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Effect of adjuvants on the degradation rate of formetanate hydrochloride in tomatoes and cucumbers under greenhouse and field conditions in Türkiye

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ABSTRACT

This study investigated the dissipation kinetics of formetanate hydrochloride (FMT) in tomatoes and cucumbers under greenhouse and open-field conditions in Türkiye. Four treatments were applied to both crops: a single dose, a double dose, FMT with a spreader, and FMT with sugar. Residue analysis was conducted using a validated QuEChERS–LC-MS/MS method. In greenhouse-grown tomatoes, the initial FMT concentrations ranged from 0.38 to 0.59 mg/kg, and the half-lives ranged from 4.25 to 4.53 days. In field-grown tomatoes, the half-lives ranged from 5.33 to 8.15 days, indicating slower degradation under open-field conditions. For greenhouse-grown cucumbers, the half-lives ranged from 2.91 to 3.47 days. Residue levels in field-grown cucumbers could not be determined due to insufficient residue concentrations. The results indicated that both environmental conditions and the addition of adjuvants influenced the degradation dynamics of FMT. These findings provide important data for improving pesticide application strategies and ensuring food safety.

1. Introduction

Pesticides are critical chemical agents employed to safeguard agricultural productivity by controlling pest infestations. Their widespread use underscores their indispensable role in securing food supply chains, particularly in regions where agriculture constitutes a major component of economic and social stability. However, excessive or improper pesticide application has raised growing concerns due to its detrimental effects on environmental sustainability and human health. Pesticide residues can contaminate air, water, and soil, leading to significant ecological disruptions, including adverse impacts on non-target organisms and biodiversity loss (Sun et al., 2020; Beaumelle et al., 2023). Moreover, persistent soil contamination diminishes soil fertility, impedes sustainable farming practices, and ultimately compromises long-term food security (Silva et al., 2018).

The adverse health implications associated with pesticide exposure are profound. Formetanate hydrochloride (FMT) is classified as a highly hazardous pesticide (Class Ib) by the World Health Organization (WHO, 2019). Formetanate hydrochloride operates as a reversible acetylcholinesterase inhibitor, exerting neurotoxic effects on target and non-target organisms alike (Malhotra et al., 2021; Heydari et al., 2022). Chronic exposure has been linked to a variety of serious health conditions, including carcinogenesis, neurodegenerative diseases, and reproductive disorders (Heydari et al., 2022; Ahmad et al., 2024; Shekhar et al., 2024). These findings highlight the urgent need for improved pesticide management strategies and reinforce the importance of understanding pesticide fate and behavior in agricultural systems.

Among various classes of pesticides, carbamates—including formetanate hydrochloride—have garnered particular attention due to their specific mechanisms of action and environmental persistence. Its physicochemical properties, such as high-water solubility, low soil adsorption, and substantial environmental mobility, contribute to its potential for contaminating aquatic ecosystems and persisting across different environmental compartments (EPA, 2006; Pathak et al., 2022). Furthermore, molecular interaction studies have shown that FMT can bind to human hemoglobin, altering its structural conformation and impairing its oxygen transport functionality, thereby accentuating its toxicological significance (Heydari et al., 2022; Singh et al., 2022).

In Türkiye, tomatoes (*Solanum lycopersicum* L.) and cucumbers (*Cucumis sativus* L.) represent two of the most economically significant horticultural crops. In 2023, Türkiye produced approximately 13.3 million tons of tomatoes and exported over 586 thousand tons of fresh

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