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Multifunctional Potential, Bioactivity, and Food Applications of *C. limon* and *P. granatum* Peels

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Introduction

Agricultural by-products have come to the fore as strategic resources for mitigating food-system losses, easing environmental pressures, and satisfying the accelerating demand for natural bioactive ingredients. Among these residues, the peels of *Citrus limon* (lemon) and *P. granatum* are now recognised as concentrated repositories of polyphenols, flavonoids, hydrolysable tannins, and volatile oils—molecules that display potent antioxidant, anti-inflammatory, antimicrobial, and cardioprotective activities. Once consigned to low-value composting or landfill, these matrices can be upgraded into high-value functional ingredients whose techno-functional and health-promoting attributes rival, and often surpass, those of their primary processed fractions.

Rising consumer preference for clean-label, plant-derived additives and the legislative drive toward sustainable production have propelled lemon- and pomegranate-peel extracts into the innovation pipelines of the food, pharmaceutical, and cosmetic sectors. Their phenolic constituents not only quench reactive oxygen species and modulate pathways implicated in chronic non-communicable diseases but also enhance colour stability, flavour complexity, and microbial safety in fortified foods, thereby extending shelf life without recourse to synthetic preservatives. In parallel, essential-oil fractions confer desirable sensory notes while contributing additional antimicrobial

leverage, underscoring the multifunctional nature of these by-products.

This volume integrates the most recent advances in extraction technologies, chemical characterisation, and bioactivity assessment of lemon and pomegranate peels, and contextualises them within current industrial practice and regulatory frameworks. Across seven interlinked chapters, it examines (i) green and scalable extraction processes and their influence on phytochemical yield and integrity; (ii) molecular mechanisms underpinning the observed therapeutic effects; (iii) formulation strategies for functional foods, nutraceuticals, and active packaging; (iv) safety, quality, and compliance considerations spanning EU and international regulations; and (v) life-cycle and techno-economic analyses that support the circular-bioeconomy rationale for peel valorisation. By fusing fundamental science with application-oriented insights, the book aims to accelerate the translation of laboratory findings into market-ready solutions, turning agro-industrial waste streams into economically and ethically valuable resources.

1 Bioactive Compounds of Lemon and Pomegranate Peels

Lemon and Pomegranate peels are rich sources of bioactive compounds, attracting considerable attention for their potential therapeutic and functional applications. Phytochemical analyses of these peels have identified a wide range of secondary metabolites, including phenolic compounds, terpenoids, flavonoids, and alkaloids, underscoring their value as natural ingredients with beneficial health properties. These findings support the increasing interest in utilizing lemon and pomegranate peels for various health-promoting applications, such as antimicrobial, antioxidant, anti-inflammatory, and anticancer activities. The present chapter explores the chemical composition of lemon and pomegranate peels, highlighting bioactive compounds' diversity and potential applications in the food, pharmaceutical, and cosmetic industries.

1.1 Bioactive Compounds in Pomegranate Peel

Pomegranate peel is similarly rich in bioactive compounds, particularly phenolic compounds, flavonoids, tannins, and alkaloids. The peel's chemical composition reflects its potential for use in various therapeutic and functional applications, ranging from cancer prevention to skin health.