Beijing Dilun Biotechnology Co., Ltd.
Specializes in R&D and manufacturing of peptide synthesis equipment, providing comprehensive technical solutions and services.
Web: www.peptidescientific.com. Email: chengchao.wei@dilunbio.com

The "Active Code" in Microalgae: How Do Algal Proteins and Peptides Safeguard Human Health?

In the vast oceans and freshwater bodies, microscopic algae quietly perform a miracle of life—not only do they supply the Earth with vast amounts of oxygen through photosynthesis, but they also synthesize a series of proteins and peptides with extraordinary biological activity. These tiny molecules are emerging as a new frontier for scientists to explore, demonstrating immense potential in fields such as medicine, food, and cosmetics. Let us together unveil the mystery of these "active codes" from the aquatic world.

I.Algae: Tiny Life Factories

Algae represent one of Earth's oldest life forms, exhibiting remarkable diversity from single-celled species like spirulina and chlorella to large marine plants such as kelp and wakame. They form the cornerstone of aquatic ecosystems. Their ability to survive in extreme environments—including high salinity, elevated temperatures, and intense radiation—has driven the evolution of unique defense mechanisms, enabling the synthesis of various protective bioactive compounds. Compared to terrestrial plants,

algae exhibit rapid growth rates, do not occupy arable land, and possess exceptionally high protein content (certain microalgae can reach 50-70% protein by dry weight). These characteristics position them as a sustainable treasure trove of bioactive compounds.

II.Diverse Active Algal Proteins and Peptides

Algae produce a wide variety of bioactive proteins and peptides, primarily including:

1.Phycocyanin: Primarily found in spirulina and certain cyanobacteria, it serves not only as a natural blue pigment but also possesses potent antioxidant and anti-inflammatory properties.

2.Lectins: Proteins capable of specifically recognizing and binding to sugar molecules. Certain algal lectins exhibit antiviral and antitumor activity.

3.Enzyme inhibitors: Such as protease inhibitors, which can regulate enzyme activity within organisms.

4.Bioactive Peptides: Small molecular fragments released from proteins through enzymatic hydrolysis, typically composed of 2–20 amino acids, exhibiting diverse physiological regulatory functions.

Although these molecules vary in structure, they share the common characteristics of high reactivity, low toxicity, and excellent biocompatibility.

III.Mechanism of Action: The Wisdom of Micromolecules

Algal-derived bioactive proteins and peptides exert their biological activities through multiple molecular mechanisms:

1.The “Free Radical Scavenger” with Antioxidant Effects

Algae-derived antioxidant peptides, such as glutathione analogues, can directly neutralize free radicals and interrupt chain oxidation reactions. More ingeniously, they also upregulate the cell's own antioxidant defense systems, such as activating the Nrf2 signaling pathway to promote the synthesis of endogenous antioxidant enzymes like superoxide dismutase (SOD) and glutathione peroxidase. This “dual-protection” mechanism makes them more efficient and safer than many synthetic antioxidants.

2. Signal Modulator for Anti-Inflammatory Effects

Inflammation is a common pathway in many chronic diseases. Certain algal proteins act like precise “molecular keys,” blocking the binding of pro-inflammatory factors (such as TNF-α and IL-6) to their receptors. For example, specific peptide segments isolated from marine red algae have been shown to inhibit the activation of the nuclear factor κB (NF-κB) signaling pathway, a core switch in the inflammatory response. This targeted regulation avoids the systemic side effects commonly associated with traditional anti-inflammatory drugs.

3.ACE inhibitors for blood pressure reduction

Angiotensin-converting enzyme (ACE) is a key enzyme in blood pressure regulation. Many algae-derived antihypertensive peptides, such as SP-1 peptide from spirulina, possess three-dimensional structures complementary to the active site of ACE. They competitively occupy the enzyme's active center without being degraded by it, thereby providing long-lasting inhibition of ACE activity. This promotes vasodilation and reduces blood pressure. These natural ACE inhibitors avoid side effects such as dry cough that may be caused by synthetic antihypertensive drugs.

4.The “Balancing Master” of Immune Regulation

Certain alginate-protein complexes can activate immune cells such as macrophages and natural killer cells, enhancing their phagocytic and cytotoxic capabilities. Interestingly, these complexes often exhibit “intelligent regulation” properties—boosting suppressed immunity without overactivating the immune system to trigger autoimmune responses. This bidirectional regulatory mechanism is particularly valuable in natural products.

5.Antimicrobial and antiviral “microbial defense line”

Algae have evolved various antimicrobial peptides in the course of survival competition. These peptides typically carry positive charges, enabling them to selectively bind to negatively charged microbial cell membranes, forming pores that cause leakage of cellular contents. Unlike traditional antibiotics, this physical membrane disruption mechanism makes it difficult for microorganisms to develop resistance. Antiviral peptides, on the other hand, may function by masking viral surface proteins, thereby preventing their binding to host cell receptors.

III.Application Areas: From the Laboratory to Everyday Life

Based on the aforementioned mechanism, algae-derived bioactive proteins and peptides have demonstrated remarkable potential across multiple fields:

Functional Foods and Nutritional Supplements：

Phycocyanin, as a natural blue pigment, has been widely used in confectionery, beverages, and dairy products. Functional foods rich in phycocyanin-derived antihypertensive peptides offer a non-pharmaceutical option for individuals with mild hypertension. Antioxidant peptides are incorporated into sports nutrition products to help mitigate oxidative stress damage following exercise. With high digestibility and a balanced amino acid profile, phycocyanin serves as a premium plant-based protein source, particularly suitable for vegetarians and those with specific dietary

requirements.

Candidates for "green drugs" in the pharmaceutical field

In cancer therapy, certain algal lectins recognize specific sugar structures on tumor cell surfaces, inducing tumor cell apoptosis or enhancing sensitivity to chemotherapy drugs. Preclinical studies indicate that phycocyanin can mitigate radiation therapy damage to normal tissues. Antidiabetic algopeptides exert their effects by mimicking insulin action or improving insulin sensitivity. These natural molecules provide unique templates for developing novel targeted therapeutics.

The "Cell Repair Specialist" in Skincare Products

Algae-derived antioxidant peptides can penetrate the skin barrier to directly neutralize free radicals generated by UV rays, reducing photoaging. Specific algal peptides also stimulate skin fibroblasts to synthesize more collagen and elastin, minimizing wrinkle formation. Anti-inflammatory peptides are suitable for sensitive skin care, alleviating redness and irritation. Compared to synthetic cosmetic ingredients, algae-derived actives are gentler and more biodegradable.

Agriculture and Aquaculture

Algal-derived antimicrobial peptides, when used as feed additives, can reduce antibiotic usage in aquaculture and enhance animal immunity. In crop protection, algal protein preparations can induce systemic disease

resistance in plants, serving as a green biopesticide.

IV.Challenges and Future Outlook

Despite promising prospects, the development of algal-derived bioactive proteins and peptides still faces challenges: large-scale cultivation and efficient extraction technologies require optimization; oral bioavailability of certain bioactive compounds remains low; mechanism-of-action research needs further exploration; and regulatory and safety assessment systems require refinement.

In the future, advances in synthetic biology may enable scientists to design “customized” algal cell factories for efficient production of specific bioactive peptides. Omics technologies (proteomics, metabolomics) will accelerate the discovery of novel bioactive compounds. Nanodelivery systems can enhance the stability and targeting of algal-derived bioactive substances.

From microscopic algal cells to human health, these natural “bioactive codes” are weaving a compelling narrative of sustainable development and technological innovation. As scientific exploration deepens, algae—this ancient life form—will undoubtedly play an increasingly vital role in addressing modern human health challenges, showcasing the boundless potential of the blue bioeconomy.