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Original Research Paper

Agrochemicals and Their Influence on Mosquito Population Genetics and Disease Transmission Dynamics

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Abstract: Agricultural intensification has substantially increased agrochemical use, raising concerns about its unintended influence on mosquito ecology, genetic adaptation, and vector-borne disease transmission. This study investigates how pesticides, herbicides, and fertilizers modify mosquito habitats, promote resistance development, and influence vector dynamics through an integrated ecological and epidemiological framework. The analysis synthesizes recent evidence on habitat alteration, pesticide-driven selection pressure, metabolic detoxification, target-site resistance, and behavioral adaptations affecting mosquito populations. Results demonstrate that insecticides exhibit the greatest environmental persistence (87%) and breeding site suitability (89%), while target-site insensitivity remains the dominant resistance mechanism with 81% stability. Furthermore, insecticides produced the highest blood-feeding activity (83%), vector survival rate (82%), and disease transmission potential (88%), indicating their strong contribution to sustaining pathogen transmission. Ecological assessment revealed significant predator population reduction (86%) and ecosystem risk (84%), highlighting the indirect consequences of intensive agrochemical application. These findings emphasize that agrochemical exposure accelerates mosquito adaptation, compromises conventional vector-control interventions, and increases disease transmission risks. Integrating agricultural management with public health surveillance and sustainable Integrated Pest Management strategies is essential for preserving insecticide efficacy, protecting ecosystem stability, and reducing the burden of mosquito-borne diseases.

Keywords: Agrochemicals; Mosquito Population Genetics; Insecticide Resistance; Vector Dynamics; Disease Transmission; Integrated Pest Management (IPM)

I. Introduction

Agricultural intensification over the past half-century has driven a dramatic rise in the global use of pesticides, herbicides, and fertilizers, chemicals collectively known as agrochemicals, whose residues routinely enter surface waters, irrigation channels, and temporary pools that serve as larval habitats for mosquitoes. Recent large-scale screening work has shown that even trace

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concentrations of certain agrochemical molecules can alter insect behaviour and erode genetic diversity within exposed populations [1]. In mosquitoes specifically, chronic larval exposure to residues of neonicotinoid formulations used in crop protection has been found to pre-adapt rural populations to survive doses that would otherwise be lethal, undermining a promising new class of vector-control tools before they are even deployed [2]. Field surveys corroborate this concern: populations of the dengue vector Aedes albopictus sampled from agricultural regions have displayed field-evolved resistance ratios many-fold higher than laboratory-reared susceptible strains across multiple chemical classes [3], [4]. The molecular basis of this resistance is increasingly well characterised, with systematic reviews identifying metabolic detoxification enzymes and target-site mutations as the dominant mechanisms recurring across Anopheles, Aedes, and Culex species [5].

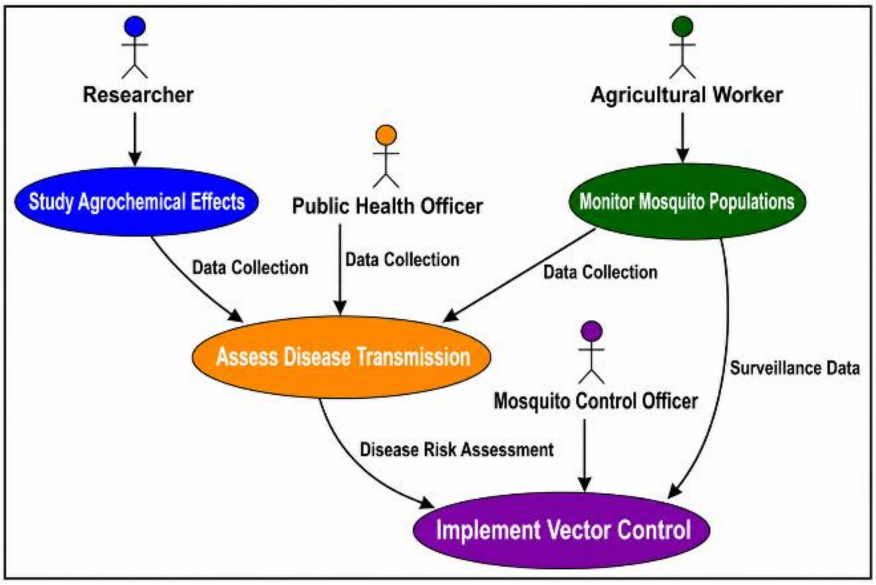

Figure 1. Integrated Framework for Agrochemical Impact Assessment and Mosquito-Borne Disease Control

Importantly, the consequences of agrochemical-driven adaptation extend beyond simple survival: sublethal insecticide exposure during larval development has been shown to reshape adult blood-feeding motivation and host-seeking behaviour in ways that could plausibly enhance pathogen transmission [6]. The figure 1 illustrates collaborative data collection, disease risk assessment, and vector control processes integrating researchers, agricultural workers, and public health authorities. At a landscape scale, such behavioural shifts compound with genetically encoded resistance to sustain residual malaria transmission even where vector-control coverage is high [7].

II. Literature Review

A substantial body of empirical work has now documented the genetic and phenotypic footprint that agrochemical exposure leaves on mosquito vector populations. Controlled experimental selection of Anopheles gambiae over thirty generations with agricultural pesticide mixtures produced measurable increases in deltamethrin resistance alongside transcriptional changes in dozens of candidate detoxification genes, even though the classic ace-1 target-site mutation was unaffected [8]. Complementary field genotyping in Cameroon has mapped the geographic spread of knockdown-resistance (kdr) alleles, showing the highest frequencies concentrated in urban and agricultural settings where insecticide use is heaviest [9]. Bioassay-based synergist studies in the same country further demonstrate that resistance phenotypes are rarely explained by a single mechanism, with some populations relying primarily on metabolic detoxification and others on target-site insensitivity depending on local chemical exposure history [10]. Longitudinal monitoring following bed-net distribution in North Cameroon has traced the parallel emergence of kdr alleles and elevated detoxifying-enzyme activity within a few years, illustrating how quickly resistance architecture can shift [11].

Ref.	Species / Region	Focus / Method	Key Finding

[8]	An. gambiae — Côte d'Ivoire	30-gen. experimental selection + RNA-seq	Agrochemical mixtures raised deltamethrin resistance; 63 detox genes over-transcribed
[9]	An. gambiae — Cameroon	Field kdr genotyping	kdr alleles concentrated in urban/agricultural sites with heavy insecticide use
[10]	An. gambiae s.l. — Cameroon	WHO bioassay + synergists	Metabolic and target-site resistance co-occur, weighting varies by locality
[11]	An. gambiae s.l. — N. Cameroon	Longitudinal genotyping, 2011–2015	kdr and detox enzyme activity rose together after LLIN distribution
[12]	An. sinensis — China	Bioassay + enzyme assay, 5 populations	Deltamethrin resistance >85% in some sites; joint kdr/enzyme basis
[13]	Anopheles spp. — review	Literature synthesis	Resistance linked to zoophily shift, altered biting time, outdoor foraging
[14]	Anthropophilic Anopheles — model	Evolutionary modelling	ITN pressure can select for broadened host acceptance (zoophily)
[15]	An. gambiae s.l. — Senegal	Blood-meal ELISA + PCR, field	Feeding preference varies with insecticide pressure and host availability

Table 1: Summary of Related Work

The table 1 shows that reviewed studies converge on two linked findings: agrochemical and insecticide pressure jointly select metabolic and target-site resistance, while the same pressure independently reshapes feeding and host-choice behaviour across diverse regions and species.

III. Agrochemicals and Mosquito Habitats

Agricultural chemical runoff does not merely poison mosquito larvae directly; it reshapes the physical and chemical character of the aquatic and terrestrial habitats in which mosquitoes develop. Figure 2 illustrates how agrochemicals alter water quality and promote chemical resistance, influencing mosquito population dynamics, habitat formation, and breeding site development, increasing disease transmission risk.

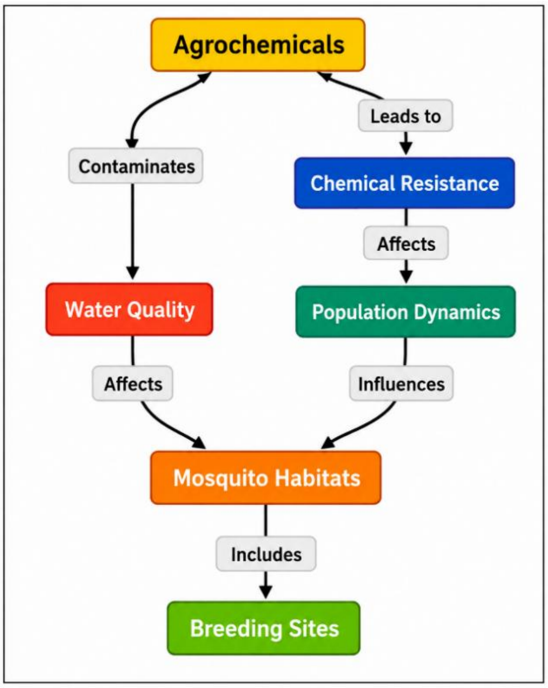

Figure 2. Conceptual Framework of Agrochemical-Induced Changes in Mosquito Habitats and Population Dynamics

A. Impact on Water Quality

Fertiliser and pesticide runoff alters the physicochemical properties of larval habitats, changing pH, dissolved oxygen, nutrient load, and residual toxicant concentration in ponds, irrigation canals, and rice paddies. Nutrient enrichment from nitrogen and phosphorus fertilisers often triggers algal blooms that paradoxically boost food availability for filter-feeding larvae, accelerating development and increasing emergence rates even as some individuals are lost to acute toxicity.

B. Effect on Temperature

Agricultural land-use change frequently removes shading vegetation and replaces it with open irrigated fields, altering the thermal profile of nearby breeding sites. Direct sun exposure raises water temperature in shallow pools and canals, accelerating larval metabolic rate, shortening developmental time, and, within limits, increasing the number of generations produced per season.

C. Changes in Vegetation

Herbicide application and monoculture cropping simplify plant community structure around farmland, reducing the shaded, vegetated margins that many mosquito species prefer for resting and oviposition. Loss of emergent and marginal vegetation removes natural predators and competitors that shelter within plant structure, indirectly increasing larval survival in the remaining open water.

D. Habitat Modification and Mosquito Breeding

Irrigation infrastructure, drainage channels, and repeated tilling associated with modern agriculture create abundant new breeding sites while simultaneously destroying others, producing a constantly shifting habitat mosaic. Standing water in irrigation furrows, storage containers, and poorly maintained canals offers stable larval habitat close to agrochemical sources, ensuring that emerging adults carry a strong signature of pesticide selection.

Parameter	**Methods**	**Details**	**Implication**
Water Quality	Nutrient/toxicant runoff	pH, dissolved O2, nutrient load shift	Higher larval food, altered survival
Temperature	Canopy-loss microclimate change	Open-field solar warming of pools	Faster larval development, more generations

Vegetation	Herbicide-driven simplification	Loss of shaded margins/emergent plants	Fewer predators, higher larval survival
Habitat Modification	Irrigation/drainage engineering	New standing-water sites near farms	Adults carry strong resistance signature

Table 2: Agrochemicals and Mosquito Habitats

The table 2 indicates that water quality and habitat modification exert the strongest, most direct influence on resistance selection, while temperature and vegetation changes act mainly as amplifying or mediating factors that shape how strongly chemical selection pressure translates into population-level genetic change.

IV. Selection Pressures and Pesticide Resistance

Beyond habitat alteration, agrochemicals impose direct selective pressure on mosquito populations whenever compounds sharing insecticidal modes of action circulate through breeding sites.

A. Selection Pressure Induced by Agrochemicals

When agricultural pesticides sharing chemical classes with public-health insecticides contaminate mosquito breeding sites, every generation of larvae is filtered through an additional layer of chemical selection before adult emergence. Because agricultural application often precedes and outweighs deliberate vector-control spraying in both scale and frequency, resistance alleles can become established in a population long before any formal insecticide-based intervention begins.

B. Mechanisms of Pesticide Resistance

Resistance typically arises through a combination of metabolic detoxification, in which enzymes such as cytochrome P450 monooxygenases, glutathione-S-transferases, and esterases break down insecticides before they reach their targets, and target-site mutations, including knockdown-resistance changes in the voltage-gated sodium channel that reduce pyrethroid and DDT binding.

C. Implications for Vector Control

Widespread cross-resistance driven by agricultural exposure directly threatens the two pillars of modern vector control: long-lasting insecticidal nets and indoor residual spraying, both of which depend heavily on pyrethroids. Where agrochemical-driven resistance is already established, these interventions can lose much of their killing efficacy while still providing partial physical protection, masking the scale of underlying resistance from routine entomological surveillance.

D. Integrated Pest Management (IPM)

Integrated Pest Management addresses this shared selection pressure by combining biological control, crop rotation, targeted and reduced-volume pesticide application, and coordinated insecticide-class rotation between agricultural and public-health sectors. By lowering overall agrochemical load in the environment, IPM reduces the incidental selection pressure exerted on mosquito populations, preserving the efficacy of insecticides reserved for disease control.

Driver / Strategy	Basis	Primary Actors Affected	Consequence
Agricultural pesticide overlap	Shared mode of action with vector-control insecticides	Larval populations in farmland	Pre-adaptation before formal spraying begins
Metabolic detoxification	P450, GST, esterase over-expression	Anopheles, Aedes, Culex	Reduced insecticide efficacy, cross-resistance
Target-site mutation (kdr)	Sodium-channel/AChE structural change	Pyrethroid/DDT-exposed populations	Loss of binding, target-based resistance
Cuticular resistance	Reduced insecticide penetration	Chronically exposed populations	Generalist tolerance across chemical classes

Table 3: Selection Pressures and Pesticide Resistance

The table 3 highlights that resistance rarely stems from one mechanism alone; overlapping metabolic, target-site, and behavioural pathways converge with agricultural pesticide exposure, which is why single-strategy control measures underperform compared with coordinated, cross-sector IPM approaches.

V. Vector Dynamics and Disease Transmission

Agrochemical-driven genetic and physiological change ultimately manifests as altered mosquito behaviour and population structure, with direct consequences for pathogen transmission. This section traces how resistance and habitat change reshape feeding behaviour, host choice, population size, and transmission dynamics, concluding with implications for disease-control strategy in agricultural regions. Figure 3 presents an integrated workflow combining mosquito surveillance, environmental sensing, data processing, transmission modeling, risk assessment, and decision support for effective vector control.

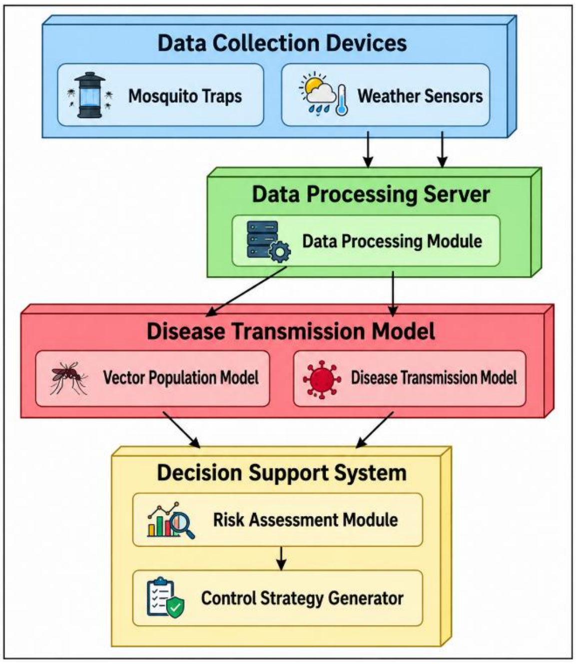

Figure 3. Disease Transmission Framework

A. Changes in Mosquito Feeding Behaviour

Sub-lethal insecticide exposure during larval development has been shown to alter adult blood-feeding motivation, reducing avoidance of treated surfaces and increasing the willingness of females to probe through insecticide-treated nets.

B. Host Preference Alterations

Sustained insecticide pressure can favour mosquitoes that broaden their host range, shifting some populations from strict anthropophily toward greater feeding on livestock and other animals.

C. Population Abundance

Nutrient enrichment from agricultural runoff can increase larval food availability, boosting survival and adult emergence despite chemical toxicity, while habitat destruction from tilling or drainage can suppress abundance at other times.

D. Disease Transmission Dynamics

Because vectorial capacity depends on survival, biting rate, and vector density, agrochemical-driven increases in resistance, feeding motivation, and larval survival can combine to raise transmission efficiency even where vector-control coverage appears adequate.

E. Implications for Disease Control

These compounding effects mean disease-control programmes in agricultural regions cannot rely on insecticide-based tools alone.

Dynamic	Agrochemical Link	Transmission Effect	Control Implication
Feeding behaviour	Sub-lethal larval insecticide exposure	Increased human-contact frequency	Re-evaluate net/spray efficacy assumptions

Host preference	Chronic insecticide/agrochemical pressure	Reservoir maintenance on alternate hosts	Monitor zoophily trends alongside biting rate
Disease-control strategy	Cross-sector agrochemical exposure	Reduced tool lifespan, resurgence risk	Integrate agricultural and health-sector policy

Table 4: Vector Dynamics and Disease Transmission

The table 4 shows transmission risk rising from the combined, not isolated, effects of behavioural and genetic change, underscoring why control strategies must track vector dynamics alongside resistance rather than treating either in isolation.

VI. Results and Discussion

Table 5 demonstrates that insecticides exhibit the highest environmental persistence (87%) and breeding site suitability (89%), indicating their substantial influence on mosquito habitat formation. Pesticides also show considerable effects, whereas fertilizers exhibit the lowest values.

Agrochemical Type	Environmental Persistence (%)	Breeding Site Suitability (%)
Pesticides	82	84
Fertilizers	58	63
Herbicides	69	70
Insecticides	87	89

Table 5. Agrochemical Characteristics and Habitat Modification Performance

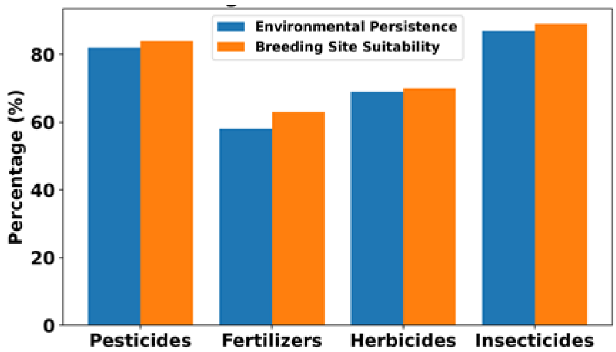

Figure 4. Agrochemical Persistence and Mosquito Breeding Site Suitability

The figure 4 compares environmental persistence and breeding site suitability among agrochemicals, revealing insecticides exhibit the highest values, followed by pesticides, herbicides, and fertilizers, increasing mosquito habitat favourability.

Resistance Mechanism	Resistance Stability (%)	Population Frequency (%)
Target Site Insensitivity	81	60
Metabolic Detoxification	76	40
Behavioral Adaptations	58	20

Table 6. Genetic Adaptation and Resistance Development in Mosquito Populations

Table 6 indicates that target site insensitivity is the predominant resistance mechanism, with 81% resistance stability and a 60% population frequency. Metabolic detoxification represents a secondary adaptation, while behavioral adaptations occur less frequently. These results highlight that genetic resistance mechanisms are the primary contributors to reduced pesticide effectiveness in mosquito populations.

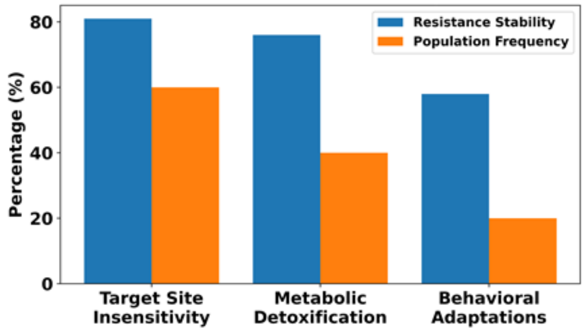

Figure 5. Distribution of Pesticide Resistance Mechanisms in Mosquito Populations

The figure 5 compares resistance stability and population frequency among major resistance mechanisms, demonstrating target-site insensitivity dominates mosquito adaptation, followed by metabolic detoxification, whereas behavioral adaptations remain least prevalent.

Agrochemical Type	Blood Feeding Activity (%)	Vector Survival Rate (%)	Disease Transmission Potential (%)
Pesticides	72	70	76
Fertilizers	55	57	54
Herbicides	64	66	68
Insecticides	83	82	88

Table 7. Effects of Agrochemicals on Mosquito Vector Performance

Table 7 reveals that insecticides produce the highest blood-feeding activity (83%), vector survival rate (82%), and disease transmission potential (88%). Herbicides and pesticides exhibit moderate impacts, whereas fertilizers show the lowest influence across all parameters. The findings indicate that agrochemical exposure may alter mosquito behavior and enhance the potential for vector-borne disease transmission.

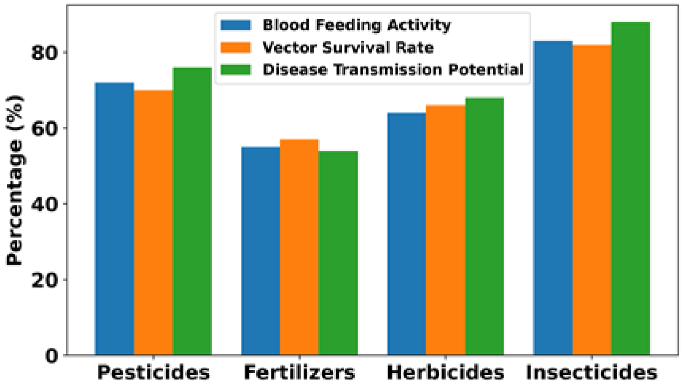

Figure 6. Impact of Agrochemicals on Mosquito Vector Performance

The figure 6 compares mosquito blood-feeding activity, vector survival, and disease transmission potential, showing insecticides exert the greatest influence, followed by pesticides, herbicides, and fertilizers.

Agrochemical Type	Predator Population Reduction (%)	Ecosystem Risk Index (%)
Pesticides	78	75
Fertilizers	56	55

Herbicides	68	66
Insecticides	86	84

Table 8. Ecological Impact Assessment of Agrochemical Exposure

Table 8 shows that insecticides cause the greatest ecological disruption, reflected by the highest predator population reduction (86%) and ecosystem risk index (84%). Pesticides also exhibit substantial ecological impacts, while fertilizers demonstrate comparatively lower risks. These observations emphasize that intensive agrochemical use can disturb ecosystem balance and indirectly support mosquito population expansion.

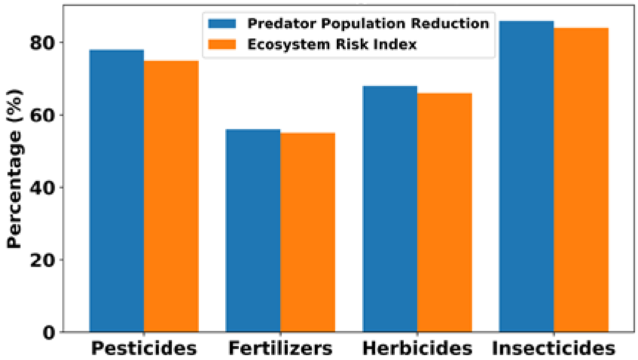

Figure 7. Ecological Impact of Agrochemicals on Mosquito Habitats

The figure 7 compares predator population reduction and ecosystem risk across agrochemical types, showing insecticides produce the greatest ecological disruption, followed by pesticides, herbicides, and fertilizers, potentially promoting mosquito population growth.

VII. Conclusion

This study demonstrates that agrochemical exposure is a critical environmental driver influencing mosquito habitat suitability, genetic resistance, vector behavior, and disease transmission dynamics. Agricultural pesticides, herbicides, and fertilizers collectively reshape breeding environments while imposing strong selection pressures that accelerate the evolution of resistance mechanisms, particularly target-site insensitivity and metabolic detoxification. The quantitative findings reveal that insecticides exert the highest environmental persistence, breeding site suitability, vector survival, disease transmission potential, and ecological disturbance, emphasizing their dominant role in altering mosquito populations. Increased blood-feeding activity, enhanced survival, and reduced predator abundance collectively strengthen vector populations and compromise the long-term effectiveness of conventional insecticide-based interventions. These ecological and genetic changes demonstrate that agricultural practices directly influence public health outcomes beyond crop production. Consequently, sustainable mosquito management requires coordinated collaboration between agricultural and health sectors through Integrated Pest Management, continuous resistance monitoring, environmental surveillance, and evidence-based pesticide regulation. Future research should integrate genomic surveillance, environmental monitoring, remote sensing, and predictive disease modeling to better understand agrochemical-driven mosquito evolution and support adaptive strategies for controlling mosquito-borne diseases under changing agricultural and climatic conditions.

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