**Integrated pest management: Novel tools, remaining challenges, and intriguing non-target effects**

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Global human suffering caused by arthropods that transmit diseases and create substantial annual economic losses in agriculture has triggered extensive research in developing efficient pest control tools. Agriculture and public health differ in the desired outcome of arthropod control (keeping pest populations under the Economic Threshold Level (ETL) vs. reducing the number of infectious bites), which limits the transfer of knowledge and practices (1). Regardless of the fundamental differences in control strategies between the two systems, the concept of Integrated Pest Management (IPM) has been recognized as the most sustainable approach (2-6). IPM does not rely on the effectiveness of a single tool but instead promotes the combined use of available methods, including environmental management, physical, biological and chemical control, to monitor pest populations and the development of pesticide resistance.

Despite IPM being considered the gold standard, little progress has been made to implement it on a broad scale, and the control of many agricultural pests and disease vectors still heavily depends on the use of synthetic pesticides. There are several reasons behind the limited compliance with IPM principles, including the labor-intensive, costly, and time-consuming execution of some integrated programs, compared to the conventional use of insecticides and acaricides, which has proven largely successful. Besides, incompatibilities between some pest management approaches need to be carefully considered to avoid a potentially disruptive effect that could decrease rather than increase the level of control (7).

The over-reliance on chemical pesticides has selected for highly insecticide/acaricide-resistant populations, threatening the efficiency of these core pest control tools (2, 8, 9). As resistance is now widespread and human health and environmental concerns are rising, there is a renewed focus on integrated approaches that will make judicious use of chemical pest control. This special issue of Current Opinion in Insect Science is composed of seven reviews that highlight the vibrant and multifaceted research of the last years, focusing on optimizing existing pest control approaches, developing novel tools to control disease vectors, and elucidating how control interventions affect not only the targeted host-arthropod but also its parasites.

***Optimizing pest control strategies***

Pest surveillance and insecticide resistance monitoring are critical components of sustainable and effective pest control strategies, allowing for evidence-based decision making. **Caputo and Manica** discuss in their review the challenges of mosquito surveillance programs and emphasize their importance in guiding mosquito-control operations, as well as in identifying thresholds of action, aiming to prevent the outbreak of diseases and reduce the nuisance caused by mosquitoes. Surveillance is also fundamental in evaluating the effectiveness of control interventions by comparing pre/post-treatment areas or treated vs. untreated areas and acting in an evidence-based way. Authors also present the available surveillance tools, providing a critical discussion about the advantages and disadvantages of the different trapping methods and refer to the potential, but also challenges, of using citizen science as a novel surveillance tool.

Preserving the effectiveness of available pesticides, with diversity in mode-of-action, is crucial. This is because the costs and time needed for the discovery, development, testing, and marketing of novel pesticides are immense. **Van Leeuwen and colleagues** stress the importance of molecular markers for insecticide/acaricide resistance monitoring in crop pests and their role in informing the use of chemical control, which will help sustain the efficiency of available chemistries. Understanding the underlying molecular mechanisms of insecticide/acaricide resistance is a prerequisite for the development of accurate, robust, and sensitive molecular markers. Hypothesis-free approaches using short- and long-read genomic data are promising to generate high-resolution markers for all molecular resistance mechanisms (10).

As a response to concerns about the impact of pesticides on human health and the environment, the portfolio of permitted pesticides in agriculture is changing, and reduced-risk compounds with a higher physiological and ecological selectivity are widely replacing broad-spectrum pesticides. **Duso and colleagues** warn, however, that a number of these "safer chemicals" may diminish the performance of major Biological Control Agents (BCAs), such as Phytoseiid mites (Acari: Mesostigmata: Phytoseiidae), key-predators of plant-feeding spider mites, thrips, and whiteflies. Indeed, modern bioassays are uncovering the sub-lethal effects of long term acaricide exposure and reveal the variability of the response depending on the route of exposure and between species within Phytoseidae (11, 12). The selectivity of pesticides may improve by understanding the genetics underpinning the physiological processes that determine toxicity. Unfortunately, sequencing efforts involving predatory mites lag in comparison with pest herbivores, and genetic mechanisms have been studied for only a limited amount of compounds. Several new approaches are proposed to increase ecological selectivity, including localized applications of pesticides and low dose partial spraying.

***Novel tools to fight vector-borne diseases***

Genetic control tools like SIT (Sterile Insect Technique) and RIDL (Release of Insects carrying a Dominant Lethal) have been used in several cases to suppress the population size of arthropod pests, like the dengue and Zika transmitting mosquito, *Ae. aegypti* (13), as well as species belonging to the Tephritidae family (Insecta: Diptera) that are major agricultural pests (14). However, these genetic control tools cannot be implemented on a large scale as they are logistically challenging, requiring the release of a large number of modified insects over a long period. Advances in biotechnology and genetics, as is the CRISPR/Cas9 technology in major vectors of diseases (15), have opened new avenues for the development of novel, highly efficient and cost-effective genetic control tools. **Nolan and Quinn** review the different types of genetic control developed throughout the years for arthropods, with an emphasis on gene drives and their different flavors. The authors critically discuss the advantages of these powerful tools and their potential to be part of IPM, but also their challenges, as they are not exempt from the development of resistance and critically, ethical and legal concerns need to be overcome for their implementation. Whether or not to use gene drives is the subject of an ongoing debate.

Another review of this special issue discusses a novel approach in controlling vector-borne diseases. **Paterson and colleagues** discuss the potential use of non-virulent, insect-specific viruses (ISV) to disrupt the transmission of pathogens in mosquitoes. The authors report on several ISVs that have been shown to interfere with the replication of arboviruses. ISVs can also have an indirect effect by boosting the vector's immune responses. Importantly ISVs can persist in the population and be vertically or horizontally transferred, where transfer may occur naturally or be engineered. Thus, there is a great potential for ISVs to be exploited as a biological control tool against arboviral diseases, as has been successfully done with *Wolbachia*, another mosquito endosymbiont (16). However, as authors point out, further studies are needed to understand better the properties of these viruses and their interaction with their natural and non-natural hosts and their microbiome.

***Effect of control interventions on parasites of arthropods***

The potential non-target effects of pest control strategies on host-parasite interactions have been rarely studied in detail. **Minetti, Ingham, and Ranson**, outline the currently available evidence that the selection of insecticide resistance in *Anopheles* mosquitoes and their sub-lethal exposure to insecticides can affect the development of *Plasmodium*, the causative agent of malaria. The putative mechanisms underlying this interaction are presented, and studies implicating the over-expression of major detoxification enzymes and immunity-related genes are critically discussed. As the authors point out, the topic of their review is of clear epidemiological importance, and further studies are needed to understand better the impact of vector control on the disease transmission.

Non-chemical management strategies of the honey bee parasite, *Varroa destructor* have mainly focused on breeding/selecting bees for *Varroa* tolerance, and the identification of genetic markers speeds up and improves breeding for more resilient bees. **Eliash & Mikeyev** point out that genomic signatures of counter-adaptation in the mite genome have not been studied in the *Apis mallifera-Varroa* system. This oversight was caused by a misconception about a minimal genetic variability within *Varroa* mite populations, and hence their limited ability to adapt. However, there is growing evidence that *Varroa* mites are more diverse than previously thought and able to adapt to high selective pressures, exemplified by their rapid evolution in response to pesticide treatments. Notably, in a recent whole-genome study (17), authors discovered that two sister species of *Varroa, V. destructor* and *V. jacobsoni*, had undergone divergent selective trajectories upon speciation, despite their shared bee host.

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