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Editorial

Special Issue on Polysaccharides: From Extraction to Applications

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The use of polysaccharides in many aspects of life dates back to the ancient era. Since then, humankind has used polysaccharide products and raw materials for food, cosmetic, medicinal and construction purposes.

The growing cost of petroleum and the prospect of a shortage of its natural deposits has prompted the search for alternative sources of energy and industrial raw materials. Polysaccharides are a common, cheap, sustainable and renewable group of organic compounds, and are considered attractive raw materials that provide access to several novel biodegradable materials for use in the chemical, food and pharmaceutical industries. Natural polysaccharides have attracted increasing interest due to their potential application across many fields [1].

Regarding their chemical structure, polysaccharides can easily be modified using physical, physicochemical, chemical and enzymatic methods. Numerous studies have confirmed the bioactivity of polysaccharides, which makes them applicable to clinical practice, nutrition and dietetics [2]. Depending on their origin, polysaccharides can exhibit antioxidative, immunomodulating, anti-inflammatory, antiviral (e.g., against HIV), antimutagenic, cancerostatic or anticlotting properties [3–5].

Polysaccharides have a wide range of key characteristics essential for their practical use; for instance, they have low, medium and high molecular weights; variable polydispersity; the ability to form linear and branched macrostructures; monofunctionality (compounds bearing solely hydroxyl groups) and polyfunctionality (compounds with hydroxyl, carboxylic and/or amino groups); a high degree of chirality; either low or high aqueous solubility; little-to-no toxicity; and immunogenicity. Thanks to these properties, polysaccharides are widely applied in nanotechnology.

Recently, the applicability of various polysaccharides in the synthesis of inorganic nanoparticles was recognized [6–8]. Polysaccharides act as reducers and stabilizers—or matrices. Such matrices bring about the formation of nanoparticles of uniform size, thus satisfying the requirements for their practical applications [9]. Nanoparticles immobilized within such matrices exhibit interesting properties such as a demand for overall functionality, barrier properties and transparency. Nanocomposites with such nanoparticles are biodegradable and environmentally benign. Thus, they have numerous potential applications in prophylaxis, therapy and agricultural production [10]. The following polysaccharides are suitable for developing nanoparticles: starch, cellulose, alginates, pectins, xanthan gum, cyclodextrins, chitosan [11], heparin [12] and hyaluronic acid [13].

Chemical modifications of polysaccharides involve acid- and base-catalyzed depolymerization, oxidation, esterification, etherification and grafting. Such modifications can convert polysaccharides from hydrophilic into hydrophobic species [14]. Supplying polysaccharides with various functional groups through sulfation, alkylation, carboxymethylation, phosphorylation, selenation, acylation, and other processes enables control of polysaccharide bioactivity.

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Physical methods include: heating [15,16], freezing [17], treating with a high pressure, sonication, treating with glow plasma [18] and electromagnetic radiation of different range of wavelengths (infrared, microwaves, visible, ultraviolet and ionizing radiation) [19,20]. Physical modifications are usually simple, cheap and safe as they do not use chemicals, enzymes or microorganisms. They are used chiefly to reduce molecular weight and viscosity and to improve the solubility of polysaccharides.

Biological modifications of polysaccharides mainly involve their enzymatic degradation. They are advantageous for their high specificity and yield with minimal side effects. Some genetic modifications for breeding plants containing polysaccharides of tailored structures have recently been developed; for instance, either hylon or waxy starches are available from genetically modified corn.

Modified polysaccharides are manufactured to satisfy the industrial demands of the food, pharmaceutical, cosmetic, pulp, textile, metallurgical and drilling industries. Among commercially available natural polysaccharides starch, cellulose and pectins are the most common; however, easy access to other polysaccharides such as carrageenans, xanthan gum, alginates could open up many more potential applications. [21]. Considerable attention is paid to eliminating traditional processes of manufacturing and using natural polysaccharides in favor of modern solutions to satisfy ecological and consumer demands.

The purpose of this Special Issue was to gather and present papers dedicated to the formation, isolation and applications of polysaccharides in various branches of science and technology. A total of 16 papers were published, including four review articles on new chitosan derivatives and their biological application [22], the characterization of pectin [23], and in particular, the influence of its extraction method on functional properties. It was shown that the functional properties of pectin are influenced by the source, methods and conditions of extraction. Górska et al. [24], in their review article, discussed the methods of obtaining and determining the structure and biological properties of polysaccharides in combination with selenium. Seleno-derivatives of polysaccharides have found wide application due to their anti-cancer, immune-enhancing, antioxidant, anti-diabetic, anti-inflammatory, hepatoprotective and neuroprotective properties. Yu et al. [25] discussed a "Comparison of Analytical Methods for Determining Methylesterification and Acetylation of Pectin" via titration, FT-IR and HPLC. Ciesielska et al. [26] presented a biomedical application of cyclodextrins cross-linked with carboxylic acid anhydrides. Cyclodextrin-based nanosponges became cross-linked via pyromellitic dianhydride due to biocompatibility, the improved solubility of lipophilic compounds, increased stability, controlled release of the active substance and reduced toxicity, and can be used in biomedicine. In the following articles, various methods of isolating polysaccharides were presented, their properties were investigated and potential applications discussed.

Poerio et al. [27] compared the physicochemical properties of chitin extracted from *Cicada orni* sloughs harvested in three different years in order to assess the stability of the source and the repeatability of the extraction process. In the next study [28], the chemical properties of a purified ginseng polysaccharide fraction and an assessment of its immune-enhancing activity using RAW264.7 macrophages were analyzed. It has been shown that the obtained polysaccharides can help to maintain homeostasis during viral and bacterial infections. In another paper [29], it was discovered that the polysaccharide fraction isolated from water extracts of Korean red ginseng may enhance the innate immune response and cause the phosphorylation of intermediates of intercellular signaling pathways in the RAW264.7 cell line. Milicaj at al. [30] increased the efficiency of the ADP-Heptose and Kdo_2-Lipid extraction processes by optimizing their extraction protocols. Liang et al. [31] isolated and identified two polysaccharides from *Flammulina velutipes*. Khairuddin et al. [32] showed that *Caulerpa lentillifera* extract can be used as a dietary supplement and an alternative method of treating diabetes.

Pater et al. [33] investigated the effect of low-temperature plasma on the activity of dry yeast in the malting process, and on improving the reserve level of polysaccharide glycogen. Markou et al. [34] showed that β-glucans are of particular interest as biologically active compounds, and polysaccharides from *Arthrospira* may be a potential ingredient for the development of new functional foods.

Subsequent works discuss the possibility of using polysaccharide nanostructures or polysaccharides for the synthesis of nanoparticles. Czakaj et al. [35] demonstrated that carboxylated cellulose nanocrystals enhance foamability and foam stability when mixed with the cationic surfactant ethyl lauroyl arginate. Rutkowski et al. [36] described the preparation of silver nanoparticles in a polysaccharide carrier, studied the inhibitory effect of the obtained materials on the development of microbial infection, and evaluated their influence on the germination degree of Tomato (*Solanum lycopersicum*) seeds in in vitro plant cultures. Nowak et al. [37] present a novel, environmentally friendly method for the preparation of sodium alginate/nanosilver/graphene oxide and sodium alginate/nanogold/graphene oxide nanocomposites and their characteristics. Their bacteriostatic properties were also tested.

Although submissions for this Special Issue have been closed, due to high interest in the subject matter, a second part has been launched.

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References

1. Cumpstey, I. Chemical Modification of Polysaccharides. *Int. Sch. Res. Not.* **2013**, *2013*, 27. [CrossRef] [PubMed]
2. Li, S.; Xiong, Q.; Lai, X.; Li, X.; Wan, M.; Zhang, J.; Yan, Y.; Cao, M.; Lu, L.; Guan, J.; et al. Molecular Modification of Polysaccharides and Resulting Bioactivities. *Compr. Rev. Food Sci. Food Saf.* **2016**, *15*, 237–250. [CrossRef]
3. Gamal-Eldeen, A.M.; Ahmed, E.F.; Abo-Zeid, M.A. In vitro cancer chemopreventive properties of polysaccharide extract from the brown alga, Sargassum latifolium. *Food Chem. Toxicol.* **2009**, *47*, 1378–1384. [CrossRef]
4. Tian, Y.; Zeng, H.; Xu, Z.; Zheng, B.; Lin, Y.; Gan, C.; Lo, Y.M. Ultrasonic-assisted extraction and antioxidant activity of polysaccharides recovered from white button mushroom (*Agaricus bisporus*). *Carbohydr. Polym.* **2012**, *88*, 522–529. [CrossRef]
5. Li, S.; Shah, N.P. Antioxidant and antibacterial activities of sulphated polysaccharides from Pleurotus eryngii and *Streptococcus thermophilus* ASCC 1275. *Food Chem.* **2014**, *165*, 262–270. [CrossRef] [PubMed]
6. Darder, M.; Aranda, P.; Ruiz-Hitzky, E. Bionanocomposites: A new concept of ecological, bioinspired, and functional hybrid materials. *Adv. Mater.* **2007**, *19*, 1309–1319. [CrossRef]
7. Dias, A.M.G.C.; Hussain, A.; Marcos, A.S.; Roque, A.C.A. A biotechnological perspective on the application of iron oxide magnetic colloids modified with polysaccharides. *Biotechnol. Adv.* **2011**, *29*, 142–155. [CrossRef] [PubMed]
8. Hanemann, T.; Szabó, D.V. Polymer-Nanoparticle Composites: From Synthesis to Modern Applications. *Materials* **2010**, *3*, 3468–3517. [CrossRef]
9. Emam, H.E.; Ahmed, H.B. Polysaccharides templates for assembly of nanosilver. *Carbohydr. Polym.* **2016**, *135*, 300–307. [CrossRef]
10. Martínez, A.M.; Benito, M.; Pérez, E.; María Teijón, J.; Dolores Blanco, M. The Role of Anionic Polysaccharides in the Preparation of Nanomedicines with Anticancer Applications. *Curr. Pharm. Des.* **2016**, *22*, 3364–3379. [CrossRef]
11. Yang, C.H.; Wang, L.S.; Chen, S.Y.; Huang, M.C.; Li, Y.H.; Lin, Y.C.; Chen, P.F.; Shaw, J.F.; Huang, K.S. Microfluidic assisted synthesis of silver nanoparticle–chitosan composite microparticles for antibacterial applications. *Int. J. Pharm.* **2016**, *510*, 493–500. [CrossRef] [PubMed]
12. Kemp, M.M.; Kumar, A.; Clement, D.; Ajayan, P.; Mousa, S.; Linhardt, R.J. Hyaluronan- and heparin-reduced silver nanoparticles with antimicrobial properties. *Nanomedicine* **2009**, *4*, 421–429. [CrossRef] [PubMed]
13. Khachatryan, G.; Khachatryan, K.; Stobinski, L.; Tomasik, P.; Fiedorowicz, M.; Lin, H.M. CdS and ZnS quantum dots embedded in hyaluronic acid films. *J. Alloys Compd.* **2009**, *481*, 402–406. [CrossRef]
14. Cunha, A.G.; Gandini, A. Turning polysaccharides into hydrophobic materials: A critical review. Part 1. Cellulose. *Cellulose* **2010**, *17*, 875–889. [CrossRef]
15. Tomasik, P.; Pałasiński, M.; Wiejak, S. The Thermal Decomposition of Carbohydrates. Part, I. The Decomposition of Mono-, Di-, and Oligo-Saccharides. *Adv. Carbohydr. Chem. Biochem.* **1989**, *47*, 203–278. [CrossRef]
16. Tomasik, P.; Jane, J.-L. Reaction of Starch and Cellulose with Products of Thermal Decomposition of Mono- and Disaccharides. *Starch-Stärke* **1995**, *47*, 24–29. [CrossRef]

17. Szymońska, J.; Krok, F. Potato starch granule nanostructure studied by high resolution non-contact AFM. *Int. J. Biol. Macromol.* **2003**, *33*, 1–7. [CrossRef]
18. Liao, C.-D.; Stobinski, L.; Tomasik, P. Effect of corona discharges on granular starches Attempted Niementowski condensation of anthranilic acid and its ester with 3-Methyl-1-phenylpyrazolin-5-one View project. *J. Food Agric. Environ.* **2003**, *1*, 143–149.
19. Lewandowicz, G.; Soral-Śmietana, M. Starch modification by iterated syneresis. *Carbohydr. Polym.* **2004**, *56*, 403–413. [CrossRef]
20. Ashogbon, A.O.; Akintayo, E.T. Recent trend in the physical and chemical modification of starches from different botanical sources: A review. *Starch-Stärke* **2014**, *66*, 41–57. [CrossRef]
21. Baldwin, A.D.; Kiick, K.L. Polysaccharide-modified synthetic polymeric biomaterials. *Pept. Sci.* **2010**, *94*, 128–140. [CrossRef]
22. Sivanesan, I.; Hasan, N.; Ali, S.K.; Shin, J.; Gopal, J.; Muthu, M.; Oh, J.W. Novel Chitosan Derivatives and Their Multifaceted Biological Applications. *Appl. Sci.* **2022**, *12*, 3267. [CrossRef]
23. Belkheiri, A.; Forouhar, A.; Ursu, A.V.; Dubessay, P.; Pierre, G.; Delattre, C.; Djelveh, G.; Abdelkafi, S.; Hamdami, N.; Michaud, P. Extraction, characterization, and applications of pectins from plant by-products. *Appl. Sci.* **2021**, *11*, 6596. [CrossRef]
24. Górska, S.; Maksymiuk, A.; Turło, J. Selenium-containing polysaccharides—Structural diversity, biosynthesis, chemical modifications and biological activity. *Appl. Sci.* **2021**, *11*, 3717. [CrossRef]
25. Yu, Y.; Wang, Y.; Liu, X.; Liu, Y.; Ji, L.; Zhou, Y.; Sun, L. Comparison of analytical methods for determining methylesterification and acetylation of pectin. *Appl. Sci.* **2021**, *11*, 4461. [CrossRef]
26. Ciesielska, A.; Ciesielski, W.; Girek, B.; Girek, T.; Koziel, K.; Kulawik, D.; Lagiewka, J. Biomedical application of cyclodextrin polymers cross-linked via dianhydrides of carboxylic acids. *Appl. Sci.* **2020**, *10*, 8463. [CrossRef]
27. Poerio, A.; Girardet, T.; Petit, C.; Fleutot, S.; Jehl, J.P.; Arab-Tehrany, E.; Mano, J.F.; Cleymand, F. Comparison of the physicochemical properties of chitin extracted from cicada orni sloughs harvested in three different years and characterization of the resulting chitosan. *Appl. Sci.* **2021**, *11*, 1278. [CrossRef]
28. Kim, S.J.; Shin, M.S.; Kim, M.; Baek, S.H.; Kang, K.S. Characterization of an immune-enhancing polysaccharide fraction isolated from heat-processed ginseng derived from panax ginseng c.A. meyer. *Appl. Sci.* **2021**, *11*, 10835. [CrossRef]
29. Gao, J.; Lee, S.; Lee, J.H.; Kang, K.S.; Shin, M.S. Signaling pathways associated with macrophage-activating polysaccharide isolated from Korea red ginseng. *Appl. Sci.* **2021**, *11*, 7111. [CrossRef]
30. Milicaj, J.; Castro, C.D.; Jaunbocus, N.; Taylor, E.A. Extraction of ADP-heptose and Kdo2-Lipid a from E. Coli deficient in the heptosyltransferase I gene. *Appl. Sci.* **2021**, *11*, 8314. [CrossRef]
31. Liang, Z.; Zheng, K.; Zhao, Q.; Shao, W.; Li, C.; Wang, J.; Ma, C.; Kang, W. Structural identification and coagulation effect of flammulina velutipes polysaccharides. *Appl. Sci.* **2021**, *11*, 1736. [CrossRef]
32. Khairuddin, K.; Sudirman, S.; Huang, L.; Kong, Z.L. Caulerpa lentillifera polysaccharides-rich extract reduces oxidative stress and proinflammatory cytokines levels associated with male reproductive functions in diabetic mice. *Appl. Sci.* **2020**, *10*, 8768. [CrossRef]
33. Pater, A.; Satora, P.; Zdaniewicz, M.; Makarewicz, M.; Khachatryan, K. The Improvement of Reserve Polysaccharide Glycogen Level and Other Quality Parameters of *S. cerevisiae* Brewing Dry Yeasts by Their Rehydration in Water, Treated with Low-Temperature, Low-Pressure Glow Plasma (LPGP). *Appl. Sci.* **2022**, *12*, 2909. [CrossRef]
34. Markou, G.; Eliopoulos, C.; Argyri, A.; Arapoglou, D. Production of arthrospira (Spirulina) platensis enriched in β-glucans through phosphorus limitation. *Appl. Sci.* **2021**, *11*, 8121. [CrossRef]
35. Czakaj, A.; Krzan, M.; Warszyński, P. The Effect of Electrolytes and Urea on the Ethyl Lauroyl Arginate and Cellulose Nanocrystals Foam Stability. *Appl. Sci.* **2022**, *12*, 2797. [CrossRef]
36. Rutkowski, M.; Krzemińska-Fiedorowicz, L.; Khachatryan, G.; Bulski, K.; Kołton, A.; Khachatryan, K. Biodegradable Silver Nanoparticles Gel and Its Impact on Tomato Seed Germination Rate in In Vitro Cultures. *Appl. Sci.* **2022**, *12*, 2722. [CrossRef]
37. Nowak, N.; Grzebieniarz, W.; Khachatryan, G.; Khachatryan, K.; Konieczna-Molenda, A.; Krzan, M.; Grzyb, J. Synthesis of Silver and Gold Nanoparticles in Sodium Alginate Matrix Enriched with Graphene Oxide and Investigation of Properties of the Obtained Thin Films. *Appl. Sci.* **2021**, *11*, 3857. [CrossRef]