IRAC GUIDANCE: FACTORS INVOLVED WITH LOWER-THAN-EXPECTED INSECTICIDE FIELD PERFORMANCE ARE OFTEN NOT RELATED TO INSECTICIDE RESISTANCE

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Insecticide Resistance Action Committee

Unexpected crop damage by a pest after a foliar application of an insecticide has been made is often firstly assumed to be because of pest resistance, but commonly there are many other factors why insecticide applications can fail to meet expectations. Before associating insecticide resistance as the reason for crop failure, commonly made mistakes regarding application decisions and practices should be excluded. Many of the reasons for control failures can be avoided by reading product labels carefully and by following label instructions fully. This guideline outlines some of the key factors and considerations for foliar applications of insecticides*.

1 Ways to measure success or failure of a spray application

Application success or failure should be properly validated. The most obvious method is counting alive and dead insects and making a mortality rate estimate or to evaluate crop damage. The absence of insects or crop damage can also be an indicator for a successful spray application. However, the presence of crop damage might result from the time before the pest insect population was controlled successfully. Comparing zones of high crop damage with zones of low crop damage can give a more complete picture. Guidelines for monitoring specific pest insect populations in different crops can be found at local extension services, government agencies or ministries, or on reputable websites. Record keeping of these evaluations should help farmers to become familiar with the exact response of their crops under their local conditions, including the efficacy of the products applied and any other visible responses.

2 Technical reasons for application failures

2.1 Spray coverage

Inadequate or uneven spray coverage is one of the major causes for control failures. Uneven spray coverage might be simply caused by gaps left in the field during spray application, or by insufficient spray penetration into dense crop canopy, not reaching the target pest. Sprays might not have been applied at the recommended label rate. Applicators might have reduced the water volume below that recommended on the label, to save water or reduce the number of stops to refill the tank of the spray equipment, or simply ignored the proper spray nozzle height above the crop canopy. Product-specific application recommendations on the label may have been ignored that might impact product performance, e.g., avoid mixing with high or low pH tank mix partners and in the case of tank mixtures assuring proper mixing of product formulations in the correct order. Local guidance on conditions suitable for spray application must be followed, as high temperature and wind conditions can have a negative impact on spray coverage. Under such conditions, spray droplets can evaporate or be subject to drift, reducing the intended spray deposit on the crop.

*Note: This paper focuses on foliar applications, however other factors may be considered for soil and seed-applied applications of insecticides

2.2 Equipment failures

Some of the most common reasons for poor product performance are application errors involving technical problems with spray equipment. For example, sprayer nozzles might have become blocked or were not properly calibrated, thereby not delivering the expected amount of insecticide formulation according to label instructions. It is also important to ensure the spray application is of the right quality (droplet size and pressure) to target pest stages that may be hiding in certain plant structures. Spray equipment should be checked regularly before and after spray applications. Detailed instructions for maintaining spray equipment can be found in many locations, on manufacturers websites. One example is provided here: https://www.croplife.org.au/wp-content/uploads/2019/10/CL_SBG_WCAG-1.pdf

2.3 Product quality

A successful insecticide application depends upon the correct dose of active ingredient being applied according to label recommendations. To assure correct dose application rates, products must be within their expiry date, and spray formulations should be prepared shortly before application. Hardness or organic matter content of water used for diluting spray formulations might also impact insecticide performance. Applicators should avoid buying products of uncertain quality and origin. Though often less expensive, purchasing counterfeit products must be avoided (https://croplifeeurope.eu/illegal-pesticides/). Poor quality insecticide formulations can also impact the tank mix compatibility of a product. Products are not always compatible with each other, and when mixed, their effectiveness might suffer. It is important to follow manufacturers guidance when preparing tank mixes.

3 Weather

Weather conditions can reduce the effectiveness of insecticide applications in several ways, for example rain shortly after spraying can wash-off spray deposits from the crop. In the case of systemic products, high temperatures and/or winds can rapidly dry the spray deposit before it can penetrate crop tissue. In addition, increased ultraviolet (UV) radiation under strong sun light, can reduce the residual time of some insecticides. These problems can be reduced by good timing of spray applications, taking weather into account, and following manufacturers guidance for a particular product. In the case where negative weather events could not be avoided, label and manufacturers guidance should be consulted and potentially a follow-up spray application should be considered especially under high pest pressure situations.

4 Biological reasons for application failures

4.1 Selecting the wrong insecticide for the purpose

Insecticides are labelled to be effective on certain pests (or life stages of certain pest species – see below), and dose rates can be different for different target insect species. The chance of obtaining good control depends on the correct identification of the target pest and a good understanding of the insect's life cycle and habits. Particularly in the cases of mixed pest species or newly emerging invasive pest species, the correct identification of the pest or pests might be difficult. It is critical to understand whether the insecticide concerned is effective on the target pest present in the field at the time of application.

4.2 Timing insecticide applications correctly according to pest life stage

Different insecticides may be effective on different pest life stages, as mentioned above. This will be clearly stated in the product label. For example, one insecticide may be effective on egg and early larval stages, whereas another may be effective on larval and/or adult stages of the pest. If a product is applied to the incorrect life stage satisfactory control is unlikely. In addition, certain life stages might not be accessible all the time because of their hidden lifestyle within the crop, for example stemborers or fruit feeders. For that reason, appropriate timing of insecticide application is critical to target the most accessible and susceptible life stages in the crop. Pest monitoring, early warning techniques or models can be useful to assist timing. Label instructions should be always checked to assure that sprays are applied at the right time in the life cycle of the target insect pest. Information about specific pest biology is usually available from extension services or on reputable websites in any country, state, or locality. It is also important to consider that some insect pests may need repeated insecticide applications to obtain successful control. Repeated insecticide sprays should be applied following resistance management protocols as promoted by IRAC (Insecticide Resistance Action Committee | IRAC (irac-online.org))

4.3 Intervention and economic thresholds

In many countries and localities around the world, specific guidance exits for intervention or economic thresholds associated with many important insect pests. Local authorities, crop advisors and farmers often try to follow this guidance to decide when to make an insecticide application. Additionally, product labels or associated manufacturer literature often indicate thresholds or recommended timings when a spray intervention will be most effective. The timing of spray applications versus the pest density occurring in the crop is always a critical factor for assessing efficacy and aligning control expectations from an insecticide treatment.

As a matter of general guidance, the control of an insect pest infestation is always easiest and most likely to succeed when it is undertaken before the pest population reaches epidemic proportions.

4.4 Pest migration and reinfestation

For some insect pests, the re-emergence of insects that seemed to be under control after an insecticide application could be caused by migration and a consecutive reinfestation of the crop. Reinfestation is frequently coming from neighboring non-treated crops or weed hosts. Area wide coordination of spray applications and good phytosanitary practice can help to prevent this problem. Another scenario is that the pest might also re-emerge after the application of a broadly active insecticide because natural enemies (i.e., predators and parasites) of the pest are reduced together with their hosts. This is typically termed "pest resurgence". In some cases, the natural enemy populations can take longer to recover than the pest population, therefore a pest population might increase rapidly as the initial or residual control of the insecticide decreases. In such cases it is vital that the pest is monitored in the crop and appropriate methods are applied to control the new pest population. Selection of appropriate insecticide sprays should follow the resistance management protocols promoted by IRAC (Insecticide Resistance Action Committee | IRAC (irac-online.org)).

5 Insecticide Resistance

Once all the factors listed above can be excluded, insecticide resistance becomes a more probable cause for insecticide application failure against a target pest. If a field or farm location also has a history of extensive use of insecticides with a single mode-of-action (MoA), resistance becomes even more likely. The biological characteristics of the target insect pest, such as short generation time, high fecundity, multiple generations per year, multiple crop hosts, all add to that risk.

IRAC recommends concerned growers, farm managers or crop consultants to:

- Consult with local advisors and determine if surrounding growers have similar pest control issues.
- Keep up to date with resistance issues by reading/listening/watching local agricultural news.
- Watch out for resistance alerts from product manufacturers, farmers unions and other organizations.
- Ask local retailers about product limitations and check if the product is still effective against your target pest.

Upon confirmation of cases of resistance, the manufacturer(s) of the insecticide product will report new cases of resistance to the respective authorities, in accordance with regional or national regulations.

5.1 Supplemental scientific information

5.1.1 Understanding relevance of resistance in the field

When starting to research a potential case of resistance in an insect pest to a particular insecticide or mode-of-action (MoA) it is often helpful to search on the internet or to consult scientific literature or databases (e.g. Arthropod Pesticide Resistance Database | Michigan State University). This is certainly worthwhile background information however care must be taken as a particular field failure of an insecticide application is very case-specific. It is helpful here to explain different types of insecticide resistance available in the literature. Many published cases of insecticide resistance refer to "**laboratory-evolved resistance**". Insects that carry genetic mutations that reduce their susceptibility can be produced easily under laboratory conditions for a large variety of insecticides and MoA. However, these resistance mechanisms may not necessarily occur under field conditions, because the genetics, mechanism, and magnitude of resistance are not necessarily the same in the laboratory versus the field. Only "**field-evolved resistance**" is relevant for spray application failures in crop situations. In addition, field-evolved resistance becomes only relevant when it leads to reduced efficacy of a pesticide applied at registered rates and has practical consequences for pest control. It is then called "**practical resistance**" (Tabashnik *et al.*, 2014). This is why IRAC defines resistance as '**a heritable change in the sensitivity of a pest population that is reflected in the repeated failure of a product to achieve the expected level of control when used according to the label recommendation for that pest species**' (See further details in the IRAC basic training module: (https://irac-online.org/documents/insecticide-resistance-training-basic-module/?ext=pdf).

5.1.2 Insecticide Resistance Monitoring and Test Methods

With the aim to detect insecticide resistance early, particularly for products with new MoAs, manufacturers, and other stakeholders, such as governmental institutions or universities carry out sensitivity monitoring programs. Standardized biological methods for sensitivity monitoring are suitable to detect the emergence and spread of local and global insecticide resistance. They allow for comparisons of field evolved resistance across space, time and between different institutions (IRAC Approved Test Methods: https://irac-online.org/test-methods/). Insecticide resistance monitoring programs usually provide a basis to compare the susceptibility of target insect populations against insect sensitivity data, which are collected prior to or at the launch of a new insecticide. Biological methods often detect resistance only when the frequency of resistant alleles is already high, especially if resistance is recessive. Unless associated with synergists, bioassays do not provide information on resistance mechanisms. It should be noted that IRAC test methods cannot normally be employed to predict the onset of insecticide/acaricide resistance nor as operational tools to guide immediate spray decisions.

Molecular assays on the other hand have been developed that can detect recessive resistance alleles earlier. They require specialized equipment and are only available for a limited number of resistance mechanisms. In addition, molecular tools can help to determine resistance mechanisms and may help in choosing the best alternative insecticide, by knowing the cross-resistance patterns associated with some resistance alleles that can metabolize insecticides from different unrelated IRAC classification groups. Of course, this type of approach occurs primarily at an expert level, rather than permitting immediate field-level actions.

Similarly, changes detected from resistance monitoring approaches do not necessarily translate into loss of control of a pest at field-level since practical resistance depends on additional factors, such as landscape ecology, effective integrated resistance management programs (rotation of MoA), and other environmental conditions. Detected changes in sensitivity of a pest to an insecticidal mode-of-action does not imply that it is impossible to control a certain population of target pest in any given locality. Thus, a single report of confirmed resistance to an insecticide does not imply that the insecticide is no longer useful either within the local region or more broadly. For further reading on resistance monitoring please see: https://irac-online.org/training-centre/resistance/monitoring/ .

6 Further Reading

IRAC Training Materials on Insecticide Resistance https://irac-online.org/training-centre/
Arthropod Pesticide Resistance Database, Michigan State University
https://www.pesticideresistance.org/

7 References

Tabashnik, B. E., Mota-Sanchez, D., Whalon, M. E., Hollingworth, R. M., & Carrière, Y. (2014). Defining terms for proactive management of resistance to Bt crops and pesticides. Journal of Economic Entomology, 107(2), 496–507. https://doi.org/10.1603/EC13458