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# Biological Efficacy and Chemical Properties of *Citrus maxima* (Pomelo) Peel Essential Oil-Based Nanoemulsions against *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae)

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## Abstract

Frequent application of synthetic insecticides to prevent post-harvest losses from stored-product pests has heightened negative impacts on the environment and public health, driving demand for sustainable alternatives. Plant-based essential oils (EOs) have significant potential to be used as bio-insecticides. However, their rapid degradation and evaporation frequently limit their effectiveness in practical applications. Encapsulating EOs in nanoemulsions aims to increase their practical feasibility by ensuring protection from external factors while enhancing functional reactivity and stability. This study developed and characterized nanoemulsions (CMNEs) containing 6% (v/v) *Citrus maxima* peel essential oil (CMEO), as well as evaluated their insecticidal contact, fumigant, and repellent efficacy against *Sitophilus oryzae*. Chemical composition of CMEO was analyzed via Gas Chromatography-Mass Spectroscopy (GC-MS). The CMEO was encapsulated through ultrasonic emulsification with Tween80 as the surfactant to obtain NEs at two EO:Tween80 combinations, CMNE1 (1:2) and CMNE2 (1:2.5). For NEs, follow-up evaluations of their physical characteristics and thermodynamic stability were carried out at room temperature 24 hours and 6 months after formulation. The GC-MS analysis of CMEO revealed d-limonene (85.4%) as the major constituent. The amplified concentration of Tween80 in CMNE2 resulted in the reduction of the particle size of CMNE1 from 23.08 nm to 18.97 nm, while the PDI changed from 0.5 and 0.43 for CMNE1 and CMNE2, respectively, favoring negative zeta-potential with -6.47 mV for CMNE1 to -3.88 mV for CMNE2 at 24 h. Notably, the nanoscale properties of developed nanoemulsions were maintained even after 6 months of storage with no visible macroscopic changes and they remained stable after undergoing various thermodynamic stability tests such as centrifugation, heating-cooling, and freeze-thaw cycles, with no phase separation observed. Encapsulating CMEO in NEs resulted in significant boost in contact toxicity with, CMNE1 exhibiting approximately 4 times higher toxicity and CMNE2 around 7 times higher toxicity after 48 hours of post-treatment. Fumigant toxicity was increased in CMNE1 and CMNE2 by approximately 3 and 4 folds, respectively, compared to CMEO. The repellency in CMNEs was significantly enhanced, reaching roughly 3 times greater than CMEO at 6 h of exposure. Overall, the current study lays the groundwork for developing CMNEs, enhancing the stability of CMEO and its bio efficacy. It suggests a sustainable and effective method for managing stored-grain insect pests while utilizing Pomelo peel, an under-utilized by-product.

**Keywords**: *Citrus maxima essential oil, Nanoemulsion, Sitophilus oryzae, Repellency, Fumigant*