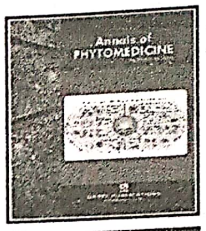
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Phytochemical diversity and nutraceutical potential in biointensive complementary cropping systems under garden-land ecosystems

K. Deepasri, P. M. Shanmugam◆, P. Kathirvelan*, K. Sathiya Bama, P.C. Prabu*** and R. Kuttimani**

Department of Agronomy, Tamil Nadu Agricultural University, Coimbatore-641 003, Tamil Nadu, India

** Department of Millets, Tamil Nadu Agricultural University, Coimbatore-641 003, Tamil Nadu, India*

*** Department of Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University, Coimbatore-641 003, Tamil Nadu, India*

**** Department of Environmental Sciences, Tamil Nadu Agricultural University, Coimbatore-641 003, Tamil Nadu, India*

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Abstract

The growing global burden of micronutrient deficiencies and diet-related chronic diseases has intensified the need to transition from yield-oriented agriculture to nutrition-sensitive and health-centered food systems. Biointensive complementary cropping systems (BICCS) practiced in garden-land ecosystems offer a promising approach to enhance phytochemical diversity and nutraceutical quality while maintaining ecological sustainability. This review synthesizes current knowledge on the conceptual, biochemical, ecological and analytical dimensions linking diversified cropping systems with phytochemical expression and functional food potential. The paper examines the mechanistic basis of secondary metabolite modulation through plant metabolic pathways, including phenylpropanoid, terpenoid and alkaloid biosynthesis and highlights how ecological drivers such as light quality, soil-plant-microbiome interactions, nutrient dynamics and moderate stress conditions influence phytochemical accumulation. Special emphasis is placed on phenolics, flavonoids, tannins, anthocyanins, terpenoids, alkaloids, saponins, carotenoids and organosulfur compounds, which collectively contribute to antioxidant, anti-inflammatory, antidiabetic, cardioprotective, antimicrobial and anticancer properties. The role of rhizosphere engineering, mycorrhizal associations, plant growth promoting rhizobacteria and organic inputs in modulating secondary metabolism is critically discussed. Analytical approaches ranging from conventional extraction and chromatographic techniques to advanced metabolomics are reviewed to provide methodological guidance for assessing phytochemical diversity in diversified systems. The review also identifies key constraints, including variability in metabolite expression, lack of standardization, limited market integration and insufficient policy support. Future directions emphasize omics-driven systems biology, breeding for phytochemical-rich varieties, climate-resilient nutraceutical agriculture and integration with functional food industries. Overall, biointensive complementary cropping systems in garden-land ecosystems emerge as integrative models that unite biodiversity conservation, soil health enhancement, ecosystem services and nutraceutical production. By linking agroecological design with metabolic optimization, these systems offer a sustainable pathway toward health-oriented agriculture capable of addressing both environmental and nutritional challenges in the twenty-first century.

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