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Lutein and zeaxanthin: Emerging frontiers in nutraceutical and pharmaceutical applications

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Abstract

Lutein and zeaxanthin, dietary xanthophyll carotenoids abundantly present in green leafy vegetables, maize, and other plant-derived sources, have emerged as critical bioactive compounds at the interface of nutrition and therapeutics. These pigments are selectively concentrated in the macular region of the human retina, where they enhance visual performance by filtering high-energy blue light and attenuating oxidative damage. Quantitative assessments indicate that dietary supplementation (10-20 mg day) significantly elevates macular pigment optical density (MPOD) and improves visual acuity and contrast sensitivity in both healthy individuals and subjects at risk of ocular degeneration. Beyond ocular health, accumulating evidence highlights their systemic protective effects mediated through antioxidant and anti-inflammatory mechanisms. *In vitro* and *in vivo* studies demonstrate that lutein and zeaxanthin effectively scavenge reactive oxygen species, reduce lipid peroxidation (20-40%) and modulate key signaling pathways involved in inflammation and apoptosis. Clinical and epidemiological studies further report improvements in cognitive function, with enhanced memory and processing speed associated with increased serum carotenoid levels. Additionally, cardiometabolic benefits, including reductions in LDL oxidation and improved lipid profiles, have been documented. Recent technological advancements have focused on enhancing bioavailability, which is inherently limited due to their lipophilic nature. Novel delivery systems such as nanoemulsions, liposomal encapsulation and microencapsulation have demonstrated up to 2-3-fold increases in absorption and stability under gastrointestinal conditions. Furthermore, food-based fortification strategies and biofortification approaches are being explored to improve dietary intake at the population level. Despite these promising findings, challenges remain including variability in bioavailability, lack of standardized dosage regimens, and limited long-term clinical validation across diverse populations. This review synthesizes current evidence on the biochemical properties, functional efficacy and emerging applications of lutein and zeaxanthin, emphasizing their growing significance in nutraceutical and pharmaceutical domains. Collectively, these carotenoids represent promising candidates for next-generation interventions aimed at promoting ocular, cognitive and systemic health.

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