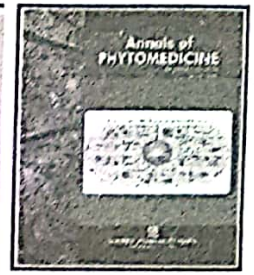
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3D food printing as an emerging platform for phytomedicine delivery: Integration of medicinal plant bioactives into personalized functional food systems

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Abstract

Three-dimensional (3D) food printing has emerged as a disruptive digital fabrication technology with expanding applications in functional foods and nutraceutical delivery. Beyond structural customization, this technology offers a novel platform for the precise incorporation, spatial distribution, and controlled release of plant-derived bioactive compounds. Medicinal plant phytochemicals, including polyphenols, flavonoids, alkaloids, terpenoids, carotenoids, and saponins, possess well-documented antioxidant, anti-inflammatory, antidiabetic, cardioprotective, and immunomodulatory activities. However, their incorporation into conventional food systems often results in instability, low bioavailability, and inflexibility in dosage.

This review critically examines the integration of phytochemicals into 3D printed food matrices, focusing on material formulation, rheological compatibility, encapsulation strategies, phytochemical stability during processing, and controlled gastrointestinal release. Applications in personalized phytomedicine, geriatric nutrition, metabolic disorder management, and immune-supportive functional foods are comprehensively discussed. Regulatory challenges, extract standardization issues, and sustainability considerations were also addressed. The convergence of additive manufacturing with phytomedicine represents a promising frontier in precision nutrition and plant-based therapeutic food systems.

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