Integrating Multi-Convolutional Neural Network Histological Analysis and Field Trials to Evaluate Carbon Dioxide and Pesticide Impacts on Honeybee Health and Colony Performance

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Apis mellifera are essential pollinators, contributing to 80% of global food crop pollination and $183 billion annually to the global economy. However, around 40–50% of hives collapse annually, with the ectoparasitic mite Varroa destructor identified as the #1 cause of this decline. Current Varroa management relies heavily on synthetic miticides. While effective, these treatments lead to chemical residue accumulation in hive products, sublethal physiological stress in bees, impaired behavior, and mite resistance. Building upon prior findings demonstrating selective mite susceptibility to hypercapnic stress, the present study compares CO_2 treatment to conventional miticides across multiple biological scales. Experimental components include a controlled adult-worker lifespan assay, histological assessment of midgut epithelial integrity, hemocyte-based immune profiling, drone reproductive viability analysis, and a ten-week field trial conducted across sixty colonies. Colony-level outcomes, including Varroa population reduction and honey production, were also evaluated. Convolutional neural networks were implemented to automate quantification of mid-gut epithelial thickness and field mite counts, improving measurement consistency and scalability. Results indicate that CO_2 is as effective as tau-fluvalinate for Varroa suppression and is more effective than amitraz and coumaphos, while maintaining adult survival, tissue integrity, immune cell abundance, and colony productivity, unlike pesticide treatments. These findings support CO_2 as a residue-free, safe, and scalable strategy for sustainable Varroa management and honeybee conservation.

Awards Won:

First Award of $6,000

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