Agrociencia

RATIONAL MANAGEMENT OF INSECTICIDES IN MONOCULTURE AREAS

Angel **Lagunes-Tejeda**[1], J. Concepción **Rodriguez-Maciel**[1*], Daniel Arturo **Rodríguez-Lagunes**[2], Juan Antonio **Villanueva-Jimenez**[1], Gonzalo **Silva-Aguayo**[3]

[1] Colegio de Postgraduados Campus Montecillo. Carretera Mexico-Texcoco km 36.5, Montecillo, Texcoco, Estado de Mexico, Mexico, C. P. 56264.
[2] Universidad Veracruzana. Facultad de Ciencias Biológicas y Agropecuarias. Peñuela, Amatlán de los Reyes, Veracruz, Mexico. C. P. 94945.
[3] Universidad de Concepción. Facultad de Agronomía. Departamento de Producción Vegetal, Vicente Méndez 595, Casilla 537, Chillán, Chile.
* Author for correspondence: concho@colpos.mx

ABSTRACT

In Mexico, some monocultures occupy large areas, and organo-synthetic insecticides are the dominant method of pest control. The conventional chemical strategy is heavily reliant on new insecticides being developed in other countries. This paper discusses the characteristics of traditional/conventional and rational insecticide management. In traditional management, companies compete to position their products in the market once authorized. When pests develop resistance, the farmer must increase the dose and frequency of applications. These actions seriously threaten the environment, human health, and crop profitability. The hope is that another insecticide will enter the market to repeat the cycle of abuse and its consequences. The alternative is a rational strategy based on scientific evidence for chemical pest control. Farmers must adhere to an insecticide resistance management program that keeps resistance gene expression and intensity at acceptable levels. We propose the creation of public and private laboratories to systematically estimate the dynamics of insecticide resistance through bioassays. This will enable decisions to be made based on scientific rather than commercial information. Changing the current paradigm for the use of these agrochemicals will result in significant improvements in the time it takes to maintain acceptable biological efficacy, economic benefits to the producer, and significant reductions in adverse effects on human health and the environment.

Keywords: insecticide resistance, chemical control, resistance management.

Citation: Lagunes-Tejeda A, Rodríguez-Maciel JC, Rodríguez-Lagunes DA, Villanueva-Jimenez JA, Silva-Aguayo G. 2023. Rational management of insecticides in monoculture areas. **Agrociencia.** doi.org/ 10.47163/ agrociencia.v57i7.2569

Editor in Chief: Dr. Fernando C. Gómez Merino

Received: October 12, 2021.
Approved: June 21, 2023.
Published in Agrociencia: October 10, 2023.

This work is licensed under a Creative Commons Attribution-Non- Commercial 4.0 International license.

INTRODUCTION

Mexico has large areas dedicated to monoculture. According to SIAP (2021), the most important annual monocultures in Mexico are sorghum (*Sorghum* spp.) with 920 168 ha in Tamaulipas; corn (*Zea mays* L.) with 418 568 ha of rainfed crops in the State of Mexico; chili (*Capsicum annuum* L.) with 36 597 ha in Zacatecas; and cotton (*Gossypium hirsutum* L.) with 116 878 ha in Chihuahua. Among the relevant perennial crops, there is avocado (*Persea americana* Mill.) with 174 992 ha in Michoacán; lemon (*Citrus* spp.) with 52 110 ha in Veracruz; and orange (*Citrus aurantium* L.) with 170 380 ha in Veracruz (SIAP, 2021). Although the indicated monoculture areas are not contiguous, plots of the same plant species, whether small or large, share the same ecological characteristics and are subject to greater pest pressure (Skoracka *et al*., 2022).

Pest insects that affect monocultures can come from the same plot, neighboring plots, or distant locations. This will depend on how the pest insects move, whether by their own means, with the help of the wind, through the trade of infested vegetative material, or by phoretic means, among other things. It also influences whether the species is multivoltine, monophagous, oligophagous, or polyphagous (Andow, 1983). Insects that survive the application of commercial insecticides due to the expression of resistance genes exchange genetic information when copulating. The dispersal of these genes is influenced by the ability of individuals to move within the agroecosystem, which has implications for their management (Uesugi *et al*., 2021). Although non-chemical methods such as the use of biological control agents are available, farmers still resort to the use of a wide range of conventional insecticides (Pardo-Melgarejo *et al*., 2022). The use of agrochemicals is preferred due to their ease of use and ability to reduce the density of insect pests in a short period of time.

The use of synthetic agricultural insecticides in Mexico has a history that begins with the arrival of DDT (Jarman and Ballschmiter, 2012). Subsequently, other insecticides began to be used, such as cyclodienes, organophosphates, carbamates, pyrethroids, neonicotinoids, spinosins, avermectins, *Bacillus thuringiensis* Berliner proteins, benzoylureas, and azadirachtin, among others (Lagunes-Tejeda and Villanueva-Jiménez, 1994). Because Mexico does not generate novel molecules of conventional insecticides, these products are imported already formulated or are formulated in the country for distribution and sale. Despite being indispensable in large-scale agricultural production, their irrational use leads to the accelerated development of resistance in insects and pest mites (Whalon *et al*., 2008), as well as contamination of soil, water, and food, and adverse effects on human health (Arellano-Aguilar and Rendón von Osten, 2016).

Insecticides will continue to be used until more effective, cost-effective, and safe alternatives are available. Currently, the strategy for using conventional insecticides in Mexico is to wait for new products to replace those that have lost their acceptable biological efficacy. The question is, what does Mexico propose to manage insecticides rationally and effectively? Do we continue with the traditional or conventional, unsustainable method, or do we adopt a rational system to benefit the farmer, the environment, and human health? This essay aims to conduct a dissertation on the characteristics and disadvantages of traditional management of insecticides and propose a rational management scheme for these agrochemicals to benefit farmers, the environment, and human health.

Traditional or conventional insecticide management

Companies must adhere to NOM-032-SAG/FITO-2014 (DOF, 2015) to perform field biological effectiveness with the target insecticide. This information, along with a series of official requirements, where applicable, leads to the legal registration of the product in question, in which the traditional strategy begins. Biological efficacy studies for registration purposes must be carried out in at least one of the places and under the conditions specified by the Official Mexican Standard. However, companies assign a connotation to this legal process: "When an insecticide obtains its registration, the authorization of use for a certain crop pest is valid for the whole Mexican Republic." This statement is not necessarily true since Mexico has many different agroecosystems that vary in climate, soil, crop variety, and agronomic management. In these complex circumstances, insecticide responses in pest populations can vary considerably.

There are populations of the same pest species whose expression of different resistance mechanisms varies in frequency and intensity from one agricultural area to another (Walsh *et al*., 2022). This is without considering that biotic and abiotic conditions can also modify the biological efficacy of an insecticide (Mweke *et al*., 2019). Consequently, authorized compounds may not be effective throughout Mexico, or label indications may imply the use of overdoses. Considering this fact, CRDC and CottonInfo (2022) indicate that the official authorization of an insecticide in Australia does not imply its recommendation for use throughout the territory. Therefore, within the list of authorized products, it is up to the technician or farmer to decide which one to use based on its local utility. Research centers and universities should lead in generating scientific evidence and advising farmers on the local efficacy of insecticides.

Traditional monoculture management involves each farmer, with technical support or independently, selecting an insecticide from a list of those officially approved for use against a specific pest. This model means that all the authorized compounds are used simultaneously, to varying degrees, throughout a region. In large areas of monocultures, the arbitrary use of all authorized insecticides simultaneously has the negative consequence of developing multiple resistance. Under this scenario, selection pressure leads the target population to develop resistance to all applied products due to gene exchange (Su and Sun, 2014). The microevolution that occurs in each monoculture plot is eventually shared at the macro level and is equivalent to the simultaneous and continuous application of a large mixture of all insecticides. This phenomenon has led to major failures, such as the one in northern Tamaulipas, Mexico, from 1960 to 1974 in the cotton crop.

Traditional insecticide management facilitated the development of multiple resistance in the *Heliothis*/*Helicoverpa zea* (Boddie) codling moth complex, with up to 22 sprays per growing season. Farmers used insecticide mixtures as a last resort, increasing the doses and application frequency, exacerbating the problem. Increased production costs, among other factors, led to the abandonment of 425 000 ha of cotton (Hess-Martínez and González-Hellmund, 1992). As a result, poverty in the region increased as alternative crops such as corn and sorghum offered lower wages per hectare, leading to the loss of sources of employment (Ramírez, 2009).

The limited participation of qualified entomologists also characterizes traditional insecticide management. It is considered that any non-competent person can make recommendations on insecticide use without sanctions. The marketing that companies use in response to farmers' needs is the mainstay of chemical pest control. The recurrent use of ineffective products negatively affects the farmer's economy and significantly harms the environment and human health.

Rational use of insecticides

Rational management recognizes the value of insecticides and acaricides for plant health. However, each application must be carried out in scenarios that allow the maximum benefit at the lowest possible risk. Therefore, their use should consider the correct taxonomic identification of the pest, crop phenology, action threshold, calibration of application equipment, mitigation of adverse effects on beneficial organisms such as pollinators and natural enemies, as well as respecting the safety interval in days between the last application and harvest, among other factors. These actions are necessary because conventional agrochemicals, if misused, can reduce their biological efficacy and harm the environment and human health. It should not be forgotten that the most important elements in food production are the producer, the consumer, and the environment. Plant protection does not depend exclusively on the use of chemical substances, but also on additional methods to keep pest insect densities under control.

The rational strategy of insecticide use is based on the effective implementation of resistance management programs aimed at conserving insecticide susceptibility in target pests; in addition, increasing the useful life of chemical products implies not increasing the dose or frequency of applications. The evolutionary forces operating in a population of pest organisms subjected to insecticide applications must be monitored using a system that tracks the efficiency of authorized products. Periodic inspection of changes in the response of pests to authorized products is supported by the systematic performance of bioassays, which allow characterization of the causes of resistance, whether metabolic or non-metabolic, the dominance of the genes involved (Casida and Durkin, 2013), and stability in the absence of selection (Wang *et al*., 2019).

It is convenient to initiate control activities with insecticides that have less cross-resistance with the other candidates to be used. Switching to another insecticide should be based on determining the stage of development of resistance mechanisms (Bielza, 2005). This information is gathered from individuals drawn from a representative sample of the population under control. Bioassay methods are available in the literature (Lagunes-Tejeda and Vázquez-Navarro, 1994; IRAC, 2021a). Growers in the same region with the same pest will use the strategy devised by experts in the field to mitigate the evolution of resistance at the regional level. The results of the bioassays may be useful for the entire region and will not be ephemeral or limited to the plot where the study is conducted. Such strategies should consider all factors that favor resistance development in the presence of commercial insecticide applications

(Georghiou, 1972) and those that contribute to reversion to susceptibility in the absence of such agrochemicals in the agricultural environment.

The correct use of insecticides implies their official authorization, having demonstrated acceptable biological effectiveness against the problem pest in the required area, presenting the least cross-resistance concerning other authorized insecticides, and being applied in accordance with good practices. This rational model requires that all producers use the same resistance management strategy. For this purpose, there are several alternatives: sequential, rotational, mosaic, and concomitant (Tabashnik, 1989). The first one could be useful for the monoculture producer. This strategy consists of using insecticides from the same mode of action group (IRAC, 2021b) and switching to another group once early alerts of changes in pest insect response to commercial applications are detected. For this strategy to be effective, efficient monitoring of pest response to pest control products must be in place. Otherwise, resistance will progress to the insecticides affected by the selection of heritable traits. Sequential use would result in resistance developing, temporarily, with the same mechanisms throughout the region.

This strategy is not really something new: it has been used in the regional control of mosquito vectors of disease as well as in the campaign against the cattle hornworm *Cochliomya hominivorax* (Coquerel) (Rodríguez-Cruz, 2002). It has also been used in regional control areas (ARCO) defined in the campaign against citrus Huanglongbing and its vector (*Diaphorina citri* Kuwayama) in what is now called the Regulated Citrus Pest Campaign. This campaign's decisions are based on regional studies of effectiveness and insecticide susceptibility (García-Méndez *et al*., 2019). Changes in the population's response to the product used are monitored, and the efficacy of alternative products not being used is evaluated. Such actions increase the probability that the use of substitute insecticides will be effective. The possibility of reusing an insecticide to which the population has developed resistance is not ruled out, provided that resistance has reverted to susceptibility. Knowledge of the natural variation in response to insecticides in susceptible populations provides a reliable reference when comparing bioassays with field populations subject to selection pressure. Information in this regard already exists for some pests that affect crops in Mexico (Lagunes-Tejeda *et al*., 2009).

The strategy proposed by IRAC (2021b), in which insecticides are classified according to their mode of action, can be used as a basis for managing extensive monocultures and refers exclusively to modes of action. That is, non-metabolic resistance only. Furthermore, it does not propose an order of use for the insecticide groups. It is limited to pointing out that changing to another mode of action is necessary without considering metabolic resistance (oxidases, phosphotriesterases, carboxylesterases, glutathione transferases, etc.). In some cases, two or more insecticides with different modes of action behave as a single resistance group because they are affected by the same enzyme (Lima *et al*., 2003; Rodríguez *et al*., 2007).

The rational strategy demands that the use of insecticides in extensive monocultures be based on the decisions of qualified personnel and that these decisions be supported by reliable information on the response of pest insect populations subject to chemical control. Plant health technicians should be organized and in constant communication with each other, using only officially authorized products with proven regional efficacy against problem insects that correspond to the resistance management sequence determined through bioassays. Each monoculture agricultural zone should have official or private laboratories certified to monitor the evolution of insecticide resistance for the crop-pest combination of interest.

CONCLUSIONS

In Mexico, pest control is based on the traditional method, with the main, and often only, requirement being that insecticides and acaricides are appropriately registered. Marketing plays a dominant role in decision-making, creating an approach that has led to plant health becoming addicted to chemical substances. Consequently, the adverse environmental and human health effects have been evident. Farmers are also harmed as production costs rise, forcing them to abandon profitable crops. As an alternative, a rational strategy based on scientific evidence is proposed as an input for decision-making.

To change the current paradigm, the participation of trained technicians and the creation of laboratories that systematically report on the status of insecticide resistance throughout the monoculture zones are required. These actions increase the likelihood that only insecticides with acceptable biological efficacy in the field will be used. Avoiding confronting resistant pests has economic advantages for the grower and significantly reduces adverse risks to both human health and the environment. However, changing the traditional paradigm to a rational one involves the active and harmonious participation of farmers, regulators, technical advisors, and scientists.

REFERENCES

Andow D. 1983. The extend of monoculture and its effects on insect pest populations with particular reference to wheat and cotton. Agriculture Ecosystems and Environment 9 (1): 25–35. https://doi.org/10.1016/0167-8809(83)90003-8

Arellano-Aguilar O, Rendón von Osten J. 2016. La huella de los plaguicidas en México. Greenpeace México: Ciudad de México, México. 21 p. https://www.greenpeace.org/static/planet4-mexico-stateless/2018/11/30b49459-30b49459-plaguicidas_en_agua_ok_em.pdf (Retrieved: September 2021).

Bielza PL. 2005. La resistencia a insecticidas: de los mecanismos a las estrategias de manejo. Phytoma 173. https://www.phytoma.com/la-revista/phytohemeroteca/173-noviembre-2005/la-resistencia-a-insecticidas-de-los-mecanismos-a-las-estrategias-de-manejo (Retrieved: September 2021).

Casida JE, Durkin KA. 2013. Neuroactive insecticides: target, selectivity, resistance, and secondary effects. Annual Review Entomology 58 (1): 99–117. https://doi.org/10.1146/annurev-ento-120811-153645

CRDC, CottonInfo. 2022. Insecticide resistance management strategy (IRMS) for 2021-22. *In* Cotton Pest Management Guide 2021-22. Sumitomo Chemical Australia: Sidney, Australia, pp: 56–60. https://www.cottoninfo.com.au/sites/default/files/documents/Cotton%20Pest%20Management%20Guide%202021%20LR-2_0.pdf (Retrieved: May 2022)

DOF (Diario Oficial de la Federación). 2015. Norma Oficial Mexicana NOM-032/SAG/FITO-2014, por la que se establecen los requisitos y especificaciones fitosanitarios para la realización de estudios de efectividad biológica de plaguicidas agrícolas y su dictamen técnico (NOM-032/SAG/FITO-2014). https://www.dof.gob.mx/nota_detalle.php?codigo=5403310&fecha=11/08/2015#gsc.tab=0 (Retrieved: September 2021).

García-Méndez VH, Ortega-Arenas LD, Villanueva-Jiménez JA, Osorio-Acosta F. 2019. Resistencia de *Diaphorina citri* Kuwayama a insecticidas en cinco áreas regionales de control en México. Southwestern Entomologist 44 (4): 947–954. https://doi.org/10.3958/059.044.0415

Georghiou GP. 1972. The evolution of resistance to pesticides. Annual Review of Ecology and Systematics 3 (1): 133–168. https://doi.org/10.1146/annurev.es.03.110172.001025

Hess-Martínez L, González-Hellmund C. 1992. El algodonero en el norte de Tamaulipas. Manual de cultivos del norte de Tamaulipas. Patronato para la Investigación, Fomento y Sanidad Vegetal. Secretaría de Agricultura y Recursos Hidráulicos, Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias, Patronato para la Investigación, Fomento y Sanidad Vegetal: Ciudad de México, México, pp: 71–82.

IRAC (Insecticide Resistance Action Committee). 2021a. Insecticide and acaricide resistance monitoring methods. http://www.irac-online.org/teams/methods (Retrieved: September 2021).IRAC (Insecticide Resistance Action Committee). 2021b. IRAC MoA Classification Scheme. http://www.iraconline.org/teams/mode-of-action (Retrieved: September 2021).

Jarman WM, Ballschmiter K. 2012. From coal to DDT: the history of the development of the pesticide DDT from synthetic dyes till Silent Spring. Endeavour 36 (4): 131–142. https://doi.org/10.1016/j.endeavour.2012.10.003

Lagunes-Tejeda A, Rodríguez-Maciel JC, de Loera-Barocio JC. 2009. Susceptibilidad a insecticidas en poblaciones de artrópodos de México. Agrociencia 43 (2): 173–196.

Lagunes-Tejeda A, Vázquez-Navarro M. 1994. El bioensayo en el manejo de insecticidas. Colegio de Postgraduados: Texcoco, México. 159 p.

Lagunes-Tejeda A, Villanueva-Jiménez JA. 1994. Toxicología y manejo de insecticidas. Colegio de Postgraduados: Texcoco, México. 264 p.

Lima JB, da-Cunha MO, Da Silva RC, Galardo AK, Soares S, Braga IA. 2003. Resistance of *Aedes aegypti* to organophosphates in several municipalities in the state of Río de Janeiro and Espírito Santo, Brazil. American Journal of Tropical Medicine and Hygiene 68 (3): 329–33.

Mweke A, Akutse KS, Ulrichs C, Fiaboe KKM, Maniania NK, Ekesi S. 2019. Efficacy of aqueous and oils formulations of a specific *Metarhizium anisopliae* isolate against *Aphis craccivora* Koch, 1854 (Hemiptera: Aphididae) under field conditions. Journal of Applied Entomology 143 (10): 1182–1192. https://doi.org/10.1111/jen.12705

Pardo-Melgarejo S, Rodríguez-Maciel JC, Pineda-Guillermo S, Morales-Hernández F, Lagunes-Tejeda A, Guzmán-Franco AW, Silva Aguayo G. 2022. Susceptibility of a Mexican field-collected wild population of *Diaphorina citri* (Hemiptera: Liviidae) to selected insecticides. Journal of Entomological Science 57 (2): 281–287. https://doi.org/10.18474/JES21-49

Ramírez JC. 2009. Cómo quebraron el sistema ejidal en La Laguna. El Siglo de Torreón. 06 July 2019. https://www.elsiglodetorreon.com.mx/noticia/2019/como-quebraron-el-sistema-ejidal-en-la-laguna.html (Retrieved: August 2021).

Rodríguez MM, Bisset JA, Fernández D. 2007. Levels of insecticide resistance and resistance mechanisms in *Aedes aegypti* (Diptera: Culicidae) from some Latin-American countries. Journal of American Mosquitoes Control Association 23 (4): 420–429. https://doi.org/10.2987/5588.1

Rodríguez-Cruz R. 2002. Estrategias para el control del dengue y del *Aedes aegypti* en las Américas. Revista Cubana de Medicina Tropical 54 (3): 189–201.

SIAP (Servicio de Información Agroalimentaria y Pesquera). 2021. Producción agrícola. https://www.gob.mx/siap/acciones-y-programas/produccion-agricola-33119 (Retrieved: September 2021).

Skoracka A, Laska A, Radwan J, Konczal M, Lewandowski M, Puchalska E, Karpicka-Ignatowska K, Przychodzka A, Raubic J, Kuczyski L. 2022. Effective specialist or jack of all trades? Experimental evolution of a crop pest in fluctuating and stable environments. Evolutionary Applications 15: 1639–1652. https://doi.org/10.1111/eva.13360

Su J, Sun XX. 2014. High level of metaflumizone resistance and multiple insecticide resistance in field populations of *Spodoptera exigua* (Lepidoptera: Noctuidae) in Guangdong Province, China. Crop Protection 61: 58–63. https://doi.org/10.1016/j.cropro.2014.03.013

Tabashnik, BE. 1989. Managing resistance with multiple pesticide tactics: theory, evidence, and recommendations. Journal of Economic Entomology 82 (5): 1263–1269. https://doi.org/10.1093/jee/82.5.1263

Uesugi R, Jouraku A, Sukonthabhirom na Pattalung S, Hinomoto N, Kuwazaki S, Kanamori H, Katayose Y, Sonoda S. 2021. Origin, selection, and spread of diamide insecticide resistance allele in field populations of diamondback moth in east and southeast Asia. Pest Management Science 77 (1): 313–324. https://doi.org/10.1002/ps.6020

Walsh TK, Heckel DG, Wu Y, Downes S, Gordon KHJ, Oakeshott JG. 2022. Determinants of insecticide resistance evolution: comparative analysis among Heliothines. Annual Review of Entomology 67 (1): 387–406. https://doi.org/10.1146/annurev-ento-080421-071655

Wang X, Lou L, Su J. 2019. Prevalence and stability of insecticide resistances in field populations of *Spodoptera litura* (Lepidoptera: Noctuidae) from Huizhou, Guangdong Province, China. Journal of Asia-Pacific Entomology 22 (3): 728–732. https://doi.org/10.1016/j.aspen.2019.05.009

Whalon ME, Mota-Sánchez DM, Hollinworth RM. 2008. Analysis of global pesticide resistance in arthropods. *In* Whalon ME, Mota-Sánchez D, Hollinworth RM. (eds.), Global Pesticide Resistance in Arthropods. CAB International: Cambridge, MA, USA, pp: 5–31.