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# SUSTAINABLE EXTRACTION OF BIOACTIVE COMPOUNDS FROM SPRUCE AND PINE GREENERY: ANTIOXIDANT AND ANTIMICROBIAL POTENTIAL

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**Abstract** – Timber harvesting of coniferous trees results in significant biomass side streams, including coniferous greenery (needles and branches), a rich source of bioactive compounds with immunostimulatory, antimicrobial, and antioxidant properties. Despite their potential applications, large-scale utilization of these bioresources remains limited due to challenges in efficient and sustainable extraction methods. This study focuses on developing environmentally friendly extraction techniques for obtaining high-value bioactive extracts from spruce (*Picea abies* L.) and pine (*Pinus sylvestris* L.) needles. Green solvents, such as glycerol and propylene glycol, were employed in extraction processes, replacing conventional organic solvents that require additional processing steps to acquire the extractives. A comparative analysis of conventional, ultrasonic-assisted, and heat-assisted extraction methods was performed to identify optimal extraction conditions. Process parameters, such as temperature, solvent concentration and extraction duration, were systematically varied to enhance the extraction yield of bioactive compounds. The extracts were analyzed for total polyphenol content and biological activity using DPPH, FRAP, and CUPRAC assays. Additionally, antimicrobial efficacy was evaluated against a range of Gram-positive and Gram-negative bacteria, including *Staphylococcus aureus*, *Listeria monocytogenes*, *Escherichia coli*, *Salmonella enterica*, and the yeast *Candida albicans*. The results demonstrated that heat-assisted extraction significantly improved polyphenol recovery and antioxidant potential, making it a promising method for large-scale applications. Propylene glycol extracts exhibited notable antimicrobial effects, particularly against *Staphylococcus aureus* and *Listeria monocytogenes*, with potential implications for pharmaceutical and food industry applications. Glycerol extracts, on the other hand, demonstrated superior antioxidant activity, making them suitable for use in cosmetics and nutraceutical formulations. Furthermore, the study highlights the role of green extraction techniques in supporting the principles of circular bioeconomy by sustainably utilizing forestry by-products. These findings underscore the potential of coniferous needle extracts as natural bioactive compounds with diverse industrial applications. Future research should focus on identifying the specific compounds in optimized extracts to define their potential applications better. Integrating green chemistry principles in biomass utilization reduces environmental impact and contributes to developing sustainable, high-value bioproducts.

**Keywords** – *Antimicrobial properties; antioxidant activity; circular bioeconomy; forestry by-products; green solvents; polyphenols; sustainable chemistry*

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