NANOBIOTICS AS SUSTAINABLE NANOPLATFORMS TO OVERCOME ANTIMICROBIAL RESISTANCE AND PROMOTE GREEN NANOMEDICINE

Mimoza Basholli Salihu[1], Toskë Kryeziu[1], Venesa Lupçi[1], Blerta Rama[1], Aida Loshaj Shala[1], Simone Carradori[2], Andreas Zimmer[4]
[1] University of Prishtina, Faculty of Medicine, Bulevardi i Dëshmorëve, Prishtina, Kosovo
[2] University of Chieti-Pescara, Department of Pharmacy, Via dei Vestini 31, Chieti, Italy
[3] University of Graz, Institute of Pharmaceutical Science, Universitätsplatz 1/EG, Graz, Austria

mimoza.basholli@uni-pr.edu

Antimicrobial resistance (AMR) poses a major global challenge, urging the development of sustainable nanodrug delivery systems that integrate nanotechnology with natural bioactives. Phenolic constituents such as carvacrol, thymol, and chlorothymol, derived from Thymus and Origanum essential oils, exhibit potent antimicrobial, antioxidant, and anti-inflammatory properties but are limited by volatility, hydrophobicity, and instability, hindering their clinical translation. This study aimed to design and optimize lipid-based nanocarriers, nanoemulsions, nanostructured lipid carriers (NLCs), and liposomes, as biocompatible delivery platforms to enhance the physicochemical stability, solubility, and biological efficacy of these compounds. Oil-in-water nanoemulsions (TEO-NE and OEO-NE) were prepared from Thymus capitatus and Origanum vulgare essential oils by high-pressure homogenization, while NLCs and liposomes were fabricated via high-pressure homogenization and ethanol injection. Comprehensive characterization included particle size, polydispersity, zeta potential, viscosity, surface tension, and encapsulation efficiency; morphology was assessed by atomic force and optical microscopy; and stability, antioxidant (DPPH), and antimicrobial activities were evaluated against Escherichia coli, Staphylococcus aureus, Pseudomonas aeruginosa, and Candida albicans. Liposomal formulations achieved high encapsulation efficiency, uniform nanoscale size, and stable negative zeta potential, confirming favorable behavior for nanodrug delivery. Both TEO-NE and OEO-NE showed superior antimicrobial and antioxidant activities compared with free oils, with O. vulgare nanoemulsion being the most active. Notably, marked differences were observed between individual phenolic compounds and their corresponding parent essential oils, indicating that molecular composition critically influences biological performance upon nanoencapsulation. A positive correlation between antioxidant and antimicrobial activities, along with a direct relationship between nanocarrier type and biological performance, indicated that formulation architecture critically modulates therapeutic output. By uniting nanotechnology with natural, renewable molecules, these lipid-based nanosystems not only offer potent strategies against AMR but also represent environmentally sustainable alternatives to synthetic antimicrobials, supporting the broader vision of green nanomedicine.

References

[1] Salihu M.B., Shala A., Çunaku A., Lupçi V., Bağcı U., Haloci E., Stefkov G., Kryeziu T., Zimmer A., J. Res. Pharm., 29 (2024) 476-485.
[2] Patra J.K., Das G., Fraceto L.F., Campos E.V.R., Rodriguez-Torres M.P., Acosta-Torres L.S., et al., J. Nanobiotechnol., 16 (2018) 1–35.
[3] Naseri N., Valizadeh H., Zakeri-Milani P., Adv. Pharm. Bull., 5 (2015) 305–313.

Mimoza Basholli Salihu, Aida Loshaj Shala, Toskë Kryeziu, Venesa Lupçi, are members of NANOBALKAN Research Center.

This work is part of the project: “Nano-based platforms and Phytochemicals for Enhanced Drug Delivery and Therapeutic Efficacy”. Financed through NanoKos (Funded by the European Commission).