Remote sensing and advanced detection technologies—such as multispectral imaging, UAV platforms, and rapid field diagnostic tools—can detect pest and disease stress before visible symptoms appear. This is achieved through canopy reflectance changes or rapid molecular detection, allowing earlier and more precise spatial interventions while reducing the need for large-scale pesticide applications (Abd El-Ghany et al., 2020; Iost Filho et al., 2020; Buja et al., 2021; John et al., 2023).

7.3 Biological and physical control methods

Biological and physical control methods should be prioritized to reduce reliance on synthetic chemical pesticides. In the control of waxberry twig blight, Bacillus siamensis S3 and B. tequilensis S5, isolated from the rhizosphere, show strong antagonistic activity against P. versicolor (Figure 2). Their culture broth and extracellular filtrates can inhibit mycelial growth by more than 75%-80% and significantly reduce lesion size on detached leaves. Microscopic observations suggest that this inhibition is closely related to the production of chitinase, protease, and lipopeptides such as surfactin, iturin, and mycosubtilin. These strains have potential for development as spray agents or soil treatments and may serve as alternatives or supplements to fungicides (Ali et al., 2020).

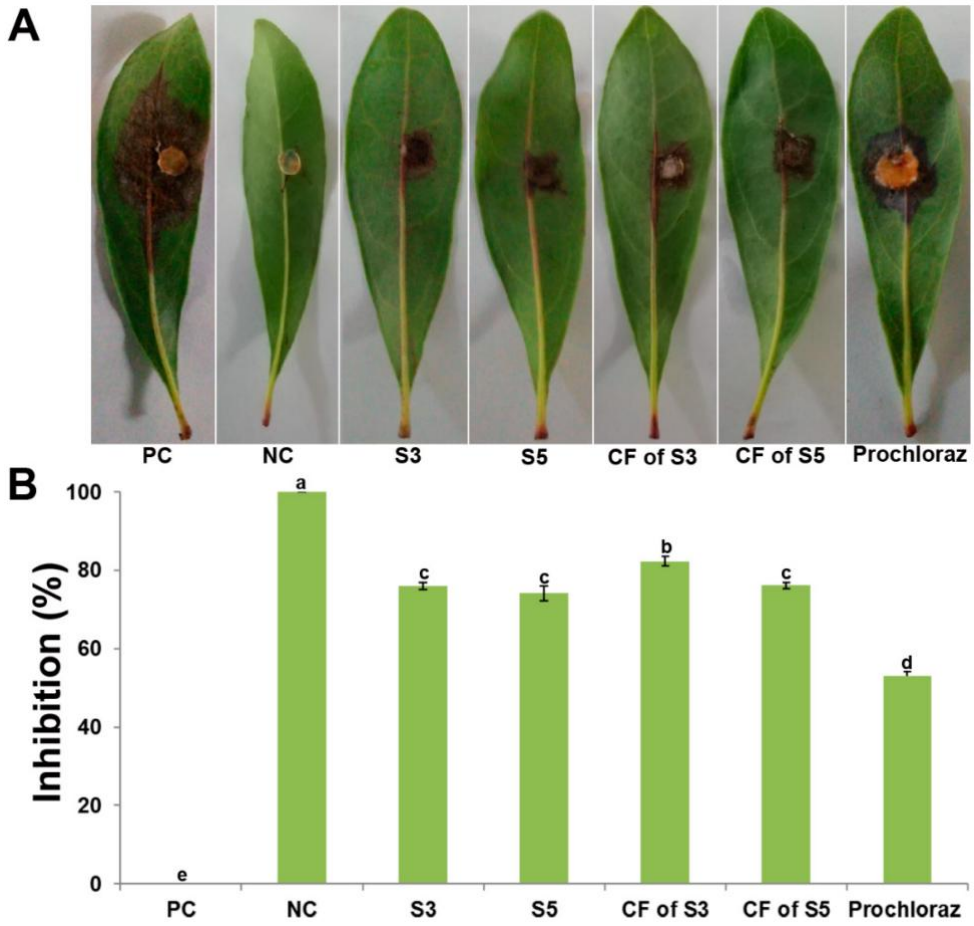

Figure 2 Detached leaf assay for antifungal activity. (A) Effects of antagonistic bacteria and their extracellular culture filtrate on bayberry leaves against P. versicolor XJ27. (B) Disease inhibition (%) relative to positive control. Data are mean ± SE of three replications for each treatment. Same letters are not significantly different at $p \leq 0.05$. For positive control (PC), only the fungal mycelial plug was inoculated. For negative control (NC), a sterile PDA plug without mycelia was used. CF, extracellular culture filtrate. Prochloraz denotes fungicide (Adopted from Ali et al., 2020)

More broadly, biological control strategies—such as the use of antagonistic microorganisms, bacteriophages, microbiome regulation, and engineered biocontrol agents—are becoming key components of sustainable disease management. These approaches should be integrated with resistant varieties, agronomic practices, and limited chemical control (Pandit et al., 2022).