When Mimetics Meets Chitosan

Yilin Guo and Xiaoyan Yu *

The concept of mimetics can be defined in terms of “learning from others” or “inspired by others”, and indeed its essence is “universal”. A well-known marvelous example of designing materials inspired by nature is human flight. Essentially, everything can be mimicked somehow in this huge world. In this sense, the characteristics of polysaccharides, including chitosan, can shed light on new product development. Owing to the interesting features of chitosan, such as nontoxicity, biodegradability, antibacterial activity, and the puzzling hydrophobic nature of chitosan films, the synthesis of chitosan-mimetic materials represents a promising strategy for developing a diverse group of functional products. The abundant amino and hydroxyl groups of chitosan are the basis for designing different functional materials. It is expected that chitosan-mimetic strategies may potentially address issues or challenges related to the commercial use of chitosan. For example, chitosan functions well as a paper additive (*e.g.* surface sizing); however, its use is strongly hampered by high cost, poor water-solubility, *etc*. In this case, chitosan-mimetic products derived from low-cost materials (*e.g*., starch) may be considered as alternatives to chitosan. Limitless types of products stemming from the interaction between mimetics and chitosan are designable, potentially creating endless opportunities for different industrial sectors.

DOI: 10.15376/biores.17.3.3877-3879

Keywords: Chitosan-mimetic materials; Biomimetics; Biopolymer; Amine group; Functional Applications

*Contact information: Key Laboratory of Biobased Materials Science and Technology (Ministry of Education)/College of Materials Science and Engineering, Northeast Forestry University, 26 Hexing Road, Harbin 150040, China; * Corresponding author: yuxiaoyan0304@126.com (Xiaoyan Yu)*

The “Universal” Concept of Mimetics

A lot of life lessons or insights can be learnt from nature. Human flight, which is mimetic of birds, is a typical example of designing materials *via* nature’s inspirations. We believe that everything in the world has its own value, and something can shed light on others in due course. Learning from successful examples benefits us in some ways, and it may help to gain success faster. The concept of mimetics is indeed universal, since it is a primary means of learning. Mimetics can help us to understand the world, fostering the advancement of different scientific disciplines: formal sciences, natural sciences, and social sciences. As an example, biomimetics can be used as guiding principles for designing paper products with tailorable functionalities (Liu *et al.* 2005; Wan *et al.* 2020). The bottom line is that learning from “others” can benefit “someone” or “something”.

Chitosan and Its Mimetic Materials

Chitin is well known to be the second most abundant biopolymer on Earth after the group of cellulose, hemicellulose, and lignin. As a structural polymer specific for the early evolution of organisms (*e.g.* arthropods), chitin molecules form fibers, and the fibers are bonded via intermolecular forces to form a networked native structure. Chitosan is a chitin-derived linear polysaccharide containing abundant amino and hydroxyl groups. The commercial production of chitosan involves deacetylation of chitin under alkaline conditions. The molecular structure of chitosan is very similar to that of cellulose, and key difference is chitosan's abundant availability of amino groups at the carbon-2 positions of repeating units (Hubbe 2019). The uses and applications of chitosan seem limitless. In the specific area of pulp and paper, researchers around the world have extensively studied the use of chitosan-based chemical additives in paper production; however, commercial uses are rare, possibly due to the imbalance between performance and price. Nevertheless, there are lots of successful uses of chitosan (*e.g.*, drug manufacturing, control of diseases of fruits and vegetables, and slimming diets) (Romanazzi *et al.* 2018).

When mimetics meets chitosan, there are definitely new inspirations of product development. It is easy to understand that the amino and hydroxyl groups of chitosan can be mimicked. The puzzling fact of chitosan films' hydrophobicity (Hubbe 2019), which might be due to the orientation of chitosan molecules. Such evidence can shed light on the design of polysaccharide-based hydrophobic materials. Chitosan's multifunctional reactivities, polycationic nature, and antibacterial properties are among the interesting features for the motivations concerning the concept of designing chitosan-mimetic materials. Typically, researchers at Beijing Institute of Technology and National Engineering & Technology Research Center for Paper Chemicals (China) recently published a work addressing the synthesis of chitosan-mimetic polymers via ring-opening metathesis polymerization (Li *et al.* 2020). As another example, in a paper published in *Progress in Polymer Science*, researchers at Boston University (United States) shared their important insights into mimetics related to different polysaccharides (Xiao and Grinstaff 2017). It is noted that besides chitosan-mimetic materials, other polysaccharide-mimetic materials such as those related to alginate are designable (Wathier *et al.* 2010). The chemical synthesis of a diverse group of materials mimicking structural or functional features of chitosan can facilitate the elucidation of chitosan's structure-performance relationships and possibly lead to new possibilities of uses and applications. Broadly speaking, different approaches of mimicking the characteristics of chitosan are applicable to the design of chitosan-mimetic materials. For instance, the treatment of starch via host-guest interaction between amylose and a fatty amine to introduce functional amino groups can be considerable as an example of using biopolymers for structural mimicking (Fanta *et al.* 2017; Guo 2022). Essentially, different types of feedstocks can be used for designing chitosan-mimetic materials.

Some Possibilities

As mentioned above, mimetics (including biomimetics) is a very broad and insightful term related to all scientific disciplines as well as all corners of life. When this term meets chitosan, there are possibilities of understanding the structural features, developing processes for efficient utilization of agricultural and industrial wastes, and commercializing value-added applications. It is noteworthy that despite chitosan's encouraging features such as antibacterial activity, there are inherent limitations in certain cases of uses and applications: (1) relatively high cost associated with production from seafood wastes, (2) poor water-solubility, and (3) limited molecule weight. In this sense, the development of chitosan-mimetic materials may shed light on new routes. However, current research activities in the area of chitosan-mimetic materials are somehow limited, and there is definitely much room for further studies. Indeed, lots of products may be developed based on mimicking the characteristics of chitosan. Besides the herein highlighted concept of chitosan-mimetic materials, chitosan can alternatively be used to mimic the functions of other substances (*e.g.* peroxidase) (Ragavan *et al.* 2018). Overall, learning from chitosan or other materials is worthwhile. When mimetics meets different materials, we are likely to have the chance to understand these materials better, and on the other hand, we may design new materials based on our improved insights.

Acknowledgements

This work was supported by the Fundamental Research Funds for Central Universities of China (2572018AB04).

References Cited

Fanta, G. F., Felker, F. C., Hay, W. T., and Selling, G. W. (2017). "Increased water resistance of paper treated with amylose-fatty ammonium salt inclusion complexes," *Ind. Crop. Prod*. 105, 231-237. DOI: 10.1016/j.indcrop.2017.04.060

Guo, Y. (2022). "Chitosan-mimetic starchy complexes: Fabrication and use in papermaking," Master Thesis of Northeast Forestry University, Harbin, China.

Hubbe, M. A. (2019). "Why, after all, are chitosan films hydrophobic?" *BioResources* 14(4), 7630-7631.

Khademibami, L., Jeremic, D., Shmulsky, R., and Barnes, H. M. (2020). "Chitosan oligomers and related nanoparticles as environmentally friendly wood preservatives," *BioResources* 15 (2), 2800-2817. DOI: 10.15376/biores.15.2.2800-2817

Li, N., Qu, X., Wang, L., Tian, Q., Chen, Y., Yao, X., Chen, S., and Jin, S. (2020). "Chemical synthesis of chitosan-mimetic polymers via ring-opening metathesis polymerization and their applications in Cu^{2+} adsorption and catalytic decomposition," *Polym. Chem.* 11(41), 6688-6700. DOI: 10.1039/D0PY00668H

Liu, Y., Yu, S., Feng, R., Bernard, A., Liu, Y., Zhang, Y., Duan, H., Shang, W., Tao, P., Song, C., and Deng, T. (2015). "A bioinspired, reusable, paper-based system for high-performance large-scale evaporation," *Adv. Mater.* 27, 2768-2774. DOI: 10.1002/adma.201500135

Ragavan, K. V., Ahmed, S. R., Weng, X., and Neethirajan, S. (2018). "Chitosan as a peroxidase mimic: Paper based sensor for the detection of hydrogen peroxide," *Sens. Actuators, B* 272, 8-13. DOI: 10.1016/j.snb.2018.05.142

Romanazzi, G., Feliziani, E., and Sivakumar, D. (2018). "Chitosan, a biopolymer with triple action on postharvest decay of fruit and vegetables: Eliciting, antimicrobial and film-forming properties," *Front. Microbiol.* 9, 2745-2745. DOI: 10.3389/fmicb.2018.02745

Wan, J., Wang, P., Qian, X., Zhang, M., Song, S., Wang, M., Guo, Q., and Shen, J. (2020). "Bioinspired paper-based nanocomposites enabled by biowax-mineral hybrids and proteins," *ACS Sustainable Chem. Eng.* 8(26), 9906–9919. DOI: 10.1021/acssuschemeng.0c03187

Wathier, M., Stoddart, S. S., Sheehy, M. J., and Grinstaff, M. W. (2010). "Acidic polysaccharide mimics via ring-opening metathesis polymerization," *J. Am. Chem. Soc.* 132(45), 15887-15889. DOI: 10.1021/ja106488h

Xiao, R., and Grinstaff, M. W. (2017). "Chemical synthesis of polysaccharides and polysaccharide mimetics," *Prog. Polym. Sci.* 74, 78-116. DOI: 10.1016/j.progpolymsci.2017.07.009