

Oligosaccharides as Essential Carbohydrates in Cellular Signaling Protein Glycosylation and Gut Microbiota Modulation

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DESCRIPTION

Oligosaccharides are complex carbohydrates composed of short chains of monosaccharide units linked together by glycosidic bonds, typically consisting of three to ten sugar residues. They occupy a unique position between monosaccharides and polysaccharides in terms of structure and function. These biomolecules are widely distributed in nature, found in plants, animals and microorganisms and they perform a variety of essential biological, nutritional and industrial roles. Unlike simple sugars, oligosaccharides are not primarily used as immediate energy sources; instead, they contribute to cell signaling, molecular recognition, gut microbiota modulation and the stabilization of proteins and lipids. Their structural diversity, which includes variations in monosaccharide composition, linkage types and branching patterns, provides them with a broad spectrum of biological activities and functional applications.

In biological systems, oligosaccharides play critical roles in cellular communication and immune function. Many oligosaccharides are attached to proteins and lipids on cell surfaces, forming glycoconjugates that participate in cell recognition, adhesion and signaling. Glycoproteins and glycolipids containing oligosaccharides are fundamental in processes such as immune response modulation, pathogen recognition and the regulation of protein stability and folding. For example, oligosaccharides present on the surface of viruses or bacteria can influence host-pathogen interactions, determining susceptibility to infections and the efficacy of immune defenses. Additionally, oligosaccharides found in human milk, often referred to as human milk oligosaccharides, promote the growth of beneficial gut bacteria, particularly bifidobacteria, contributing to the establishment of a healthy intestinal microbiome in infants and providing protection against gastrointestinal infections.

The prebiotic properties of oligosaccharides highlight their importance in nutrition and health. Certain dietary oligosaccharides, such as fructooligosaccharides and galactooligosaccharides, resist digestion in the upper

gastrointestinal tract and reach the colon intact, where they serve as substrates for beneficial microorganisms. This selective fermentation promotes the growth of healthy gut bacteria, improves intestinal barrier function, enhances nutrient absorption and modulates immune activity. Studies have shown that regular consumption of prebiotic oligosaccharides can reduce the risk of metabolic disorders, improve lipid metabolism and positively influence glucose regulation. These health-promoting effects make oligosaccharides a focus of functional food development and nutraceutical applications, demonstrating their potential to prevent chronic diseases and support overall wellness.

Oligosaccharides also have significant applications in biotechnology, pharmaceuticals and the food industry. In pharmaceuticals, they are utilized as drug delivery enhancers, stabilizers for therapeutic proteins and modulators of immune responses. Their ability to selectively bind to proteins or receptors enables the development of vaccines, diagnostic tools and targeted therapies. In the food industry, oligosaccharides serve as low-calorie sweeteners, texture modifiers and prebiotic ingredients that enhance the nutritional profile of functional foods. The chemical and enzymatic synthesis of oligosaccharides allows the production of highly defined structures for specific industrial and biomedical purposes, expanding their utility across diverse sectors.

The study of oligosaccharides has advanced considerably due to innovations in analytical and structural characterization techniques. Nuclear magnetic resonance spectroscopy, mass spectrometry, chromatography and advanced computational tools allow researchers to determine the composition, sequence, linkage types and three-dimensional structures of oligosaccharides. These insights are essential for understanding the relationship between oligosaccharide structure and function, facilitating the design of molecules with modified biological activities. Furthermore, advances in glycoengineering and microbial biotechnology have enabled the production of custom oligosaccharides with enhanced prebiotic, immunomodulatory and therapeutic properties, offering new opportunities for research and application in medicine, nutrition and industry.

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CONCLUSION

In conclusion, oligosaccharides are versatile and biologically significant carbohydrates that bridge the gap between simple sugars and polysaccharides. Their roles in cellular signaling, immune modulation, gut microbiota support and molecular stabilization highlight their importance in maintaining physiological health. Beyond biology, oligosaccharides have far-reaching applications in nutrition, pharmaceuticals,

biotechnology and functional food development. Continued research into their structure, function and synthetic production is likely to expand their utilization, providing innovative solutions for health, disease prevention and industrial biotechnology. As analytical techniques and biotechnological methods advance, oligosaccharides are poised to become even more central to scientific discovery and practical applications, highlighting their enduring relevance across multiple disciplines.