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Natural Defence Potential of *Syzygium aromaticum* Oil Against Microbial and Fungal Pathogens

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Abstract: The increasing prevalence of antimicrobial resistance (AMR) among pathogenic microorganisms poses a serious threat to global public health and necessitates the development of effective alternative antimicrobial agents. Plant-derived essential oils have emerged as promising candidates due to their broad-spectrum activity and multi-target mechanisms of action. The present study evaluated the antibacterial and antifungal potential of *Syzygium aromaticum* (clove) essential oil against selected pathogenic microorganisms. Clove oil was extracted from dried flower buds by hydro-distillation and tested against Gram-positive bacteria (*Staphylococcus aureus*, *Bacillus subtilis*), Gram-negative bacteria (*Escherichia coli*, *Salmonella typhi*), and pathogenic fungi (*Candida albicans* and *Aspergillus niger*). Antimicrobial activity was assessed using agar well diffusion and broth microdilution methods, following Clinical and Laboratory Standards Institute guidelines. The essential oil exhibited significant, concentration-dependent antibacterial and antifungal activity, with greater efficacy against Gram-positive bacteria. *Staphylococcus aureus* showed the highest susceptibility, with a minimum inhibitory concentration (MIC) of 0.125 mg/mL, whereas *E. coli* displayed comparatively higher resistance (MIC: 0.25 mg/mL). Pronounced antifungal activity was observed against *Candida albicans*. The antimicrobial efficacy of clove oil is attributed primarily to its high phenolic content, particularly eugenol, which disrupts microbial membrane integrity, increases permeability, and interferes with key metabolic processes. The multi-target mode of action reduces the likelihood of resistance development. These findings support the potential application of *Syzygium aromaticum* essential oil as a natural antimicrobial agent in pharmaceutical, food preservation, and cosmetic formulations, warranting further *in vivo* and toxicological investigations.

Keywords: *Syzygium aromaticum*; clove essential oil; eugenol; antimicrobial activity; antifungal activity; minimum inhibitory concentration; natural antimicrobials

I. INTRODUCTION

The rapid escalation of antimicrobial resistance (AMR) among pathogenic microorganisms represents a major global health challenge, significantly compromising the therapeutic efficacy of existing antibiotics and antifungal agents. Resistant bacterial strains and opportunistic fungi are increasingly implicated in persistent and recurrent infections, leading to prolonged illness, elevated healthcare costs, and increased mortality worldwide [1]. This growing threat has intensified the search for alternative antimicrobial strategies that are effective, safe, and environmentally sustainable.

Natural products, particularly plant-derived essential oils, have gained considerable attention as potential antimicrobial agents due to their complex chemical profiles and broad-spectrum biological activities. Essential oils are composed of diverse bioactive secondary metabolites that act through multiple cellular targets, including microbial membranes, metabolic enzymes, and genetic material. This multi-target mechanism reduces the probability of resistance development compared to conventional single-target synthetic drugs [2]. Moreover, essential oils obtained from culinary and medicinal plants are often regarded as safe for human use, further supporting their potential application in pharmaceutical, food, and cosmetic industries [3].

Syzygium aromaticum (L.) Merr. & Perry, commonly known as clove, is an aromatic spice belonging to the family Myrtaceae and is widely cultivated in tropical regions. Traditionally, clove has been utilized for its analgesic, antiseptic, anti-inflammatory, and antimicrobial properties. The essential oil extracted from clove buds is rich in phenolic compounds, predominantly eugenol, which constitutes approximately 70–85% of the oil and is recognized as the primary contributor to its antimicrobial activity [4].

Previous investigations have reported potent antibacterial activity of clove essential oil against both Gram-positive and Gram-negative bacteria, including clinically relevant pathogens such as *Staphylococcus aureus*, *Escherichia coli*, and *Salmonella* species [5]. Eugenol exerts its antibacterial effect mainly by disrupting cytoplasmic membrane integrity, increasing permeability, and causing leakage of vital intracellular components, ultimately leading to cell death. Additionally, clove oil has demonstrated inhibitory effects on biofilm formation and microbial virulence mechanisms.

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