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Natural larvicides from the Amazon: a promising alternative in the face of resistance to synthetic insecticides

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Abstract

The global rise of arboviral diseases, combined with increasing resistance of mosquito vectors to synthetic insecticides, highlights the urgent need for alternative control strategies. In this context, natural compounds derived from plants have gained attention as sustainable tools for vector management. The Amazon, due to its exceptional biodiversity, represents an important source of bioactive substances with larvicidal potential. Several studies have shown that essential oils extracted from Amazonian plants exhibit high toxicity against mosquito larvae at low lethal concentrations, such as those reported for *Siparuna guianensis* and *Trattinnickia burserifolia*. In addition to their potency, these compounds demonstrate environmental selectivity, presenting low toxicity to non-target aquatic organisms and reducing the risk of resistance development due to their complex chemical composition. Although volatility and environmental degradation may limit their persistence, advances in nanobiotechnology, including nano emulsions and inclusion complexes, have improved their stability and applicability. Thus, Amazonian essential oils represent promising candidates for sustainable mosquito control within integrated pest management programs.

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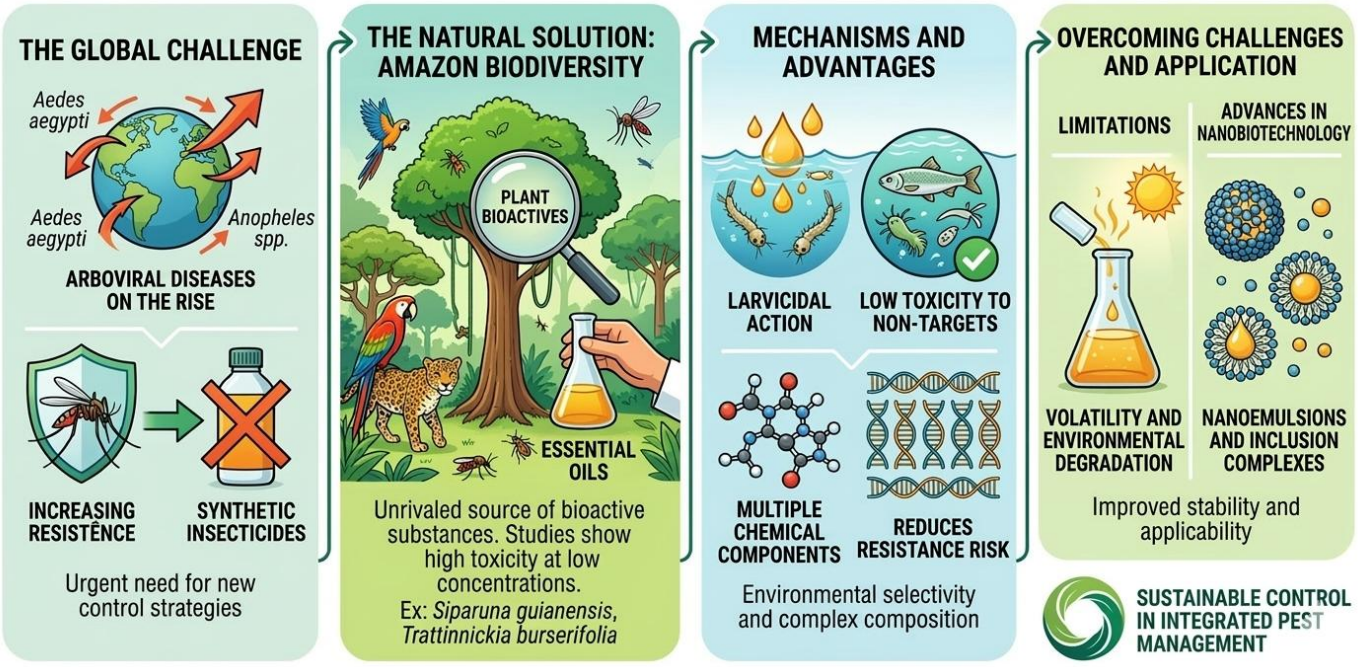

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The increasing global incidence of arboviruses, combined with the growing resistance of vectors to synthetic insecticides, highlights the urgent need for new strategies to control medically important mosquitoes. In this context, alternatives based on natural compounds have received increasing attention from the scientific community (Govindarajan and Benelli, 2016; Pavela *et al.*, 2019). Amazon, recognized for its extraordinary biodiversity, is an important reservoir of bioactive substances with potential for sustainable vector control. Several studies have demonstrated that plants from this region produce secondary metabolites capable of exhibiting high larvicidal activity against mosquitoes (Dias *et al.*, 2015; Scalvenzi *et al.*, 2019). Thus, larvicides based on essential oils (EOs) extracted from Amazonian plants can be considered promising tools for integrated pest management (IPM), as they combine high biological activity, low lethal concentrations, and greater safety for non-target organisms.

The effectiveness of these bioproducts can be observed in the extremely low lethal concentrations reported in literature. Amazonian plant species have demonstrated high toxicity against mosquito vector larvae. For example, the essential oil of *Siparuna guianensis* presents an $LC_B$of only 0.89 µg/mL, whereas the essential oil of *Trattinnickia burserifolia* showed an LC_{50} of 14.51 µg/mL in larvicidal bioassays (Maia Filho *et al.*, 2025; Oliveira *et al.*, 2025). These values highlight the high potential of these natural compounds, particularly when compared with the technical criteria used to classify promising larvicides. According to Pavela (2015), substances with LC50 values equal to or lower than 100 µg/mL can already be considered highly promising for the development of natural larvicides. Therefore, the results obtained for species from the Amazonian flora reinforce the feasibility of using these essential oils as strategic components in IPM programs aimed at mosquito control.

In addition to their high larvicidal potency, essential oils exhibit important environmental selectivity, a fundamental characteristic for sustainable vector control strategies. Studies have indicated that these compounds show low or no toxicity to non-target aquatic organisms, such as the invertebrates *Daphnia magna* and *Eisenia fetida*, in contrast to synthetic insecticides such as α-cypermethrin (Pavela *et al.*, 2019). This selectivity is associated with the chemical complexity of essential oils, which consist of mixtures of monoterpenes and sesquiterpenes capable of acting through multiple mechanisms of action. Such molecular diversity significantly reduces the likelihood of resistance development in mosquito vectors (Brandão *et al.*, 2025; Maia Filho *et al.*, 2025). Thus, in addition to being effective in mosquito control, EOs contribute to the preservation of aquatic biodiversity and the sustainability of pest management programs.

Despite these advantages, some studies have argued that the high volatility and rapid environmental degradation of essential oils may limit their persistence in the environment and, consequently, their large-scale application (M. Gupta and D. Gupta, 2022; Pavela *et al.*, 2019). Although this concern is valid, recent advances in nanobiotechnology have helped to overcome these limitations. Modern formulations, such as nanoemulsions and inclusion complexes, increase compound stability, improve their dispersion in water, and enable the controlled release of active ingredients (M. Gupta and D. Gupta, 2022; Pandiyan *et al.*, 2019). Therefore, these technologies significantly expand the application potential of essential oils in vector control programs.

In summary, the bioprospecting of Amazonian flora represents a promising strategy for the development of natural larvicides that target mosquito vectors. Incorporating these compounds into integrated pest management programs may contribute to more effective control of arboviruses while simultaneously reducing ecotoxicological impacts and mitigating the growing problem of resistance to synthetic insecticides. In this context, expanding investments in field research and strengthening partnerships between scientific institutions and the productive sector are essential steps to transform this biotechnological potential into practical solutions for public health.

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