

Gene drive strategies of pest control in agricultural systems: Challenges and opportunities



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Talk outline

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PERSPECTIVE

Evolutionary Applications  WILEY

1. Context of agricultural pest control
2. Spectrum of gene drive strategies
3. Current status
4. Threshold-dependent systems
5. Ecology & life history
6. Opportunities
7. Challenges
8. Risk assessment & confinement

Gene drive strategies of pest control in agricultural systems: Challenges and opportunities

Abstract

Recent advances in gene-editing technologies have opened new avenues for genetic pest control strategies, in particular around the use of gene drives to suppress or modify pest populations. Significant uncertainty, however, surrounds the applicability of these strategies to novel target species, their efficacy in natural populations and their eventual safety and acceptability as control methods. In this article, we identify issues associated with the potential use of gene drives in agricultural systems, to control pests and diseases that impose a significant cost to agriculture around the world. We first review the need for innovative approaches and provide an overview of the most relevant biological and ecological traits of agricultural pests that could impact the outcome of gene drive approaches. We then describe the specific challenges associated with using gene drives in agricultural systems, as well as the opportunities that these environments may offer, focusing in particular on the advantages of high-threshold gene drives. Overall, we aim to provide a comprehensive view of the potential opportunities and the remaining uncertainties around the use of gene drives in agricultural systems.

societal opposition in many parts of the world and an increasing list of banned pesticides (Nag & Gite, 2020). Furthermore, new pests are constantly emerging, while existing pests are establishing themselves in new agro-ecosystems around the world. There is a need for scientific advances to offer novel, sustainable and safer pest control approaches relative to pesticides.

Genetic pest control strategies have been considered for decades as an alternative to chemical approaches and a potential addition to the pest control toolbox (Curtis, 1968; Gould, 2008). In the broadest sense, genetic control strategies use genetically manipulated strains of a pest organism to achieve one of two main objectives: population suppression, aiming at lowering the densities of natural target populations or eliminating them entirely, or population replacement, aiming at replacing natural pests with less damaging individuals. A subset of these approaches, referred to as gene drives, make use of the super-Mendelian inheritance patterns of selfish genetic elements to drive genetic cargo (i.e. any genetic material of interest, such as a gene conferring resistance to a disease or a gene imposing conditional lethality) into natural populations. These elements are also themselves often referred to as 'gene drives', and in this article, we make sure to systematically distinguish between a 'gene drive element' (the genetic material with selfish inheritance properties) and a 'gene drive strategy' (the pest control approach that aims to suppress or replace populations).

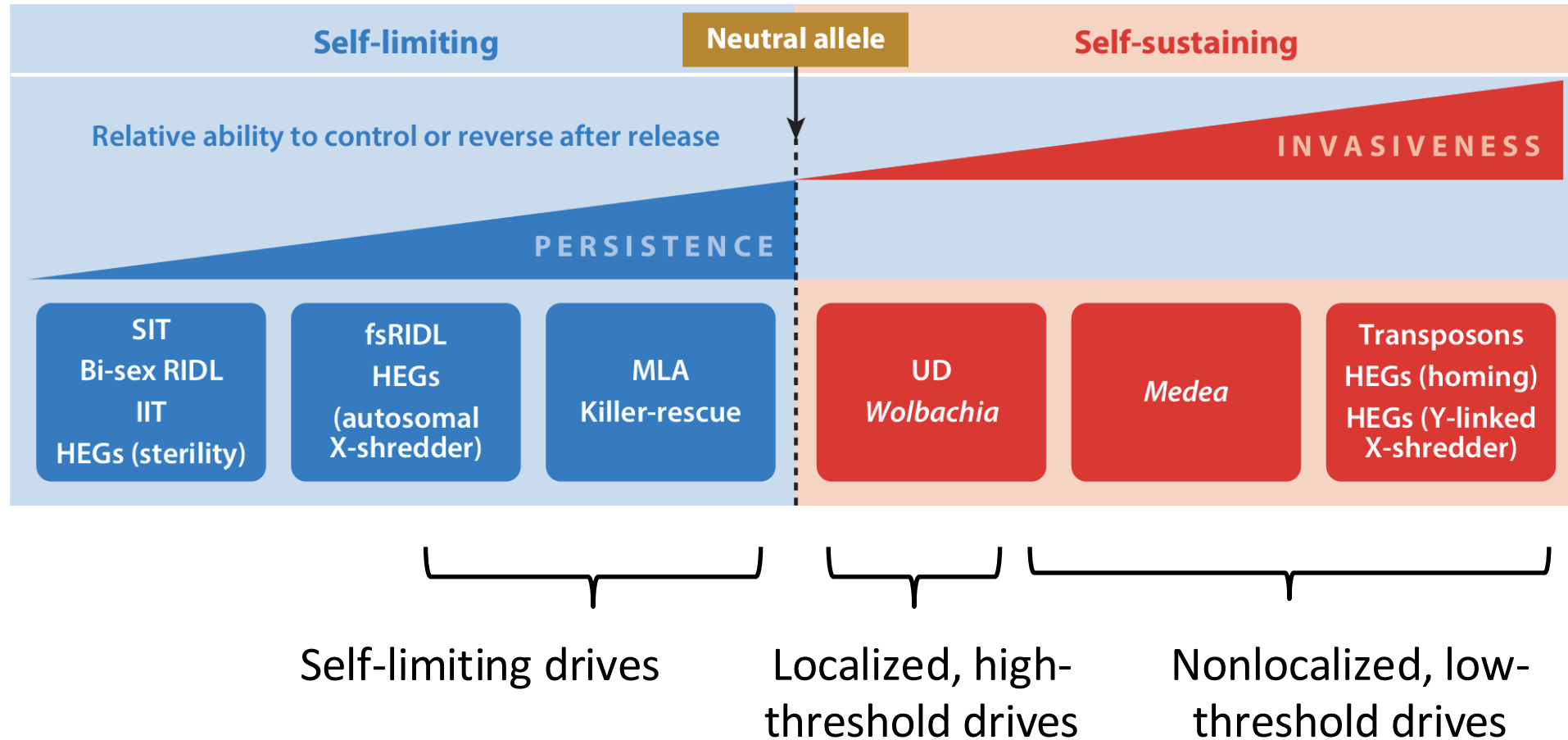
Gene drive elements can be derived from naturally existing selfish genetic elements or engineered from entirely synthetic designs.

Context of agricultural pest control

- **Agricultural pests** cause significant **economic losses** worldwide (~\$540 billion if left unchecked). They also pose a **threat** to **food safety**.
- **Current control strategies** are heavily **reliant** on **chemical pesticides**.
- **Pesticides** face **threat** of **resistance**. There is also evidence of **human & environmental harm**, leading to **societal opposition & bans**. **New pests** are constantly **emerging**.
- Interest in **new tools**.



Spectrum of gene drive strategies



Current status

PNAS

Synthetically engineered *Medea* gene drive system in the worldwide crop pest *Drosophila suzukii*

Anna Buchman^{a,b,c}, John M. Marshall^d, Dennis Ostrovski^{a,b}, Ting Yang^{a,b,c}, and Omar S. Akbari^{a,b,c,e,1}

nature communications

Gene drive and genetic sex conversion in the global agricultural pest *Ceratitis capitata*

Received: 22 August 2023

Accepted: 12 December 2023

Angela Meccariello¹✉, Shibo Hou¹, Serafima Davydova¹, James Daniel Fawcett¹, Alexandra Siddall², Philip T. Leftwich², Flavia Krsticevic³, Philippos Aris Papathanos³ & Nikolai Windbichler¹✉

GENE CONVENE
GLOBAL COLLABORATIVE
Advancing Best Practices in Genetic
Biocentral Technology

Today's Webinar: Gene Drive Strategies for New World Screwworm Suppression in Uruguay



Dr. Tatiana Basika
INIA/Institute Pasteur Montevideo



Dr. Rossina Novas
INIA/Institute Pasteur Montevideo

GEN
Biotechnology

CRISPR-Cas9-Mediated Mutagenesis of the Asian Citrus Psyllid, *Diaphorina citri*

Duverney Chaverra-Rodriguez^{1,†,‡}, Michelle Bui^{1,†,‡}, Cody L. Gilleland^{1,2}, Jason L. Rasgon³⁻⁵ and Omar S. Akbari^{1,*}

nature

Super-Mendelian inheritance mediated by CRISPR-Cas9 in the female mouse germline

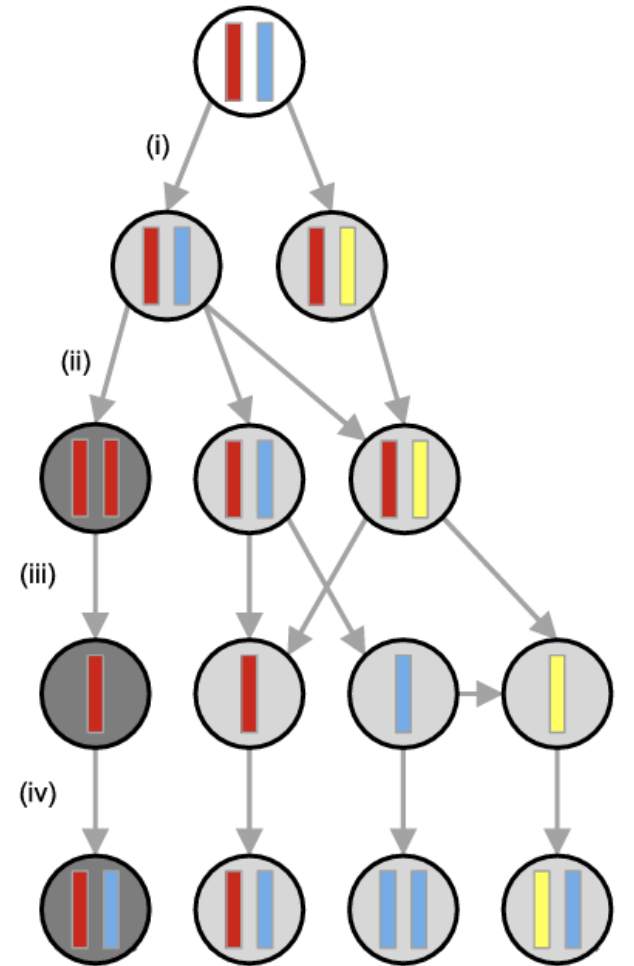
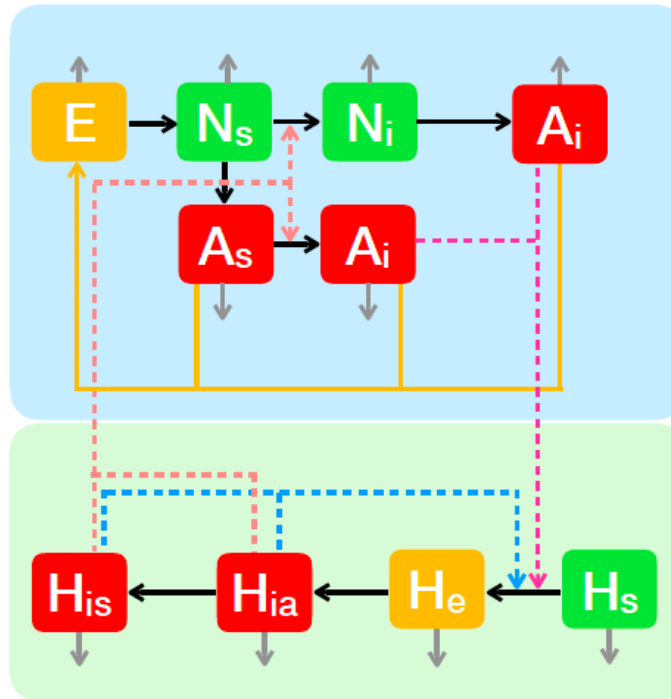
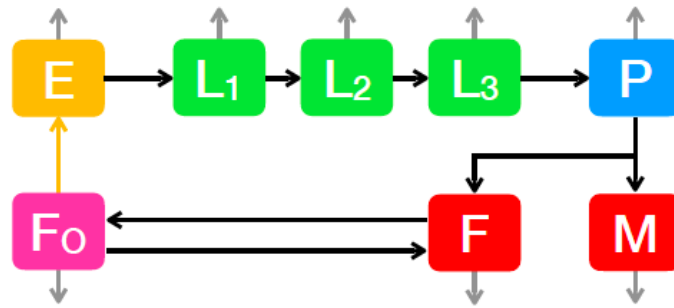
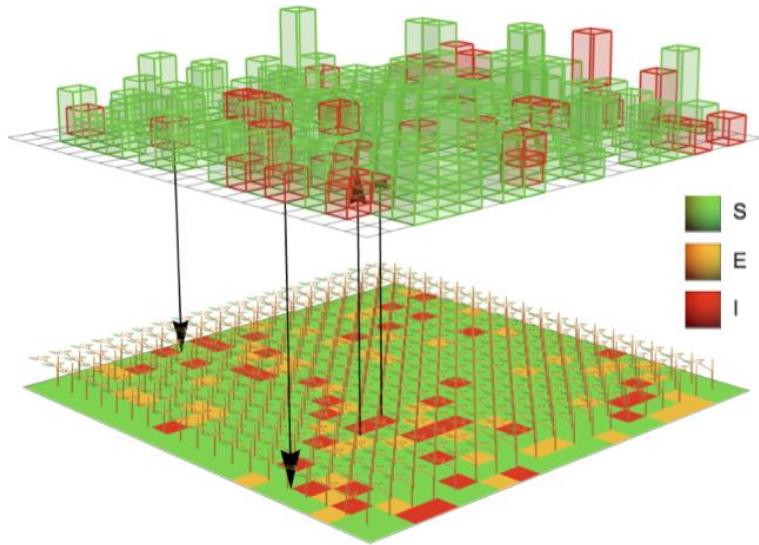
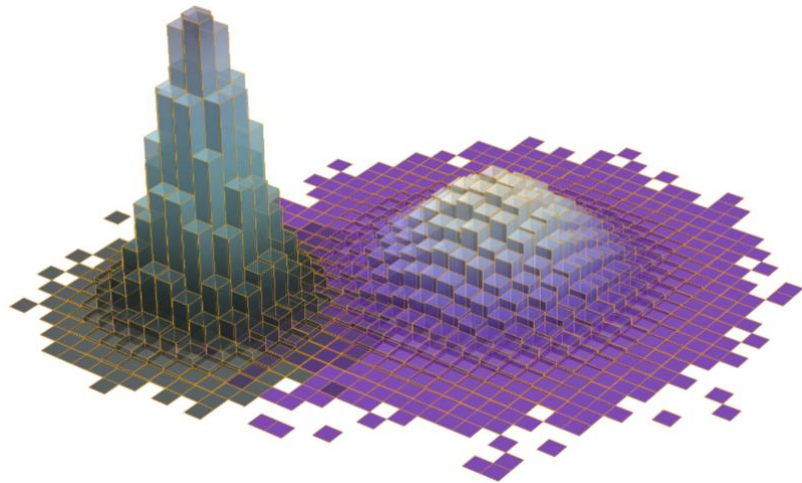
Hannah A. Grunwald^{1,5}, Valentino M. Gantz^{1,5}, Gunnar Poplawski^{2,4,5}, Xiang-Ru S. Xu¹, Ethan Bier^{1,3} & Kimberly L. Cooper^{1,3*}

PROCEEDINGS B

Gene drives in plants: opportunities and challenges for weed control and engineered resilience

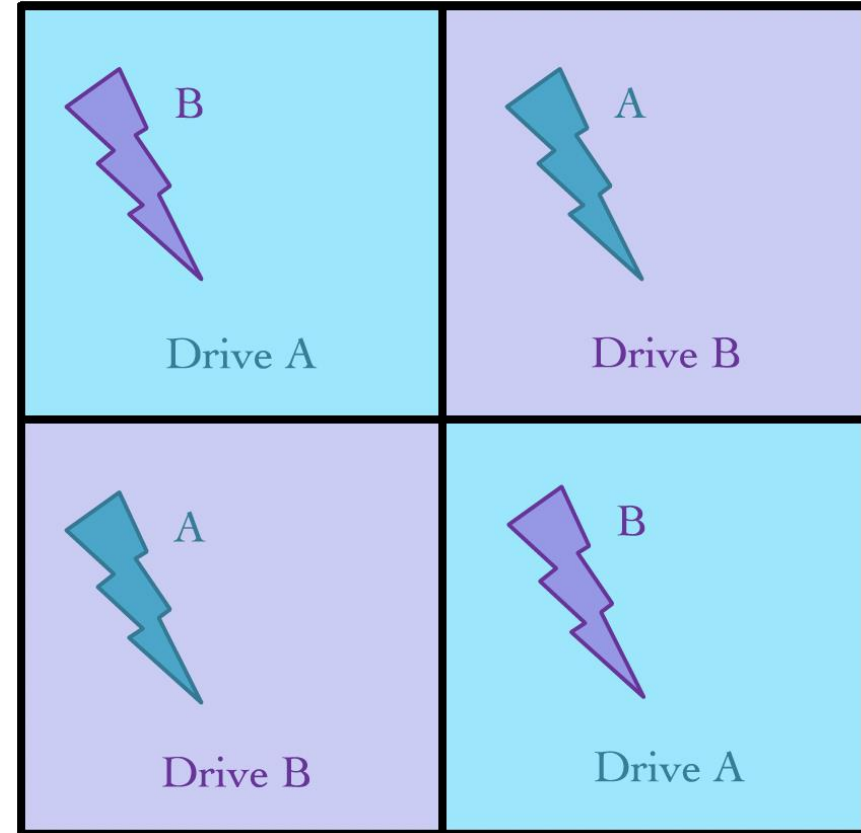
Luke G. Barrett^{1,3}, Mathieu Legros^{1,3}, Nagalingam Kumaran², Donna Glassop¹, S. Raghu² and Donald M. Gardiner¹

Ecology & life history considerations



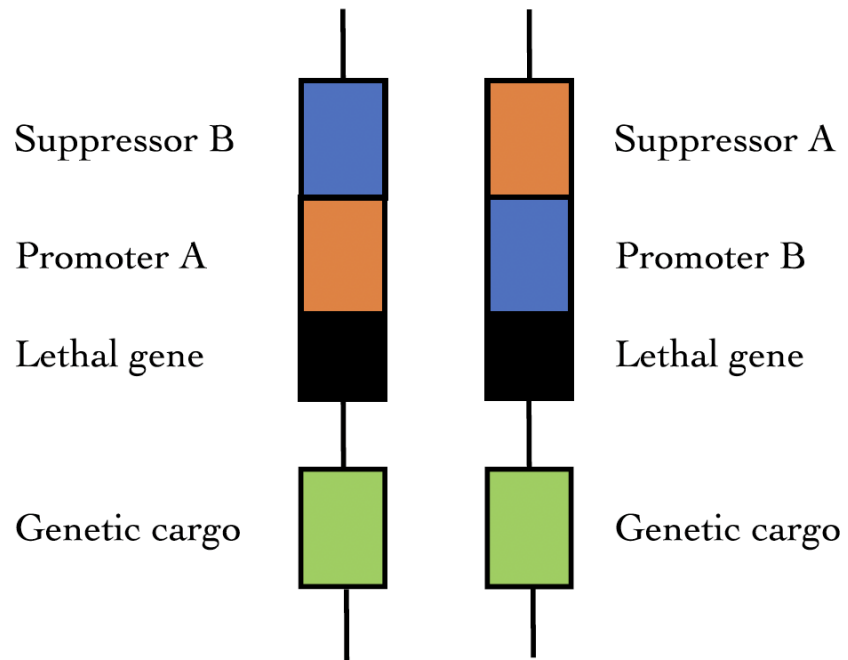
Opportunities

- **Agricultural systems are heavily managed.** This aligns with **genetic control strategies**, which require close management of allele frequencies & population densities.
- This opens up a range of **opportunities** to implement strategies to **promote spread** or **confinement**, & to **recall** systems, via **temporal &/or spatial manipulation of selective pressures**.
- Could help to **reduce reliance on pesticides**.

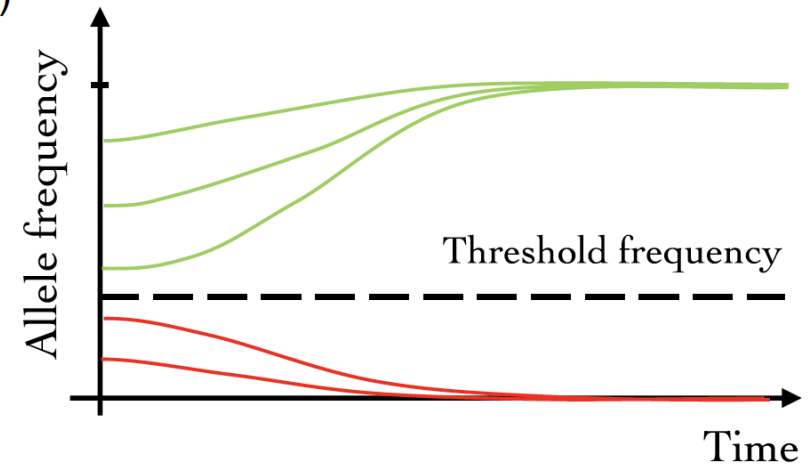


Threshold-dependent systems

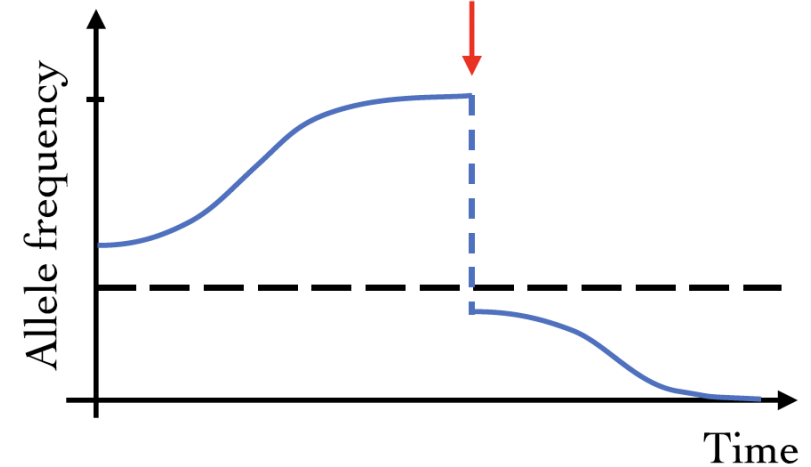
(b)



(c)

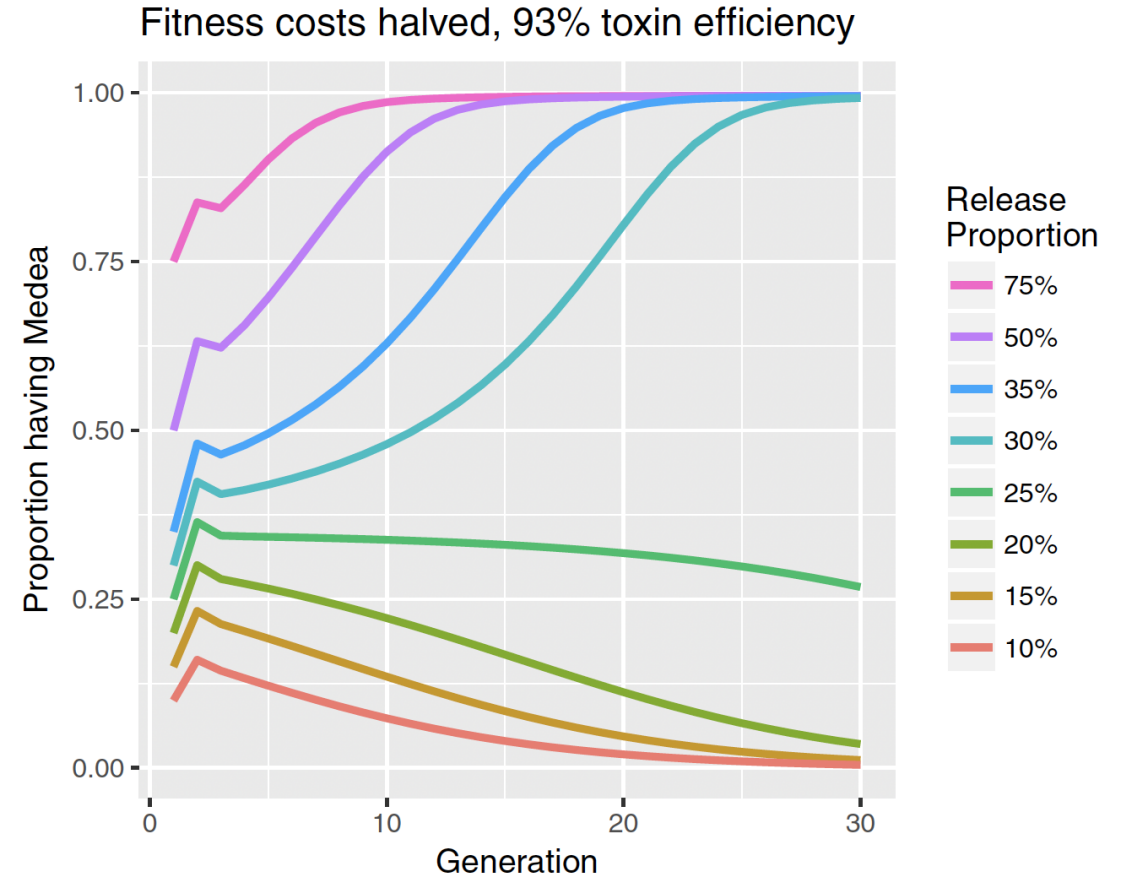
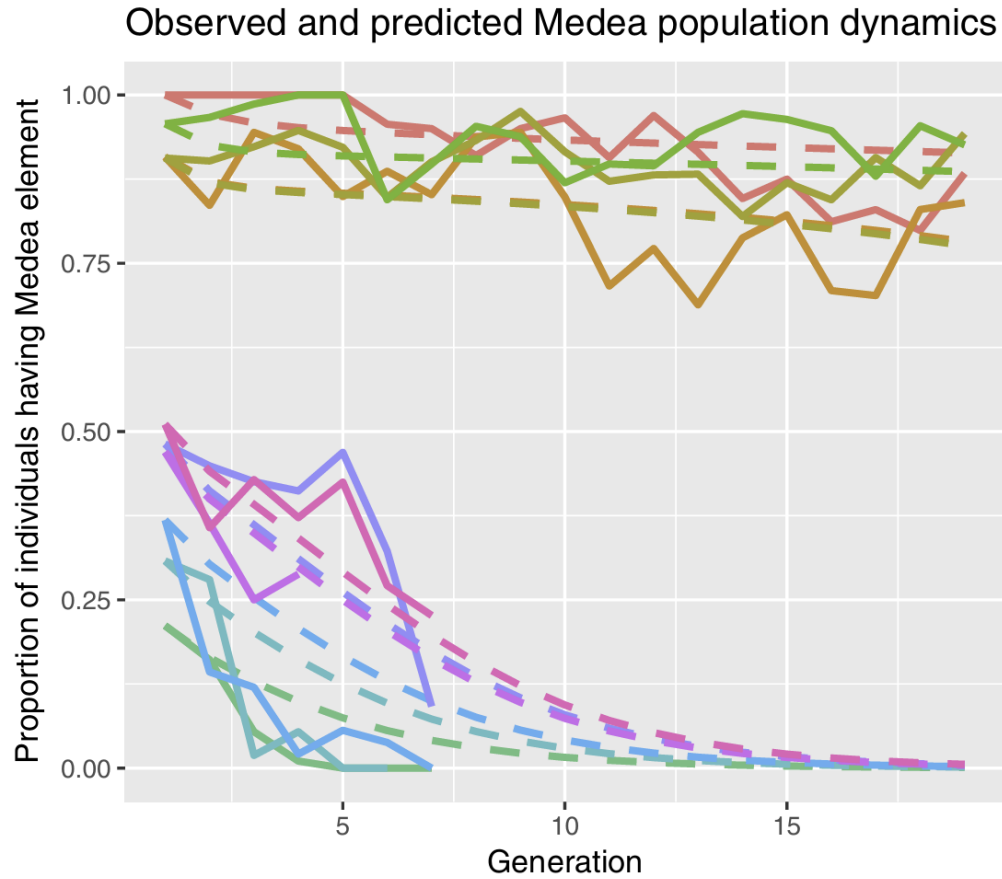


(d)



- Legros M, Marshall JM, Mafayden S, Hayes KR *et al.* (2021) *Evol Appl*

Medea in *Drosophila suzukii*

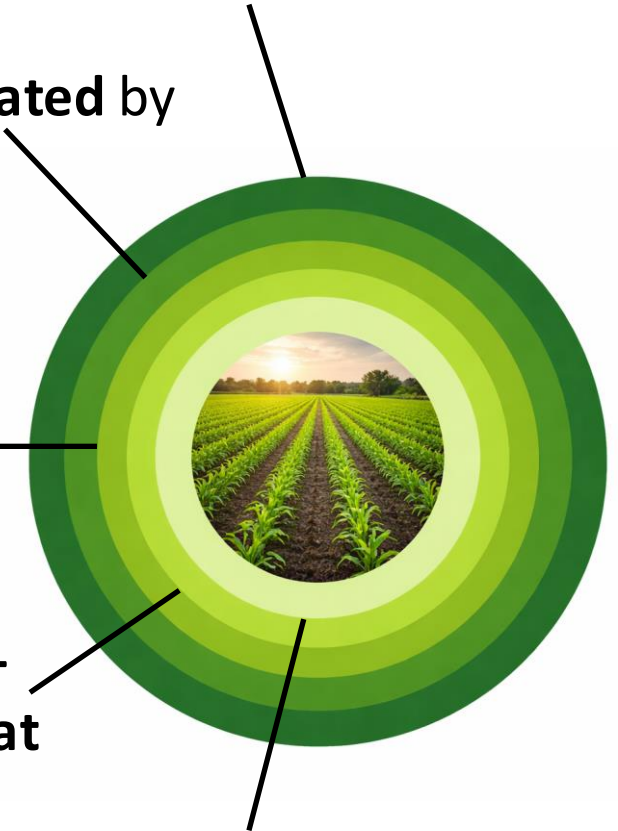


- Buchman A, Marshall JM, Ostrovski D, Yang T, Akbari OS (2018) Proc Natl Acad Sci USA

Risk assessment & confinement

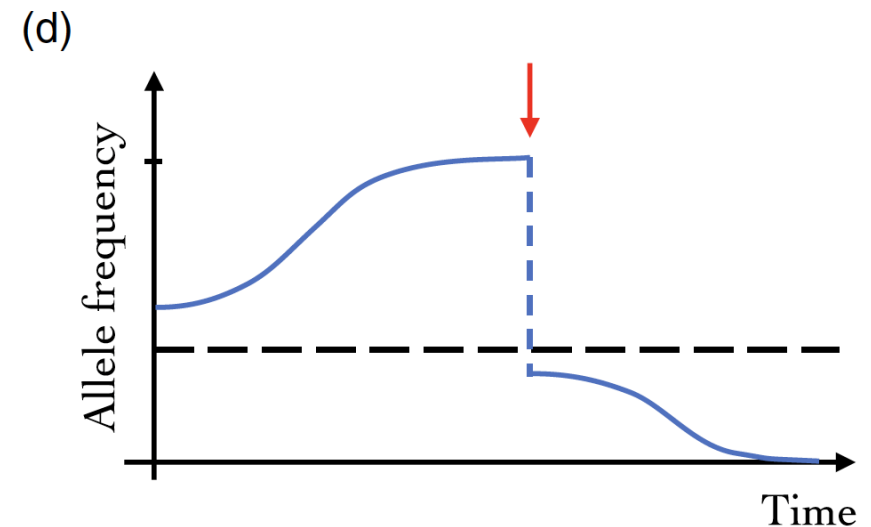
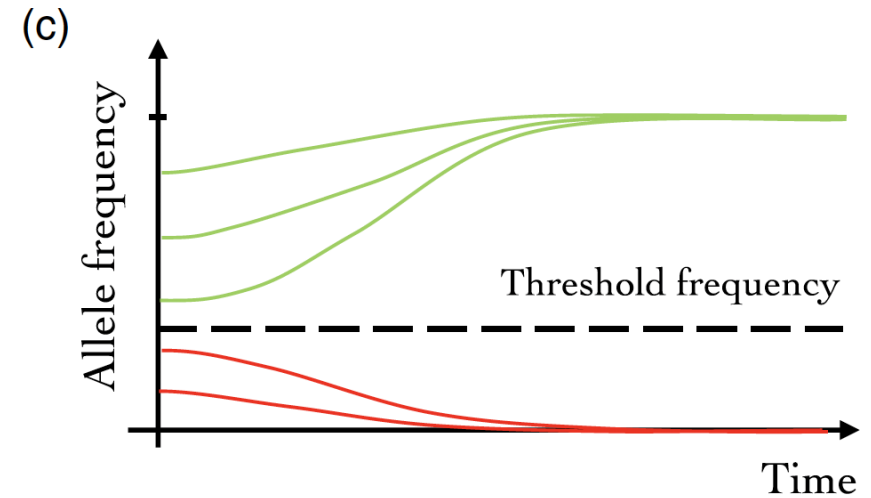
| Topic | Potential environmental risk assessment issues |
|---|---|
| 1. Construct spread and persistence | (a) Change in biocide resistance; (b) Change in fitness; (c) Predicted geographic range; (d) Effects following introgression of transgene in sexually compatible species; (e) Effects following horizontal transfer of transgene to other organisms |
| 2. Human and animal health | (a) Change in pathogenicity or vector competence (target and nontarget pathogens); (b) Toxicity and allergenicity; (c) Epidemiological efficacy; (d) Impacts on pets or livestock |
| 3. Target populations | (a) Failure (or partial failure) to achieve target outcomes; (b) Niche replacement; (c) Adverse effects due to altered genetic diversity of a laboratory reared population; (d) Changes in agricultural or land management practices |
| 4. Nontarget populations | (a) Impacts on threatened or endangered species; (b) Adverse changes to food webs (e.g. through competitive or trophic interactions); (c) Impacts on ecosystem services; (d) Effects on other pests and diseases |
| 5. Stability over evolutionary relevant time frames | (a) Construct stability; (b) Population dynamics over evolutionary relevant time frames; (c) Synergistic genetic interactions and consequences of multiple 'stacked' transgenic modifications |

- 1. Promoters activated by molecule only present at release setting**
- 2. Lethality gene activated by chemical in surrounding areas**
- 3. Genes/promoters only functional in target organism**
- 4. Trial site not contiguous to other habitat**
- 5. Traps/insecticides around field site**

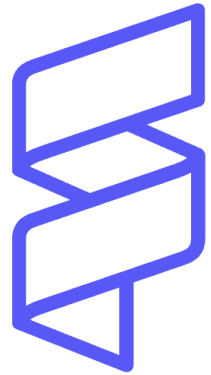


Concluding thoughts

- Need for **innovative, paradigm-breaking solutions** for **pest control & resistance management**.
- **Agricultural systems being heavily managed** presents **opportunities** to promote **spread, confinement & recall**.
- **Threshold-dependent systems** are particularly **well-suited**.
- **Large number of pest species** to target. A **deep understanding** of their **molecular biology & ecology** is required. Early **progress** has been made in **several species**.



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