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# Silver nanoparticles-essential oils combined treatments to enhance the antibacterial and antifungal properties against foodborne pathogens and spoilage microorganisms

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Abstract

Plant-derived essential oils (EOs) and commercial silver nanoparticles (AgNPs) were tested to evaluate their antibacterial and antifungal efficiency against two pathogenic bacteria (*Escherichia coli* O157:H7 and *Salmonella* Typhimurium) and three spoilage fungi (Aspergillus niger, Penicillium chrysogenum, and Mucor circinelloides). A broth microdilution assay was used to determine the minimal inhibitory concentration (MIC) of EOs and AgNPs. In the MIC assay, the cinnamon EO, Mediterranean formulation, citrus EO and spherical-shaped silver nanoparticles (AgNPs) (AGC 1, AGC 0.5, AGPP and AGPPH) showed moderate to high antibacterial and antifungal properties, with MIC ranging from 7.8 to 62.5 ppm for AgNPs and 312.5–1250 ppm for EOs against the tested bacteria and fungi. The possible interaction between the EOs and the AgNPs was determined using a checkerboard method by evaluating fractional inhibitory concentration (FIC) values. The combination of two or more EOs and AgNPs (Active combination 1: AGPPH+cinnamon EO, Active combination 2: AGC 0.5+Mediterranean formulation+citrus EO, Active combination 3: AGPP+cinnamon EO+Asian formulation+lavang EO) showed synergistic effects (FIC <1.0) against all tested bacteria and fungi. A modified Gompertz model was used to evaluate growth parameters including maximum colony diameter (A), maximum growth rate ($V_m$), and lag phase (λ), under the three active combinations suggested by the checkerboard method using a vapor assay. The three active combinations 1, 2 and 3 reduced the growth rate and maximum colony diameter of *E. coli*, *S.* Typhimurium, *A. niger*, *P. chrysogenum*, and *M. circinelloides*, and extended their lag phase from 1 to 5 days. In *in situ* tests with inoculated rice, the three active combinations showed a significant reduction of all tested bacteria and fungi at 27 °C for 28 days.