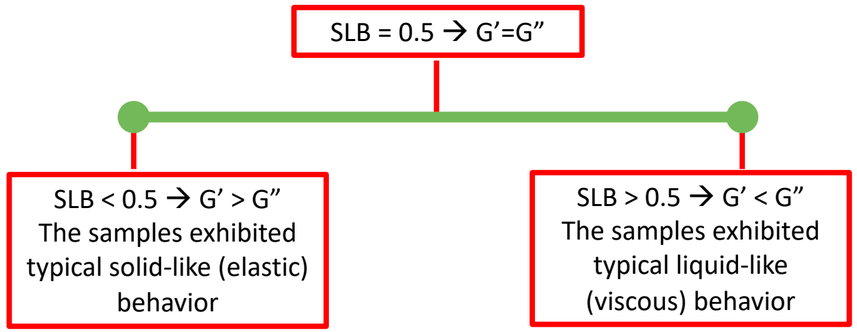
- Florowska, A., Hilal, A., Florowski, T., Mrozek, P., & Wroniak, M. (2022). Sodium Alginate and Chitosan as Components Modifying the Properties of Inulin Hydrogels. *Gels*, *8*(1), 63. https://doi.org/10.3390/gels8010063
- Qayum, A., Hussain, M., Li, M., Li, J., Shi, R., Li, T., Anwar, A., Ahmed, Z., Hou, J., & Jiang, Z. (2021). Gelling, microstructure and water-holding properties of alpha-lactalbumin emulsion gel: Impact of combined ultrasound pretreatment and laccase cross-linking. Food Hydrocolloids, 110. https://doi.org/10.1016/j.foodhyd.2020.106122

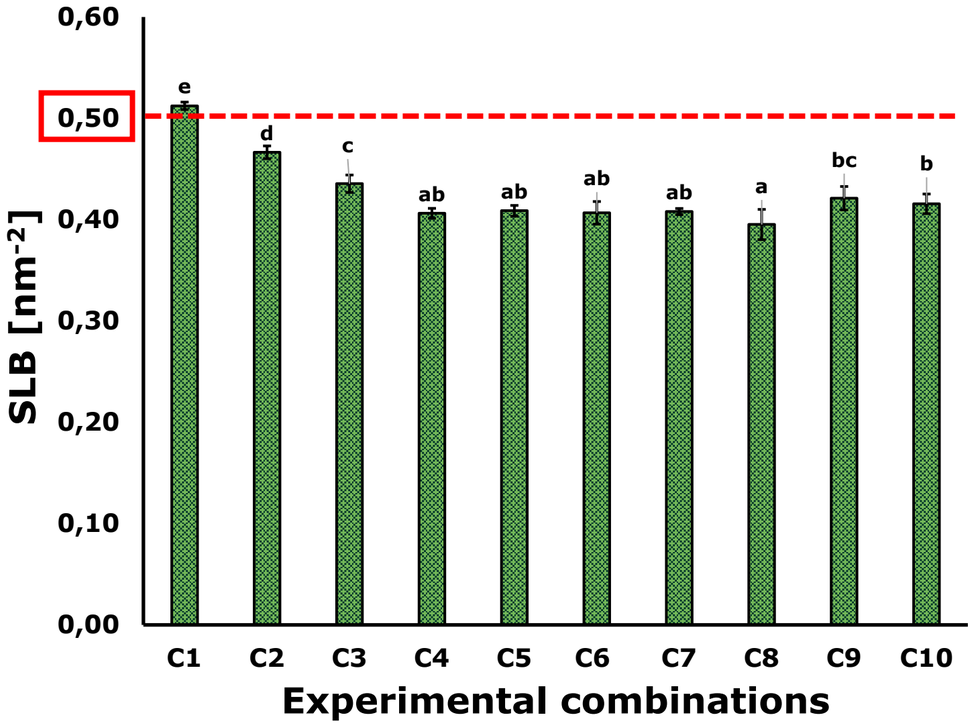
Results

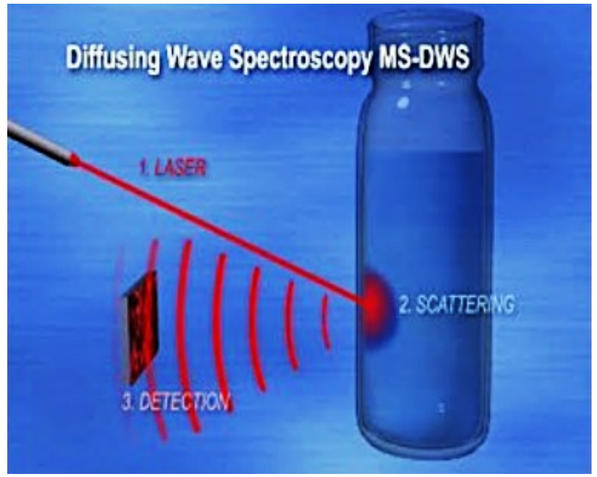
2) Microrheological properties - Rheolaser Master device (Formulaction, L'Union, France)

Solid-liquid balance (SLB)

- SLB is proportional to the viscoelastic properties of the studied sample. SLB is related to the following functional characteristics: adhesion, shape stability, texture, spreadability, and physical stability.
- SLB corresponds to the ratio of the loss modulus G" to the elastic modulus G' (G"/G').
- All the hydrogel combinations (except C1) were exhibiting solid-like behaviors (SLB < 0.5).







WARSAW UNIVERSITY OF LIFE SCIENCES

References

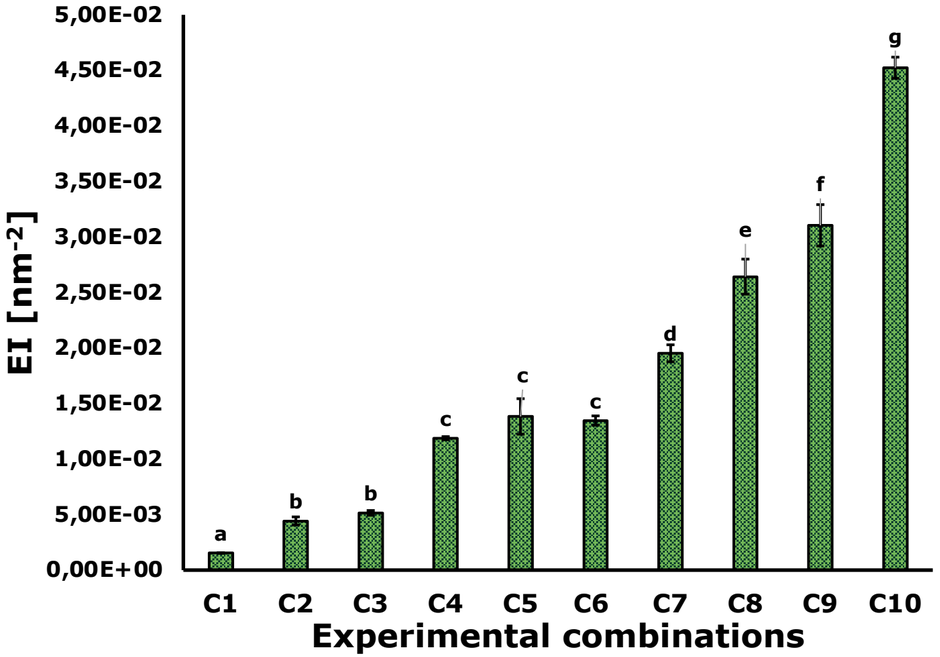
- Mao, Y., Nielsen, P., & Ali, J. (2022). Passive and Active Microrheology for Biomedical Systems. Frontiers in Bioengineering and Biotechnology, 10. https://doi.org/10.3389/fbioe.2022.916354
- Hafner, J., Oelschlaeger, C., & Willenbacher, N. (2020). Microrheology imaging of fiber suspensions – a case study for lyophilized collagen I in HCl solutions. Soft Matter, 16(39), 9014–9027. https://doi.org/10.1039/D0SM01096K
- Szymańska, I., Żbikowska, A., & Kowalska, M. (2020). Physical stability of model emulsions based on ethyl cellulose oleogels. International Agrophysics, 34(3), 289–300. https://doi.org/10.31545/intagr/122333

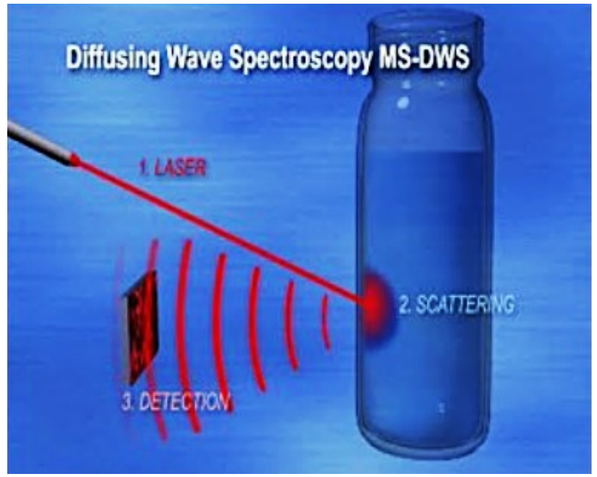
Results

2) Microrheological properties - Rheolaser Master device (Formulaction, L'Union, France)

Elasticity Index (EI):

- The elasticity index (EI) is directly proportional to the elastic modulus G' and provides information about the sample's elasticity, which is due to the solid-like characteristic.
- EI can be linked to functional characteristics such as mesh size (polymer), hardness, gelation speed, and stress recovery.
- The high elasticity of a hydrogel suggests that a high number of polymers formed a network leading to a highly dense structure.
- The combination C10 (containing 15% PP and 2% PS) had the highest EI value, while C1 (containing 10% PP and 1.5% PS) had the lowest EI value.





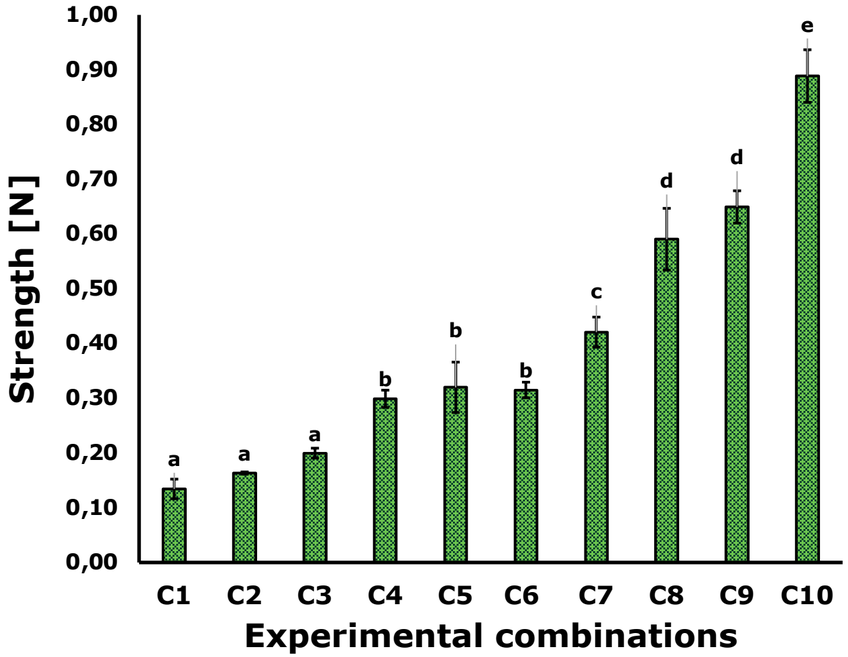
WARSAW UNIVERSITY OF LIFE SCIENCES

References

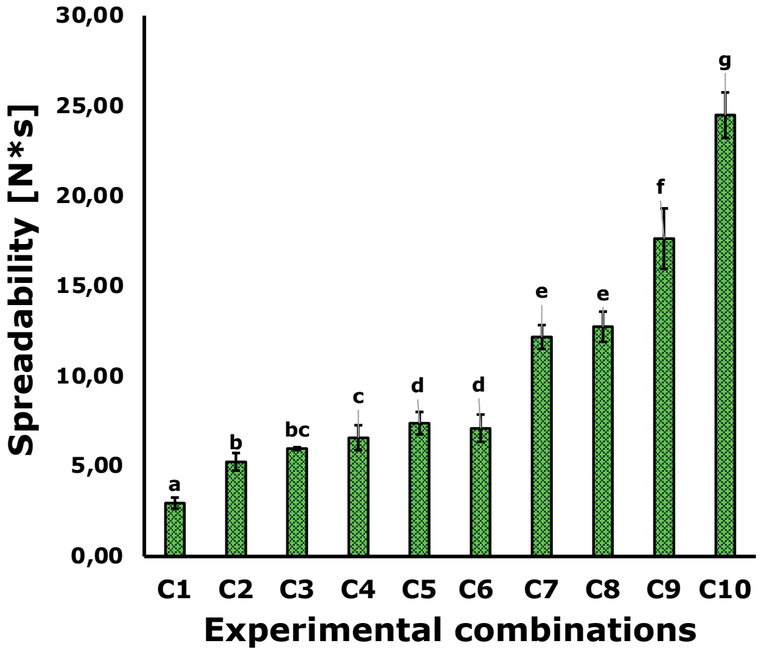
- Mao, Y., Nielsen, P., & Ali, J. (2022). Passive and Active Microrheology for Biomedical Systems. Frontiers in Bioengineering and Biotechnology, 10. https://doi.org/10.3389/fbioe.2022.916354
- Hafner, J., Oelschlaeger, C., & Willenbacher, N. (2020). Microrheology imaging of fiber suspensions – a case study for lyophilized collagen I in HCl solutions. Soft Matter, 16(39), 9014–9027. https://doi.org/10.1039/D0SM01096K
- Szymańska, I., Żbikowska, A., & Kowalska, M. (2020). Physical stability of model emulsions based on ethyl cellulose oleogels. International Agrophysics, 34(3), 289–300. https://doi.org/10.31545/intagr/122333

Results

3) Textural Properties - texture analyzer (TA.XT Plus, Stable Micro Mixtures, Surrey, UK)



- The strength parameter represents the amount of force required to penetrate the structure of the studied hydrogel. A high strength value suggest that the structure of the hydrogel is compact.



- The spreadability parameter is related to the ease with which a sample (hydrogel), can be applied in a thin, even layer. A high spreadability value indicates that the hydrogel is less spreadable.

WARSAW UNIVERSITY OF LIFE SCIENCES

References

- Florowska, A., Hilal, A., Florowski, T., Mrozek, P., & Wroniak, M. (2022). Sodium Alginate and Chitosan as Components Modifying the Properties of Inulin Hydrogels. *Gels*, *8*(1), 63. https://doi.org/10.3390/gels8010063
- Florowska, A., Hilal, A., Florowski, T., & Wroniak, M. (2020). Addition of Selected Plant-Derived Proteins as Modifiers of Inulin Hydrogels Properties. Foods, 9(7), 845. https://doi.org/10.3390/foods9070845
- Mousavi, S. M. R., Rafe, A., & Yeganehzad, S. (2019). Textural, mechanical, and microstructural properties of restructured pimiento alginate-guar gels. Journal of Texture Studies, 50(2), 155–164. https://doi.org/10.1111/jtxs.12385

Results

4) Color parameters in the CIE system (L*, a*, b*) – Minolta CR-200 colorimeter (Minolta, Japan)

✦ To determine the color differences between all the samples, **the total color difference parameter ΔE** was calculated:

Experimental combinations	C10	C9	C8	C7	C6	C5	C4	C3	C2	C1
C1	3,7	3,2	2,6	2,3	1,8	1,8	2,0	1,7	1,5	-
C2	2,3	2,1	1,9	1,0	1,1	1,5	1,7	0,3	-	
C3	2,2	2,1	1,9	0,9	1,0	1,6	1,8	-		
C4	2,5	1,7	0,9	1,5	0,9	0,4	-			
C5	2,5	1,8	1,0	1,3	0,6	-				
C6	2,1	1,6	1,1	0,8	-					
C7	1,5	1,2	1,2	-						
C8	1,8	0,9	-							
C9	0,9	-								
C10	-									

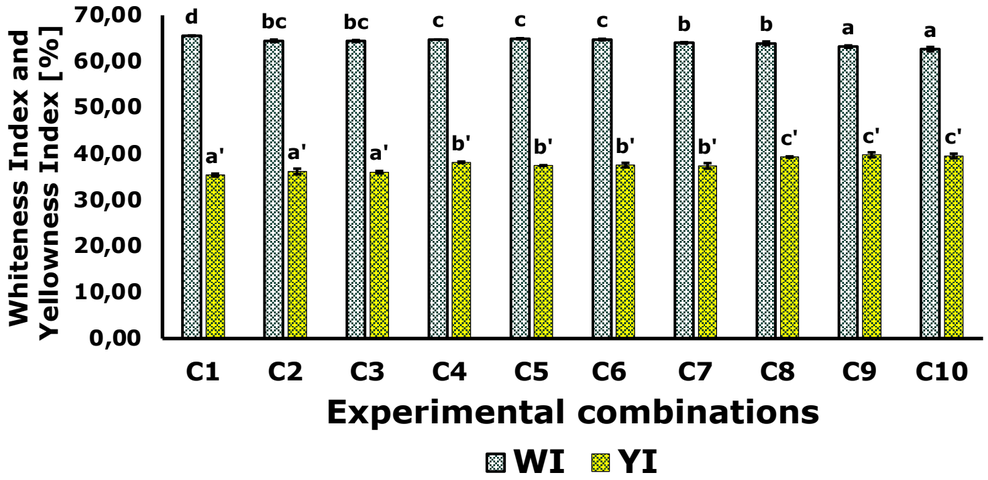
$$\Delta E = \sqrt{(L^*_{s1} - L^*_{s2})^2 + (a^*_{s1} - a^*_{s2})^2 + (b^*_{s1} - b^*_{s2})^2}$$, where: L^*_{S1}; a^*_{S1}; b^*_{S1} and L^*_{S2}; a^*_{S2}; b^*_{S2} refer to the color parameters of the compared samples.

0 < ΔE < 1	1 < ΔE < 2	2 < ΔE < 3.5	3.5 < ΔE < 5	5 < ΔE
Observer does not notice the difference	Only experienced observer can notice the difference	Unexperienced observer also notices the difference	Clear difference in color is noticed	Observer notices two different colors

✦ To determine the whiteness and yellowness of the obtained samples, **the whiteness index (WI) and yellowness index (YI)** of each combination was calculated:

$$WI = 100 - \sqrt{(100 - L^*)^2 + a^{*2} + b^{*2}},$$

$$YI = 142.86 \times \left(\frac{b^*}{L^*}\right)$$, where: L*, a*, and b* refer to the color parameters of each analyzed sample.



WARSAW UNIVERSITY OF LIFE SCIENCES

References

✦ Sobol, Z., Jakubowski, T., & Nawara, P. (2020). Application of the CIE L*a*b* method for the evaluation of the color of fried products from potato tubers exposed to C band ultraviolet light. Sustainability (Switzerland), 12(8). https://doi.org/10.3390/SU12083487

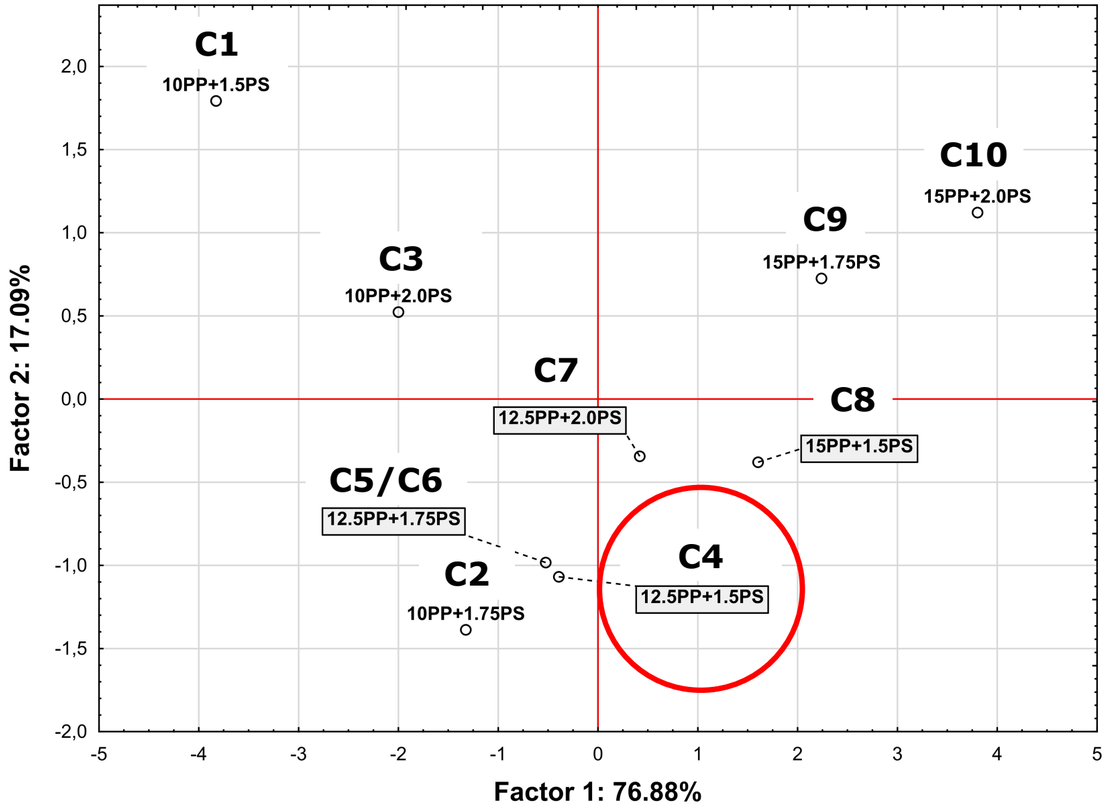
✦ Florowska, A., Florowski, T., Sokołowska, B., Adamczak, L., & Szymańska, I. (2021). Effects of Pressure Level and Time Treatment of High Hydrostatic Pressure (HHP) on Inulin Gelation and Properties of Obtained Hydrogels. Foods, 10(11), 2514. https://doi.org/10.3390/foods10112514

✦ Tang, C., Zhang, W., Zou, Y., Xing, L., Zheng, H., Xu, X., & Zhou, G. (2017). Influence of RosA-protein adducts formation on myofibrillar protein gelation properties under oxidative stress. Food Hydrocolloids, 67, 197–205. https://doi.org/10.1016/j.foodhyd.2017.01.006

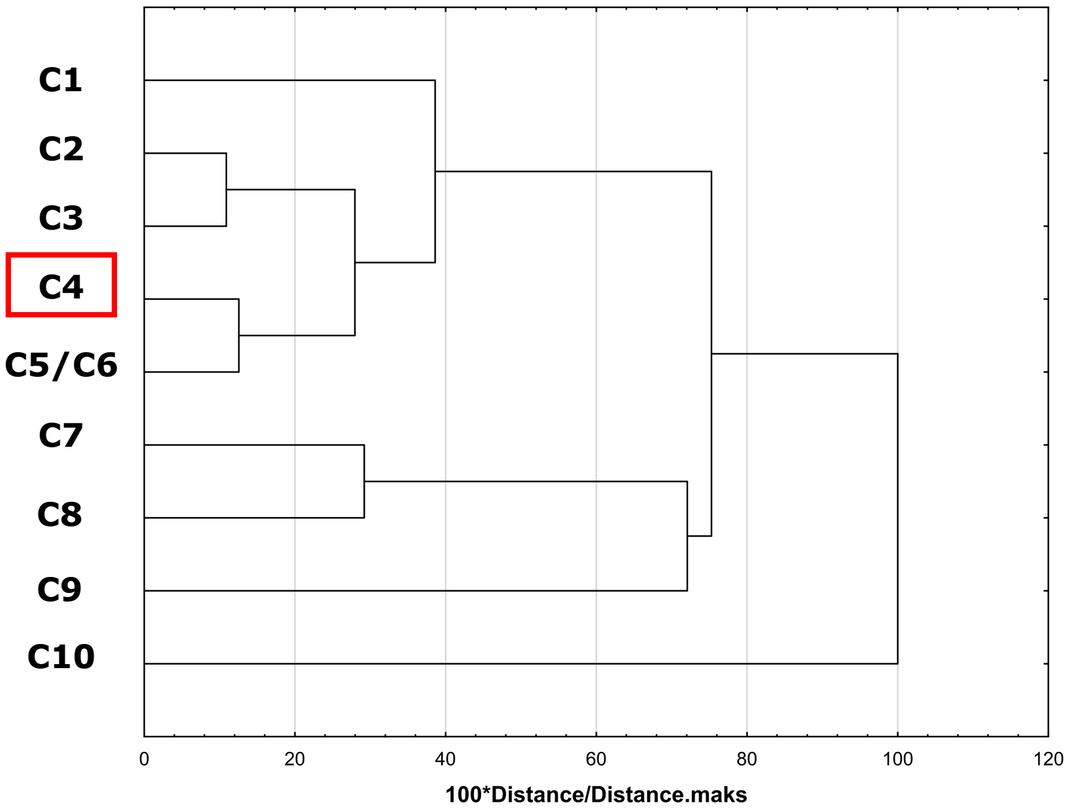
Results

5) statistical analysis – Principal component analysis (PCA) and Hierarchal cluster analysis HCA (Statistica 13.3, TIBCO Software Inc., Palo Alto, CA, USA)

PCA



HCA



WARSAW UNIVERSITY OF LIFE SCIENCES

Conclusion

This research objective was to evaluate the physicochemical and textural properties of the binary hydrogels obtained using plant-based protein and prebiotic polysaccharide.

- **The physicochemical and textural properties of the obtained binary hydrogels can be controlled by modulating the concentration levels of both pea protein and psyllium husk.**
- **In terms of the analyzed properties, the most optimal variant was the one containing 12.5% pea protein and 1.5% psyllium husk.**
- **Such binary hydrogels can be used as a structural matrix in plant-based functional food development, by modulating the texture attributes and helping to fortify such foods by acting as a delivery system for nutrients and bioactive ingredients.**

WARSAW
UNIVERSITY
OF LIFE SCIENCES

Contact Information

Adonis Hilal, WULS PhD Candidate

Email: adonis_hilal@sggw.edu.pl

LinkedIn: www.linkedin.com/in/adonis-h-a85398161

WARSAW
UNIVERSITY
OF LIFE SCIENCES

Warsaw University of Life Sciences
166 Nowoursynowska St., 02-787
Warsaw

www.sggw.edu.pl