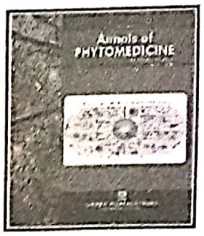
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β-carotene as a functional bioactive compound: Chemical characteristics, biological functions, nutritional sources, health benefits and pharmaceutical and industrial applications

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Abstract

β-carotene, a major member of the carotenoid family, is a multifunctional bioactive compound with significant relevance in nutrition, human health, pharmaceutical formulations and industrial applications. Structurally characterized by a highly conjugated polyene chain with two β-ionone rings, β-carotene functions as the most efficient provitamin A carotenoid and plays a critical role in maintaining physiological functions. This review comprehensively discusses the chemical characteristics, biological functions, nutritional sources, health benefits, and pharmaceutical and industrial applications of β-carotene. Naturally abundant in fruits, vegetables and microalgae, β-carotene serves as a primary dietary source of vitamin A, particularly in populations dependent on plant-based foods. Biologically, β-carotene exhibits strong antioxidant activity by scavenging reactive oxygen species and quenching singlet oxygen, thereby protecting cellular components from oxidative stress. Through its enzymatic conversion into retinoids, it contributes to visual function, immune regulation, epithelial tissue maintenance and gene expression. Increasing scientific evidence suggests its potential protective role against various chronic diseases, including cardiovascular disorders, metabolic diseases, cancer and neurodegenerative conditions. Additionally, β-carotene contributes to skin health and photoprotection, highlighting its therapeutic relevance. In the pharmaceutical sector, β-carotene is widely incorporated into nutraceuticals, dietary supplements and formulations designed to prevent vitamin A deficiency. However, its clinical and industrial utilization is challenged by poor aqueous solubility, chemical instability and limited bioavailability. Recent advances in nanotechnology-based delivery systems and encapsulation strategies have significantly improved its stability, bioavailability and therapeutic efficacy. Industrially, β-carotene is extensively employed as a natural colorant, functional food ingredient, cosmetic additive and animal feed supplement, with increasing demand driven by consumer preference for natural and sustainable products. Emerging developments in biotechnological production, precision nutrition and advanced delivery platforms are further expanding its applications. Despite its broad therapeutic potential, concerns related to high-dose supplementation and variable bioavailability warrant further investigation. Overall, β-carotene represents a promising functional bioactive compound with diverse applications, and continued interdisciplinary research is essential to fully harness its potential for improving human health and promoting sustainable industrial development.

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