Despite their relative safety, some plant extracts can still pose risks if used improperly or at high concentrations. Therefore, thorough ecotoxicological assessments are necessary before large-scale application to ensure non-target species such as pollinators, aquatic invertebrates, and vertebrates remain unharmed (Pavela et al., 2019; Hillary et al., 2024). The rapid biodegradability of many plant compounds also reduces the risk of bioaccumulation and long-term environmental persistence. Overall, current evidence supports the use of plant-based products as environmentally friendly mosquito control agents with a favorable safety profile for non-target organisms.

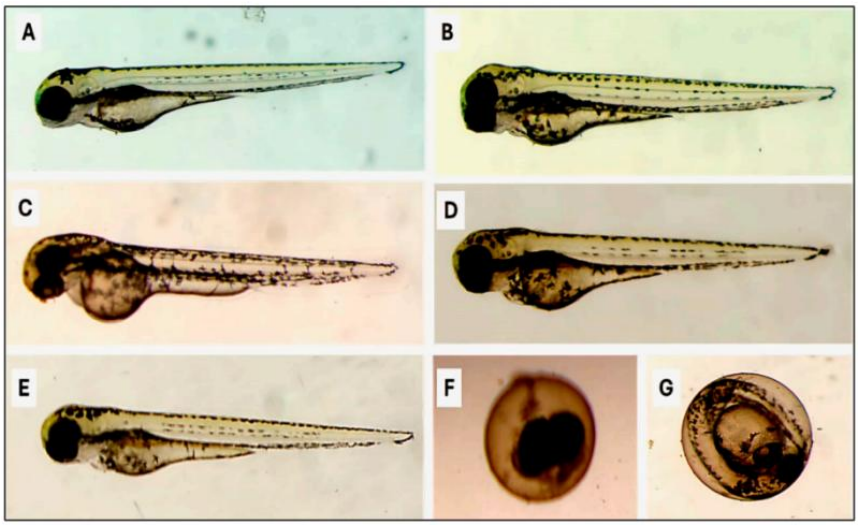

Figure 4 Biosafety evaluation of *H. eretus* in the zebrafish embryos. Representative micrographs of the zebrafish embryos at 3 days post-fertilization were treated with the crude methanolic extract of the marine sponge H. erectus and its various fractions. The embryos treated with the crude methanolic extract (B), as well as the n-hexane (<25 µL) (C), chloroform (D), and n-butanol (E) fractions, developed normally with no observable differences in morphology or growth compared to the control group (A). However, the embryos exposed to a higher concentration of n-hexane (>25 uL) showed complete lethality (F). Additionally, unhatched embryos were also observed in some treatments (G) (Adopted from Alqurashi et al., 2025)

7.2 Environmental degradation and residue characteristics of plant extracts

Plant-derived insecticidal compounds typically degrade more rapidly in the environment than conventional chemical insecticides, resulting in lower residual toxicity and reduced ecological impact. Many phytochemicals such as terpenoids, flavonoids, and alkaloids are naturally biodegradable under sunlight and microbial action, which limits their persistence in soil and water bodies (Pavela et al., 2019; Hillary et al., 2024). This rapid degradation helps prevent contamination of aquatic ecosystems and reduces the likelihood of adverse effects on non-target organisms over time.

However, some formulations like neem oil may face challenges related to stability under atmospheric conditions; direct application can lead to quick disintegration reducing efficacy (Chatterjee et al., 2023). Advances in formulation technologies such as nanoemulsions or encapsulation have been developed to enhance stability and prolong residual activity while maintaining environmental safety. These improved formulations balance effective mosquito control with minimal environmental footprint by controlling release rates and protecting active ingredients from rapid degradation.

7.3 Comparison with conventional chemical insecticides

Compared to synthetic chemical insecticides like organophosphates and pyrethroids, plant-based extracts offer several advantages including reduced toxicity to humans and wildlife, lower environmental persistence, and decreased risk of resistance development in mosquito populations (Demirak and Canpolat, 2022; Hillary et al., 2024). Synthetic chemicals often cause pollution through bio-magnification and have been linked to health issues such as neurotoxicity and skin irritation in humans (Hillary et al., 2024). In contrast, botanical insecticides tend to be safer due to their natural origin and complex mixtures of active compounds that reduce the chance of mosquitoes developing resistance.