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GENETICALLY MODIFIED INSECTS: OPPORTUNITIES AND CHALLENGES

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ABSTRACT

This paper present recent advances in genetically modified (GM) insect research. Genetically modified (GM) insects are a rapidly advancing biotechnology with applications in public health, agriculture, and environmental management. Using tools such as CRISPR/Cas9, transgenesis, and RNA interference, scientists have developed insects with traits that suppress populations, block disease transmission, or reduce crop damage. Compared to chemical pesticides, GM insects offer targeted and sustainable solutions, yet uncertainties remain regarding ecosystem effects, resistance, and social acceptance. Careful research and strong international regulation are required to ensure that the benefits of GM insects are realized while minimizing potential risks.

INTRODUCTION

Genetic modification (GM) is the area of biotechnology which concerns itself with the manipulation of the genetic material in living organisms, enabling them to perform specific functions (Morse S., et al., 2008, Zhang C. et al. 2016).

Currently, the GM crop pipeline has expanded to cover other fruits, vegetables and cereals such as lettuce, strawberries, eggplant, sugarcane, rice, wheat, carrots etc. with planned uses to increase vaccine bioproduction, nutrients in animal feed as well as confer salinity and drought resistant traits for plant growth in unfavourable climates and environment (Bawa et al. 2013, Zhang C. et al. 2016).

Another problem faced by GM crops currently is pest resistance due to gene overexpression leading to pest evolution via natural selection. Indeed, an analysis of 77 studies' results by (Tabashnik *et al., 2013)* depicted reduced *Bt*-crop efficacy caused by field evolved pest resistance for 5 out of 13 (38.4 %) major pest species examined in 2013, compared to just one in 2005.

Genetic systems for controlling transmission of vector-borne diseases are moving from discovery-stage demonstrations of proofs-of-principle to the next phases of development. A successful transition requires meeting safety and efficacy criteria defined in target product profiles (Carballar Lejarazú, R, C, et al., 2020).

Anopheles stephensi is a competent malaria vector mainly present in southern Asia and the Arabian Peninsula. Since 2012, it has invaded several countries of eastern Africa, creating an emerging risk of urban transmission (Larrosa-Godall M, et a., 2025).

MATERIAL AND METHODS

There are several methods used in genetic modification (GM), although the most widely used methods are CRISPR/Cas9, transgenesis (piggyBac), and RIDL/SIT approaches in applied programs**.** Gene drives are the most powerful but also the most controversial because they can spread rapidly in nature.

Transgenesis

Inserting a new gene into the insect genome (often from another species).

Example: Adding a "self-limiting" gene in *Aedes aegypti* that causes offspring to die.

Tools: *piggyBac* transposable elements, microinjection of embryos.

CRISPR/Cas9 Gene Editing

Uses CRISPR–Cas9 to cut and edit DNA at precise locations.

Can be used to:

Knock out genes (e.g., those needed for fertility).

Insert new genes (e.g., making mosquitoes resistant to *Plasmodium*, the malaria parasite).

Widely applied in *Anopheles* and *Aedes* mosquitoes.

Sterile Insect Technique (SIT) with Genetic Engineering

Classic SIT uses radiation to sterilize insects.

Genetic versions (like RIDL = *Release of Insects carrying a Dominant Lethal*) insert lethal genes that kill offspring.

Example: Oxitec's GM *Aedes aegypti*.

RESULTS AND DISCUSSIONS

A genetically modified insect (GMI) is an insect whose genetic material has been altered using biotechnology. Scientists use genetic modification to give insects new traits, often to help solve agricultural, environmental, or public health challenges.

Main Goals of Genetic Modification in Insects:

Disease Control

Mosquitoes are the most studied GM insects because they spread malaria, dengue, Zika, and chikungunya.

Aedes aegypti mosquitoes engineered to carry a "self-limiting gene," causing offspring to die before reaching adulthood, reducing mosquito populations.

Another approach is modifying mosquitoes to make them resistant to carrying the malaria parasite.

Agriculture

GM insects can protect crops by reducing populations of pests like moths, beetles, and fruit flies.

Example: Diamondback moths modified with a gene that prevents females from surviving to adulthood.

Environmental Management

GM insects can replace or suppress invasive species that damage ecosystems.

Gene drives (genetic systems that spread a trait rapidly through a population) are being studied to either suppress pest populations or spread beneficial traits.

Techniques Used:
CRISPR/Cas9 – precise editing of insect DNA.
Transgenesis – inserting genes from another species.
Gene drives – engineered genetic elements that ensure a modified gene spreads rapidly in the population.
Benefits:
Reduces reliance on chemical insecticides.
Targets specific species without affecting other insects like bees.
Can help control deadly diseases and protect food security.
Risks & Concerns:
Potential unintended effects on ecosystems.
Ethical debates about releasing GM insects into the wild.
Possible development of resistance in insect populations.
A number of insect species have already been genetically modified and studied, mostly in labs but some also in field trials.
Mosquitoes (most studied)
Aedes aegypti spread dengue, Zika, chikungunya, yellow fever.
Modified to carry a *self-limiting gene* (offspring die young).
Field trials: Brazil, Cayman Islands, Panama.
Anopheles gambiae / Anopheles stephensi → malaria vectors.
Modified to resist carrying the malaria parasite (*Plasmodium*).
Gene drive systems being developed to suppress or alter populations.
Culex quinquefasciatus spread West Nile virus & lymphatic filariasis.
Early-stage modification research.
Agricultural Pests
Diamondback moth (Plutella xylostella)
Pest of cabbages & crucifer crops
Modified strains with self-limiting traits tested in New York (field trials).
Mediterranean fruit fly (Ceratitis capitata, "Medfly")
Damages fruits worldwide.
GM versions designed to suppress wild populations.
Pink bollworm (Pectinophora gossypiella)
Cotton pest.
Modified strains released in the U.S. to help with eradication efforts.

Table 1

Insect species currently used in GM

Species	Purpose of Modification
Aedes aegypti (mosquito)	Self-limiting genes to reduce populations; disease control (dengue, Zika, chikungunya, yellow fever)
Anopheles gambiae / Anopheles stephensi (mosquitoes)	Resistance to malaria parasite; gene drives for population suppression
Culex quinquefasciatus (mosquito)	Reduce transmission of West Nile virus & lymphatic filariasis
Diamondback moth (*Plutella xylostella*)	Crop protection; self-limiting strains to suppress populations

Mediterranean fruit fly (*Ceratitis capitata*)	Reduce fruit crop damage; population suppression
Pink bollworm (*Pectinophora gossypiella*)	Cotton pest suppression
Drosophila melanogaster (fruit fly)	Model organism for genetics research
Honeybee (*Apis mellifera*)	Experimental disease resistance (e.g., Varroa mite, viruses)
Other agricultural pests (locusts, beetles)	Pest resistance & suppression

Other Species in Research

Drosophila melanogaster (fruit fly)

Model organism; widely modified for research, not for field release.

Honeybees (Apis mellifera)

Experimental modifications for disease resistance (lab-based, very controversial).

CONCLUSIONS

Significant progress has been made with genetically modified insects, especially mosquitoes (*Aedes aegypti*) and some agricultural pests (e.g., diamondback moth, pink bollworm).

GM insects can provide targeted alternatives to chemical pesticides, helping reduce environmental damage and human exposure.

For public health, modified mosquitoes offer promising tools to reduce diseases like malaria, dengue, and Zika.

However, risks remain, including ecological impacts, potential development of resistance, and ethical concerns about releasing gene drives into the wild.Adoption depends heavily on public acceptance, regulatory frameworks, and transparent communication about risks and benefits.

RECOMMENDATIONS

Expand Risk Assessment

Conduct long-term ecological studies before large-scale releases.

Assess effects on food chains, biodiversity, and ecosystem stability.

Improve Regulation & Oversight

Develop clear international guidelines for GM insect testing and release.

Coordinate between countries since insects easily cross borders.

Engage the Public

Increase community involvement and transparency in decision-making.

Provide accessible information on how GM insects work and their safety.

Diversify Approaches

Avoid reliance on a single genetic strategy (to reduce risk of resistance).

Combine GM insects with traditional pest control (integrated pest management).

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