INSECT RESISTANCE MANAGEMENT FOR GENETICALLY MODIFIED CROPS

ESA Position Statement on Insect Resistance Management for Genetically Modified Crops
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Genetically modified (GM) crops expressing insecticidal substances in their tissues have been grown for over two decades, resulting in higher crop yields, a decrease in insecticide use, and an increase in farm profitability. This benefits farmers, the environment, and society as a whole.[1] However, widespread adoption and season-long expression of insecticidal substances in GM crops can apply strong selection pressure on the herbivorous insect populations that they target. Insect pest populations that develop resistance to GM crops have the potential to greatly diminish the benefits of this technology. Insect resistance management (IRM) programs to delay resistance frequently entail trade-offs between near-term individual and local costs and expected long-term societal benefits. Consequently, their successful implementation requires cooperation among researchers, educators, technology developers, farmers, governments, and other stakeholders. Successful IRM is an important component of integrated pest management (IPM) programs.

Current IRM policies have prevented or delayed pest resistance to many GM crops; however, the threat remains. Over the past 25 years, 19 cases of practical resistance by major pests to GM crops have been documented around the world.[2] Ten of these have occurred in North America where IRM plans are required by regulators. These pests can cost farmers and society billions of dollars in losses every year. Three insect species account for 63 percent of these cases, demonstrating that the hard-to-control pests with histories of resistance problems are usually the ones evolving resistance against GM crops. On average, the first observation of resistance to unique GM traits occurs after six years on average, but in many cases pests have remained susceptible for more than 10 years. Given the variability in outcomes across different systems, additional research into what alters efficacy, adoption, and coordination of IRM and IPM policies are needed. Research into the economic and sociological implications of these policies is needed to ensure that costs and benefits are shared appropriately across society.

RECOMMENDATIONS FOR REDUCING THE THREAT OF PEST RESISTANCE TO GM CROPS

Recognizing the potential for broad societal benefits from insect-protected GM crops, programs and policies that will reduce the development and impact of insect resistance to the crops should include the following:

- Research that furthers our understanding of pest biology, factors that influence GM crop efficacy, and the benefits and costs of insect-resistance management. This includes support for cross-disciplinary research that facilitates greater collaboration between entomologists, social scientists, and economists to overcome the economic and sociological barriers to successful IRM and IPM.

- Understanding that private developers, public institutions, and regulators should (a) cooperate in promoting practical, science-driven IRM practices within IPM programs, (b) coordinate monitoring programs that enable early detection and economically proportionate responses to emerging resistance, and (c) support use of GM crop technology, which considers both near-term grower needs and sustainable pest management.

[1] National Academies of Sciences, Engineering, and Medicine, 2016. *Genetically engineered crops: experiences and prospects*. National Academies Press
[2] Tabashnik, B.E., Y. Carrière. 2019. Global Patterns of Resistance to Bt Crops Highlighting Pink Bollworm in the United States, China, and India, Journal of Economic Entomology 112, 2513–2523

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- Education, incentives, and assistance for growers to implement IRM tactics within IPM programs. These require promoting a communication infrastructure that coordinates common messages about product stewardship and stimulates action toward long-term preservation of growers' livelihoods. This infrastructure should include strong public-university research and extension networks, as well as locally driven engagement with farmers to encourage IRM programs in ways that are relevant for local conditions and culture.

- Predictable and reasonable regulatory requirements and review timelines for new GM crops that possess insect-resistant traits. The regulatory process and decision making should be transparent and enable IRM programs that reduce the risk of resistance and promote sustainable use while also considering other societal demands of agriculture.

BACKGROUND ON IRM IN GM CROPS

Humans have been managing crops for thousands of years, often selecting plants with mechanisms to protect themselves from pests; in turn, pests have evolved resistance mechanisms to overcome those defenses. Agriculturalists and entomologists continuously need to manage crop defenses to counteract the evolution of resistance by insects. Genetically modified crops that possess insect-protection traits have been available to farmers since 1996 and present an opportunity to introduce new plant-defense mechanisms. The first generation of GM crops expressed insecticidal genes from the soil bacterium *Bacillus thuringiensis*, or Bt, which has been the source of a variety of manufactured microbial insecticides for more than 75 years.

A global meta-analysis found that insect-protection traits resulted in 22 percent higher crop yields, a 37 percent decrease in insecticide use, and a 68 percent increase in farm profitability.[3] In addition, GM crops have improved worker safety and enhanced simplicity and flexibility of farm management. However, the eventual development of resistance in target pest populations can occur as a consequence of using any pest control tool. After almost 25 years of commercial use, 19 cases of field-relevant resistance to specific Bt crops across five major pest species have been reported in India, South Africa, South America, and the U.S. [2]. In at least one case, the resistance has remained even after withdrawal of the affected crop. The potential for future widespread insect resistance development is a major threat to the sustained benefits of GM crops. Resistance management programs are therefore essential to extend and preserve these benefits.

Insect resistance management is a science-based set of approaches to long-term pest management to ensure that resistance does not interfere with the ability of all stakeholders to accomplish their goals.[4] When fully implemented over time, IRM programs for these GM crops:

- Maintain incentives for technology developers to continue innovation (they improve return on investment)

- Benefit farmers (they realize cost savings, convenience, yield protection, reduce pesticide handling, and they implement sustainable pest management practices)

- Protect the environment (through reduced- or better-targeted insecticide applications),

- And help consumers (via lower pesticide residues and increased food security).

KEY CONCEPTS FOR SUCCESSFUL IRM

IRM is part of IPM: IPM is the foundation of modern agricultural pest management philosophy. IPM emphasizes the integration of multiple tactics (cultural practices, breeding for host plant defenses, biological control using predators, parasitoids and pathogens, and chemical applications when necessary at economic thresholds) to manage pest populations at levels that are economically and socially acceptable.

[3] Klumper, W. and Qaim, M. 2014. A meta-analysis of the impacts of genetically modified crops. PLoS ONE 9(11): e111629. doi:10.1371/journal.pone.0111629.
[4] Onstad, D. W. 2014. Insect Resistance Management: Biology, Economics and Prediction. 2nd Ed. Academic Press. 538 pp.

Many entomologists consider GM crops as a type of host-plant defense and thus one of the tactical pillars of IPM. Historically, the primary goal of IPM has been efficient management of a crop at the field level over a single season. Incorporating IRM into IPM broadens the program for area-wide, long-term pest management**.**

Like IPM, IRM uses multiple tactics to achieve its goal of slowing development of resistance in pest populations. IRM is based on four approaches: 1) diversification of control tactics, 2) reduction of selection pressure for each control tactic, 3) maintenance of a refuge for development of susceptible pest individuals and immigration to promote mixing with resistant individuals, and 4) evaluation of any development of resistance through the use of monitoring and models.[5] The best solution for a given situation depends on the insect species, the crop, the environment, the farming practices, and the goals of the stakeholders. Ideally, combining multiple IPM tactics, reducing overall pest pressure, preserving beneficial parasitoids and predators, scouting, and applying insecticides at established thresholds reduces the likelihood of resistance developing in GM crops. In practice, reality is more complicated, and additional research and outreach are needed to understand and explain the best set of options.

In many cases, IRM begins with deploying adequate non-insect-protected crop refuge and more than one insecticidal trait active against the same pest (known as pyramiding). Refuges reduce the proportion of the pest population that is under active selection for resistance and, in the case of high-dose products, can greatly delay development of resistance to the GM crop. Pyramids provide control of insects that may carry resistance alleles for one insecticidal component. Any IPM tactic, such as expansion of non-GM host plant resistance, biological control, use of pesticides, pest and resistance monitoring, rotation among GM technologies, and limitation of GM acreage, will contribute to reducing selection for resistance alleles in a population. IPM and IRM add operational and logistical complexities in managing crops and farms because farmers must closely monitor their fields, carefully select and plant crop seeds, and track season-long incidence and management of pests. In addition, the landscape scale of pest populations and resistant insects can create the impression that the actions of an individual farmer are not important as long as the neighbors are following the IPM and IRM recommendations. When the pests infest multiple crops in a landscape and are selected by multiple control tactics, IRM and IPM become even more complicated.

While farmers are likely to recognize the threat that resistance poses to pest management, if delaying resistance becomes too burdensome in the short term due to inconvenience or financial loss or risk, they will be reluctant to adopt IRM techniques. For example, maintaining a refuge of vulnerable plants for susceptible pests is a foundational strategy, but if the pest population causes significant damage to refuge plants, producers are less likely to comply. When adequate funding is available, interdisciplinary research involving economists, social scientists and entomologists can find policies and practices that overcome barriers to implementation and balance the short-term objectives and long-term goals of stakeholders. Essentially, new efforts are needed to encourage the development of cross-disciplinary solutions for sound IRM strategies and management approaches that can reduce the challenges of applying IPM and improve adoption of IRM.

Coordination and Cooperation: Because of the complexities and trade-offs associated with implementing effective IRM programs, research is needed to better characterize the trade-offs and motivations of developers, seed dealers, and farmers as individuals and as part of the agricultural community when implementing IRM tactics.[6] Resistance management strategies are only successful at the landscape level, because this is where most pest populations exchange genes. Effective IRM thus requires cooperation of all producers in a given area. Pests move across agricultural landscapes, and resistance can affect multiple GM crops and insecticidal proteins at the same time. If some farmers practice IRM and others do not, the non-IRM farmers will benefit from the practices of the IRM farmers in the short-term, while the IRM farmers will not receive all of the benefits from their investments in the long-term.

[5] McGaughey, W. H., and Whalon, M. E. (1992). Managing insect resistance to *Bacillus thuringiensis* toxins. Science. 258, 1451-1455.

[6] Carrière, Y., Brown, Z.S., Downes, S.J. et al. Governing evolution: A socioecological comparison of resistance management for insecticidal transgenic Bt crops among four countries. Ambio 49, 1–16 (2020). https://doi.org/10.1007/s13280-019-01167-0

Diverse stakeholder groups—including farmers, crop consultants, grower associations, land-grant university researchers and extension scientists, crop consultants, seed companies, biotechnology companies, landowners, and government agencies—have responsibilities for different aspects of resistance management. This diversity reflects the societal benefits of effective IRM that preserves and promotes the economic, environmental, and food security gains enabled by GM crops.

To properly accomplish IRM, stakeholders must coordinate to recognize their different needs, and they should be encouraged to take responsibility for actions that will optimize economic and environmental benefits over the long term. It is critical that entomologists in the public and private sectors, supported and enabled by economists, sociologists, government regulators and policymakers, and in partnership with technology developers, build community cooperation around IRM strategies that satisfy both short-term and long-term needs.

SUMMARY

Insect pests cause significant losses in agricultural production. GM crops that are protected from insect damage provide billions of dollars of economic benefit to farmers worldwide, reduce farm input and management costs, and ensure a more secure, environmentally sensitive, and profitable food supply. However, insect pests have a propensity to overcome control tactics, including GM crops. Given the importance of GM crops in meeting the demand for agricultural production, we must develop, implement, and support policies in the public and private sectors that maintain their efficacy and durability despite pest adaptability.

IRM programs require understanding multiple dynamics, including pest and crop biology, economics, social acceptance, and farmer behavior. Effective implementation requires coordination among researchers, developers, users, farm advisors, and regulators. Therefore, ESA advocates research that furthers our understanding of pest biology, factors that influence GM crop efficacy, and the benefits and costs of insect-resistance management, as well as public/private programs that build farmer-community cooperation.

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