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Development and Market Prospect Analysis of *Cordyceps* Polysaccharides in the Pharmaceutical and Health Product Industries

Huixian Li, Jianhui Li
Institute of Life Sciences, Jiyang College of Zhejiang A&F University, Zhuji, 311800, Zhejiang, China
Corresponding author: jianhui.li@jicat.org

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Abstract *Cordyceps* polysaccharides, as one of the main active ingredients in *Cordyceps*, have attracted much attention due to their unique biological activity and health functions. This study systematically investigated the chemical structure, extraction methods, antioxidant, anti-inflammatory, and immunomodulatory biological activities of *Cordyceps* polysaccharides, and summarized their applications and development status in the fields of medicine and health products. In the field of medicine, *Cordyceps* polysaccharides have shown significant potential in anti-tumor, antiviral, and metabolic disease treatment; In the field of health products, *Cordyceps* polysaccharides have been widely used due to their ability to enhance immunity and exhibit synergistic effects with other active ingredients. In addition, the study analyzed the market prospects of *Cordyceps* polysaccharide products, including global market demand and growth trends, as well as their competitiveness and challenges in the fields of medicine and health products. The study also summarized the technological bottlenecks and innovative directions faced in the industrialization process of *Cordyceps* polysaccharides, and proposed a future development path for sustainable production and green technology. Through in-depth analysis of domestic and international market opportunities and strategic planning, this study provides theoretical basis and practical guidance for the global market promotion and industrial application of *Cordyceps* polysaccharides. *Cordyceps* polysaccharides, as functional natural products, have broad development prospects in the pharmaceutical and health product industries.

Keywords *Cordyceps* polysaccharides; Pharmaceutical applications; Health product development; Bioactivities; Market prospects; Industrialization technology

1 Introduction

Cordyceps polysaccharides are actually extracted from fungi of the *Cordyceps* genus. As a bioactive macromolecule, they have been used for a long time in traditional medicine mainly because they are believed to have various benefits for the body. Species like *Cordyceps sinensis* or *Cordyceps militaris* are common sources (Luo et al., 2017). However, the situation is a bit different now. With the advancement of biotechnology, *Cordyceps* can be cultivated in a controlled environment, which makes the supply of polysaccharides more stable, the quality better, and the research and application more convenient. Although the sources and processing methods may vary, the structures of these polysaccharides are generally complex, with multiple monosaccharides linked together by glycosidic bonds. Studies have shown that they do have a wide range of therapeutic potential (Yang et al., 2020).

Cordyceps polysaccharides have many biological activities that people are more concerned about, such as antioxidation, anti-inflammation, immune regulation and anti-tumor aspects (Hu et al., 2022). The research mentioned that they can help eliminate free radicals, thereby reducing the oxidative damage to cells to a certain extent. At the same time, they also stimulate immune cells such as macrophages and T cells, making the immune response more coordinated. In addition, it also has an impact on cancer cells, inducing their apoptosis and thereby inhibiting tumor growth. Not only for immunity and tumors, *Cordyceps* polysaccharides also have effects on metabolism, such as improving glucose metabolism and insulin sensitivity. Therefore, some people think that it may also be somewhat helpful in the management of metabolic diseases like diabetes. In fact, its benefits are not limited to these. There are also some reports on antiviral and cardiovascular protection. These findings make it a promising ingredient in both the fields of drugs and health supplements (Shashidhar et al., 2015; Shi et al., 2020).

The main purpose of this study is to explore the development potential and market potential of *Cordyceps* polysaccharides in the fields of medicine and health products. We will systematically review its chemical structure, biological activity, and existing applications, in order to identify which technological aspects can still be innovated and the key directions for commercialization. Of course, the demands of the global market are constantly changing, with both challenges and opportunities. This part will also be analyzed in depth, with the aim of providing practical strategic recommendations for sustainable production and market expansion. Overall, it is hoped that through these works, we can deepen everyone's scientific understanding of *Cordyceps* polysaccharides, promote their more effective industrialization, and make them a natural product with clear functions, truly playing a role in improving public health and supplementing existing medical methods.

2 Physicochemical Properties and Bioactivity of *Cordyceps* Polysaccharides

2.1 Chemical structure and extraction methods

Cordyceps polysaccharides-especially the part extracted from *Cordyceps militaris*-actually have quite diverse extraction methods and relatively complex structures, so there have always been many studies focusing on this aspect. Generally speaking, this type of polysaccharide mainly consists of some biologically active β -glucan, but the actual structure may also change due to different conditions. For instance, it was found that *Cordyceps militaris* polysaccharides cultivated in an environment with a pH of 8 to 9 have higher antioxidant activity. The process of extracting and purifying these polysaccharides is rather troublesome. The commonly used method is hot water extraction, combined with methods such as ion exchange or gel permeation chromatography, to separate polysaccharides with relatively specific structures (Jing et al., 2015). Not only these, more detailed structural analyses still rely on techniques such as nuclear magnetic resonance (NMR) and Fourier transform infrared spectroscopy (FT-IR) to clearly see how the glycosidic bonds are connected and whether there are branches, etc. (Bi et al., 2018).

2.2 Antioxidant, anti-inflammatory, and immunomodulatory functions

Cordyceps polysaccharides have many biological activities that are of great concern, especially in antioxidant, anti-inflammatory, and immune regulation aspects. Research has found that they have a significant ability to scavenge free radicals and can also protect DNA well, reducing damage caused by oxidation. In terms of immune response, these polysaccharides can enhance lymphocyte proliferation and also increase macrophage activity-although this process is often related to signaling pathways such as TLR2, MAPK, and NF-κ B. In addition, *Cordyceps* polysaccharides have shown certain anti-inflammatory effects, which also suggests their potential application space in treating some inflammation related diseases (Ren et al., 2019).

2.3 Recent advances in pharmacological studies

Recent pharmacological studies have found that *Cordyceps* polysaccharides actually have many potential therapeutic uses. For instance, they can be used as natural immune stimulants or in the auxiliary management of some metabolic diseases. Take the polysaccharides proposed in *Cordyceps* cicadae as an example. It can help improve glucose metabolism through signaling pathways such as PI3K/Akt, and at the same time reduce insulin resistance. The effect of lowering blood sugar is quite obvious (Zhang et al., 2019). In addition, if some structural modifications are made to these polysaccharides, such as carboxymethylation or acetylation, their biological activities can be further enhanced-for instance, by inhibiting α -glucosidase. These results all indicate that *Cordyceps* polysaccharides may have considerable application prospects in the development of functional foods or drugs in the future (Liu et al., 2020).

3 Applications of *Cordyceps* Polysaccharides in Medicine

3.1 Potential applications in anti-tumor drugs

When it comes to *Cordyceps* polysaccharides, especially those extracted from *Cordyceps sinensis*, more and more people are paying attention to the development of anti-tumor drugs nowadays, and many studies have indeed seen its potential in anti-cancer (Cai et al., 2024). For instance, experiments have found that this type of polysaccharide can enhance immune function and induce apoptosis of tumor cells through pathways such as IL-10/STAT3/Bcl2 and Cyto-c/Caspase8/310, thereby inhibiting the growth of H22 tumors in mice. In fact, it is not just like this. At

present, *Cordyceps* polysaccharides with relatively large molecular weights are regarded as the part that plays a major anti-tumor role. On the one hand, they improve the immune response; on the other hand, they also promote the apoptosis of tumor cells, which is quite crucial in such mechanisms (Figure 1) (Yan et al., 2013).

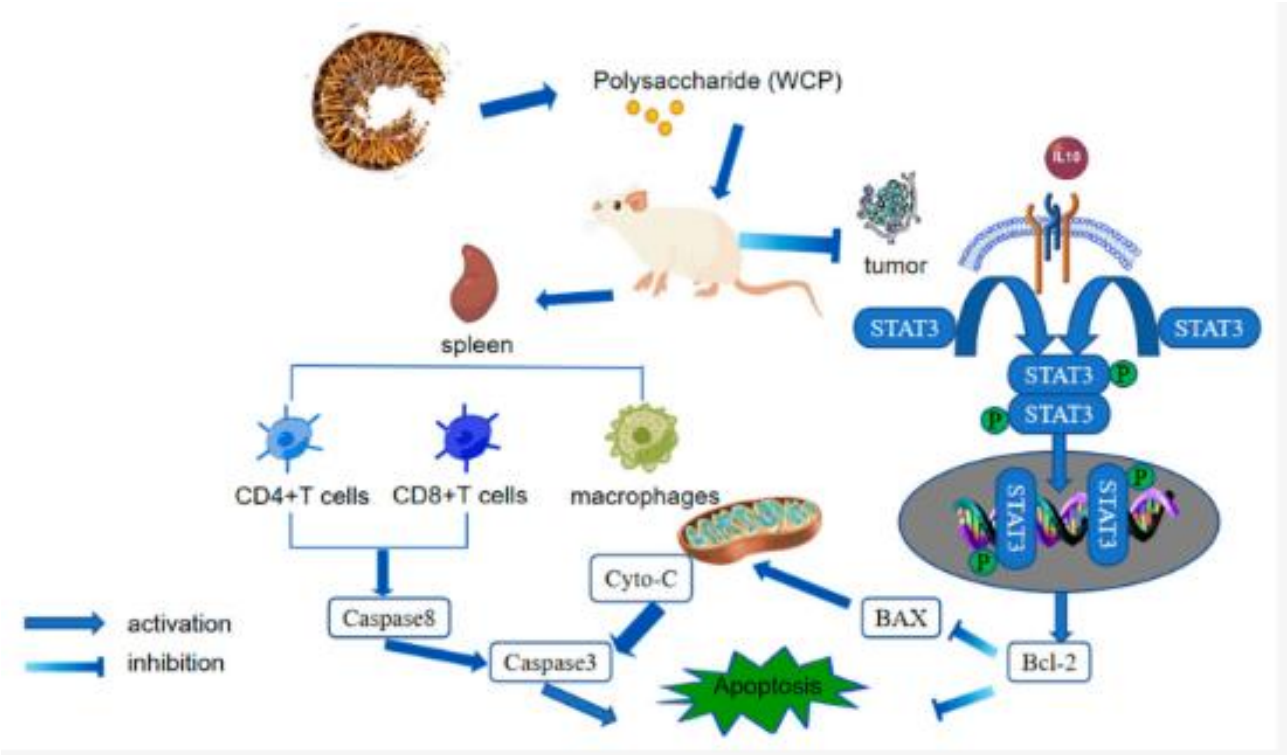

Figure 1 Schematic diagram of *Cordyceps* polysaccharides inhibiting H22 cell proliferation (Adopted from Tan et al., 2023)

3.2 Research and progress in antiviral and immunotherapy

Cordyceps polysaccharides are actually quite popular in antiviral and immunotherapy, and many studies are discussing this. They can stimulate immune responses, such as activating T lymphocytes and macrophages, which in turn promotes the secretion of cytokines such as IL-2, IL-6, and IL-8. In addition to regulating immunity, these polysaccharides themselves also have certain antioxidant effects, which can help cells resist the damage caused by oxidative stress, which is important for maintaining the normal function of the immune system (Chen et al., 2023). Because of these immunomodulatory effects, many people now consider *Cordyceps* polysaccharides as an ideal natural ingredient, which may be used to enhance immune responses and even fight against certain viral infections (Peng et al., 2013).

3.3 Mechanisms in treating metabolic diseases

In fact, *Cordyceps* polysaccharide has various functions in metabolic diseases. For example, it has obvious effects in reducing blood sugar and is also helpful in the management of metabolic disorders such as diabetes (Cheung et al., 2009). Not only that, it can also regulate the gut microbiota-which is actually crucial for metabolic health. Research has found that *Cordyceps* polysaccharides can alter the composition of gut microbiota, increasing beneficial bacteria and short chain fatty acids, thereby helping to regulate metabolism (Li et al., 2003). In addition, its antioxidant properties also help alleviate oxidative stress commonly seen in metabolic diseases, improving metabolic health from another perspective.

4 Development of *Cordyceps* Polysaccharides in the Health Products Sector

4.1 Development of functional health products to boost immunity

Cordyceps polysaccharides are now widely used in many health products that enhance immunity, mainly because they can regulate the immune system. Polysaccharides extracted from *Cordyceps sinensis* and *Cordyceps militaris*, studies have shown that they do have the potential to enhance immune responses. For instance, *Cordyceps militaris* polysaccharides can promote the proliferation of lymphosplenocytes. It seems that it may be used as a

natural immune stimulant in the development of functional foods or drugs in the future (Finnegan et al., 2023). Not only does it directly act on immune cells, but *Cordyceps sinensis* polysaccharides can also help prevent problems such as ulcerative colitis by regulating the intestinal flora and improving intestinal health, demonstrating a good immunomodulatory ability (Figure 2) (Jiang et al., 2021).

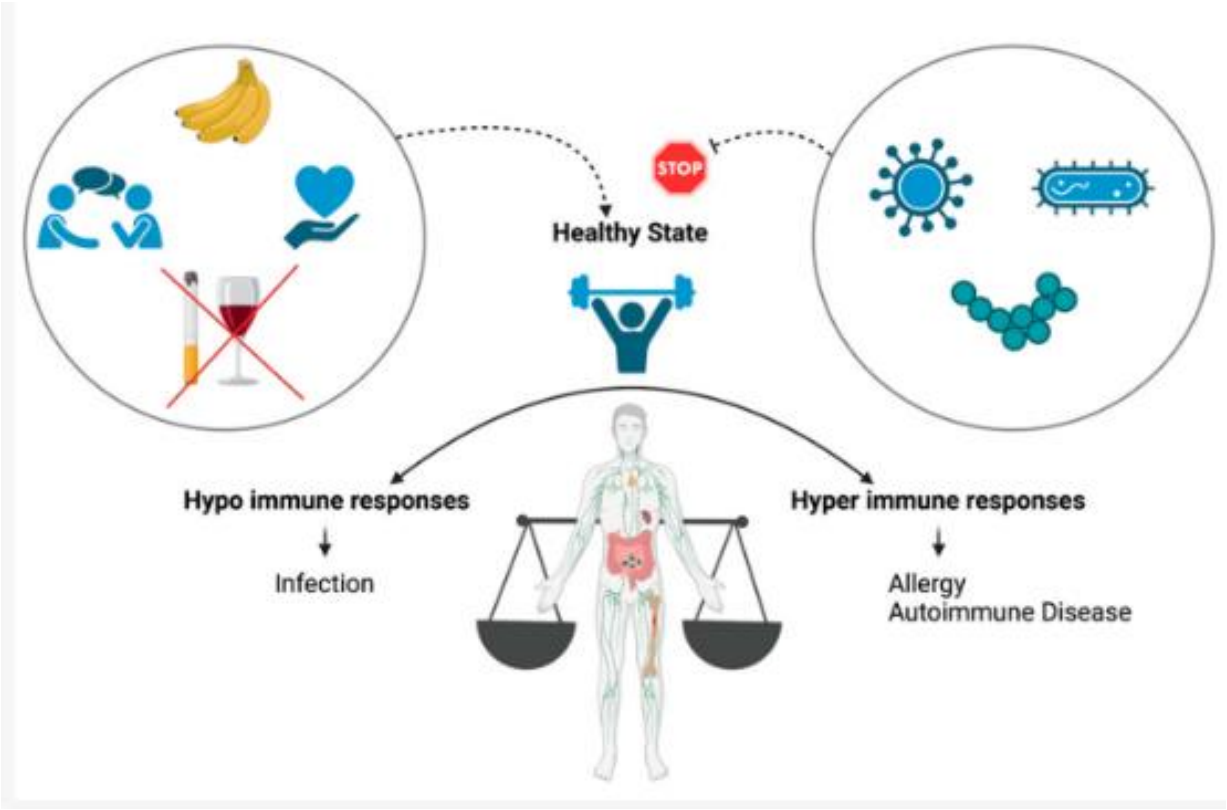

Figure 2 Effect chart of functional food to improve human immune response (Adopted from Finnegan et al., 2023)

4.2 Synergistic effects with other functional components

If *Cordyceps* polysaccharides are used in combination with other active ingredients, they can actually have better health benefits. For example, studies have shown that polysaccharides extracted from silkworm *Cordyceps* inherently have certain antioxidant and anti-tumor potential, and when combined with other functional components, the effect is even stronger and can synergistically improve health status. On the other hand, the structure of *Cordyceps* polysaccharides itself is diverse, which allows them to act on different biological pathways and even enhance the efficacy of other therapeutic agents (Ashaolu, 2020). Due to the potential for synergistic effects, *Cordyceps* polysaccharides are increasingly regarded as an ideal ingredient in complex health formulas (Liu and Du, 2024).

4.3 Current applications and competitive advantages in the health product market

Cordyceps polysaccharides can now be found in many health products, mainly because they have a wide range of biological activities, such as anti-tumor, antioxidant, and immune regulatory effects. Especially in the management of metabolic syndrome, people are more concerned about its ability to alleviate high blood sugar and regulate gut microbiota (Lee et al., 2021). One advantage of it is that it comes from natural sources and has multiple functions, which is in line with the trend of many people pursuing holistic and natural health solutions nowadays. In addition, extraction and purification technologies have been advancing in recent years, making *Cordyceps* polysaccharides more effective and widely used in the health product market (Tan et al., 2023).

5 Market Prospects for *Cordyceps* Polysaccharide Products

5.1 Global market demand and growth trends

The global demand for *Cordyceps* polysaccharides is indeed rising rapidly now, mainly because it has shown many potential benefits in the fields of health food and medicine. Well-known ones like *Cordyceps sinensis* and

Cordyceps militaris are highly valued for their bioactive polysaccharides, such as those that can regulate immunity and have antioxidant properties. It even has some anti-tumor effects (Lakner et al., 2019). As more and more people come to know these benefits, natural and effective health supplements naturally become more popular, which also drives the development of the market. However, wild *Cordyceps sinensis* is already scarce and expensive, so now artificially cultivated *Cordyceps sinensis* is gradually being developed-this more accessible and reasonably priced alternative has indeed expanded the coverage of the entire market (Mehralian and Shabaninejad, 2014).

5.2 Competitive analysis in the pharmaceutical and health products sectors

In the field of medicine and health supplements, *Cordyceps* polysaccharides do indeed have to contend with a considerable amount of competition from other natural products and synthetic drugs. However, to be fair, its rather unique immunomodulatory ability, coupled with its antioxidant properties, has enabled it to maintain a certain market advantage (Sahai and Yadav, 2024). Although the extraction and purification process is rather complex and the polysaccharide structures are diverse, which sometimes cause some troubles, on the contrary, it actually becomes an opportunity to make product differentiation (Xu et al., 2019). Now, it can be seen that those enterprises that can efficiently produce high-quality polysaccharides and prove their efficacy through solid scientific research are indeed more likely to gain some advantages in market competition.

5.3 Major factors restricting market expansion and solutions

The market expansion of *Cordyceps* polysaccharides is actually restricted by many factors. For instance, the extraction and purification processes themselves are quite complex and the cost is not low. In addition, the relationship between the structure and activity of polysaccharides is still not very clear at present, which also makes its development and application not so easy to advance (Wang et al., 2015). To solve these problems, it may still be necessary to rely on continuous research to optimize production methods and at the same time gain a deeper understanding of exactly how the biological activities of these polysaccharides function. On the other hand, strengthening consumer education and promoting more about the actual health benefits of *Cordyceps* polysaccharides also has the opportunity to drive market demand and help this market grow further.

6 Industrialization Technologies and Challenges of *Cordyceps* Polysaccharides

6.1 Progress in current industrialization technologies

There have been many advances in the industrialization technology of *Cordyceps* polysaccharides recently, especially in the optimization of fermentation processes. For example, by adjusting fermentation conditions such as temperature, pH value, or nutrient composition, the yield and quality of active polysaccharides in *Cordyceps sinensis* have been improved. In addition, gene manipulation techniques such as CRISPR/Cas9 have also been applied to *Cordyceps militaris* to modify metabolic pathways and increase the production of secondary metabolites, including polysaccharides (Idigova et al., 2023). These technological advancements have made the fermentation process more efficient and controllable, laying the foundation for large-scale production in the future.

6.2 Directions for technological innovation and production optimization

Future technological innovations may focus more on optimizing fermentation conditions and adopting some more advanced biotechnology strategies. For instance, studies have shown that the use of stimulants such as Tween 80 and vitamin B6 can significantly increase the production of polysaccharides in *Cordyceps militaris* cells, which also provides a new idea for improving production efficiency (He and Liao, 2024). In addition, if combined with the solid-state fermentation technology based on rice, not only can the polysaccharide content be increased, but also its antioxidant activity can be enhanced, which provides the possibility for the development of products that focus more on health functions (Bertocci et al., 2021). All these directions actually indicate that only by continuously innovating in fermentation technology can the yield and biological activity be increased to a higher level.

6.3 Prospects for sustainable and green production models

Nowadays, more and more people are paying attention to whether the production of *Cordyceps* polysaccharides can be more sustainable and environmentally friendly. For example, some practices use agricultural waste as the

culture medium for *Cordyceps militaris*, which not only reduces costs but also meets the requirements of environmental sustainability (Hu et al., 2024). If this approach is combined with biotechnology methods that reduce resource consumption and waste emissions, it actually provides a more sustainable path for the industrialization of *Cordyceps* polysaccharides. Promoting such green production models should reduce the ecological impact of *Cordyceps* cultivation and also drive the development of more environmentally friendly and healthy products (Ding et al., 2023).

7 Market Opportunities and Strategic Planning

7.1 Analysis of domestic and international market opportunities

Cordyceps polysaccharides, due to their biological activities such as anti-tumor, antioxidant and immune regulation, actually show considerable potential both in the domestic and international markets. Especially in China, *Cordyceps sinensis* itself has always been highly recognized as a traditional medicinal material. This cultural background actually lays a solid foundation for its application in health products. Natural and functional foods are becoming increasingly popular internationally, especially in regions with a high demand for alternative and complementary medicine. *Cordyceps* polysaccharides have just caught up with this trend. It has diverse structures and rich biological activities, all of which make it a rather attractive raw material in the pharmaceutical and health products industry (Chernatony, 2001).

7.2 Importance of strategic collaboration and brand building

Strategic cooperation and brand building are indeed crucial for the true commercialization of *Cordyceps* polysaccharide products. If we collaborate with research institutions, we can gain a deeper understanding of its biological activity and also have the opportunity to improve the currently complex extraction and purification processes. To establish a reliable brand, it is necessary to emphasize the traditional value of *Cordyceps* and have scientific support, so as to easily gain consumer trust and gradually expand market influence. In addition, collaborating with health and wellness product companies can also promote the integration of *Cordyceps* polysaccharides into existing product lines, thereby increasing market penetration (Micu, 2024).

7.3 Globalization pathways and challenges for *Cordyceps* polysaccharide products

To truly promote *Cordyceps* polysaccharide products globally, several issues and challenges need to be addressed. Firstly, standardized extraction and purification methods need to be developed in order to ensure stable product quality and gain international market recognition (Ying et al., 2020). However, in Western markets, the standards for safety and effectiveness are usually stricter, sometimes becoming barriers to entry. In addition, the high cost and complex cultivation and extraction process of natural *Cordyceps* have indeed brought many difficulties to large-scale production and distribution. To address these challenges, it may be necessary to invest more in research and development, as well as communicate and cooperate more with international regulatory agencies, in order to enter different markets more smoothly (Tsai, 2011).

8 Concluding Remarks

This research actually highlights the potential of *Cordyceps* polysaccharides in medicine and health products-it does exhibit many biological activities, such as antioxidation, anti-tumor, immune regulation, and even helping to lower blood sugar. The structures of these polysaccharides are inherently diverse, so their activities are relatively broad, and they can be regarded as promising candidate components for therapeutic applications. One novelty of the research lies in the relatively detailed characterization of the polysaccharide structure and the explanation of their biological activity mechanisms. These works provide some theoretical support for their future application in functional foods or drugs.

Future research may need to pay more attention to the specific mechanism of action behind the biological activity of *Cordyceps* polysaccharides, especially how its structure and function are related. On the other hand, the extraction and purification processes still need to be further optimized so that the output and purity can be increased. In fact, it is also possible to see if there will be a synergistic effect when it is used in combination with other bioactive ingredients. Maybe it can find some new ideas for therapeutic applications. Of course, conducting clinical trials is still very crucial. After all, it is necessary to actually verify whether it is truly both safe and effective for the human body.

Cordyceps polysaccharides do have many potential applications in the pharmaceutical and health product industries, mainly due to their various biological activities and potential health benefits. For example, it can regulate immunity, resist oxidation, and even have anti-tumor effects, making it a valuable ingredient in the development of new therapeutic agents or functional foods. As research deepens, there should be more opportunities for *Cordyceps* polysaccharides to be included in mainstream health products-after all, their natural sources, combined with various health benefits, will drive their practical application and make the market more accepting.

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Conflict of Interest Disclosure

The authors affirm that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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