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Virulence Characterization of Meatborne Escherichia Coli and Antimicrobial Efficiency of Essential Oils for Food Waste Reduction Strategies

Catalina-Elena Constantin[1,*], Carmen Curuțiu[1,2] and Alina Maria Holban[1,2]

[1]*Department of Microbiology and Immunology, Faculty of Biology, University of Bucharest, 030018 Bucharest, Romania*
[2]*Research Institute of the University of Bucharest, University of Bucharest, 030018 Bucharest, Romania*

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Abstract

Introduction: Meat and meat-derived products are highly susceptible to microbial contamination due to their nutritional composition, high water activity, and frequent handling during processing, storage, and distribution. Among the microorganisms commonly associated with meat contamination, *Escherichia coli*, *Salmonella spp.*, *Listeria monocytogenes*, *Staphylococcus aureus*, *Campylobacter spp.*, *Pseudomonas spp.*, and spoilage-associated bacteria are important for food safety, shelf-life limitation, and food waste generation. *Escherichia coli* is particularly relevant as an indicator of fecal contamination and poor hygiene, but also as a potential foodborne pathogen. Understanding the virulence, antimicrobial resistance, and persistence of meatborne *E. coli* isolates may support antimicrobial strategies, such as active packaging systems loaded with essential oils (EOs), designed to reduce microbial load, delay spoilage, and limit food waste. Materials and methods: In this study, 35 *Escherichia coli* strains isolated from meat samples were analyzed. The isolates were characterized regarding virulence-associated enzymatic factors, antimicrobial resistance, biofilm-forming ability, and susceptibility to natural antimicrobial compounds. Enzymatic virulence factors were evaluated on culture media supplemented with specific substrates, targeting caseinase, esculinase, lecithinase, DNase, lipase, and gelatinase activities. Biofilm formation was assessed after 24 and 48 h using crystal violet staining and spectrophotometric quantification. Antibiotic susceptibility was determined by disk diffusion according to CLSI recommendations. The antimicrobial activity of thyme and cinnamon EOs was evaluated by an adapted disk diffusion assay, while the minimum inhibitory concentration (MIC) was determined by broth microdilution. Results: The analyzed *E. coli* isolates showed heterogeneous phenotypic profiles, confirming the diversity of meatborne bacterial contaminants. Among the investigated virulence-associated enzymes, caseinase was the most frequently expressed factor, being detected in most isolates, while esculin hydrolysis was also commonly observed. In contrast, lecithinase, DNase, lipase, and gelatinase activities were not expressed. Biofilm formation varied between isolates and incubation times, with several strains showing increased biomass at 24 and 48 h, suggesting enhanced adhesion and persistence on food-contact surfaces. Antibiotic resistance was generally low; however, the highest rate was observed for trimethoprim-sulfamethoxazole, and one multidrug-resistant strain was identified. Thyme and cinnamon EOs displayed pronounced antibacterial activity, with MIC values ranging between 0.62% and 1.25%. Based on these results, biodegradable antimicrobial active packaging for meat products is proposed as a strategy for reducing microbial contamination

and food waste. The packaging concept involves biopolymeric films based on carboxymethyl cellulose, chitosan, alginate, gelatin, or nanocellulose, functionalized with thyme and/or cinnamon-derived compounds and combined with antimicrobial ZnO nanoparticles. The developed films are currently under antimicrobial evaluation against meatborne contaminants. Conclusions: This study connects virulence characterization of *E. coli* strains isolated from meat with antimicrobial active packaging as a sustainable food preservation strategy. Integrating microbiological risk assessment with biodegradable antimicrobial materials may improve meat safety, reduce bacterial persistence, extend shelf life, and contribute to food waste reduction.

Keywords: Escherichia coli, meat products, antimicrobial active packaging, food waste, biofilm

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