Management of Resistance in Agricultural Insect Pests

M. I. Abdel-Megeed
Faculty of Agriculture, Ain Shams University, 68 Hadayek Shoubra, 11241, Shoubra, Cairo, Egypt.

Abstract

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The evolution of resistance is determined by many factors that influenced the degree of selection pressure through biological, behavioral and operational means. Integrated Pest Management (IPM) proved to be the most effective tool for management of resistance in agricultural pests. Principals, strategies, constraints and challenges for IPM system are considered. Another direction for management of resistance by using chemical strategies are categorized under three principal ways: (1) management by moderation through reduced dosages, application short persistent insecticides, avoidance of slow release formulation, (2) management by saturation i.e. suppression of detoxication mechanisms by synergists, (3) management by multiple attack by using mixtures of chemicals and pesticide rotations.

Introduction

Within the evolutionary insignificant period of 79 years, beginning since Melander's first case of resistance to a pesticide was reported (21), the phenomenon of resistance has significantly proliferated to represent a great problem for pest control program. It is well known that, resistance is not limited, it occurs in many types of organisms. Resistance to one or more pesticides has been reported in at least 447 species of insects and mites, in addition 100 species of plant pathogens, and 48 species of weeds (13). By 1984 at least 17 insect species were resistant to all major classes of insecticides (10). As of 1999, pest resistance to pesticides was estimated to cost U.S.A. agriculture about 1.5 billion $ in increased pesticide costs and decreased yield.

As mentioned by Georghiou and Taylor (11), the evolution of resistance is determined by many factors that influence the degree of selection pressure through biological, behavioral and operational means. Significant advances have been made since Melander's observations in genetics, physiology and biochemistry of resistance but little progress has been achieved for retarding or avoiding its evolution. However, the recent discoveries of new pesticides and the increasing emphasis on integrated pest management (IPM) have raised hopes that some practical approach could achieve satisfactory results in this respect (14). However, development of a new pesticide costs an average of 80 million $, while the typical time before a pest develops resistance is only 10-25 years, there after the pesticide's utility decreases.

Rational pest-control strategies must be designed to manage resistance, both to increase the effectiveness of pesticides and to reduce environmental contamination. These strategies should be based on integrated pest management (IPM) techniques. It is also vital to use chemical strategies to manage resistance of pests to pesticides. Therefore, the present article was directed to clarify this need.

Management of Resistance

General Considerations

Pesticide resistance management is an effort to slow or prevent the development of resistance. There are three goals of resistance management: avoiding resistance where and if possible, delaying resistance as long as possible and making resistance revert to susceptibility (6). Some scientists have come to refer to resistance management as "resistance mitigation" (16). Resistance management is difficult, especially in high value crops like fruit, where high quality standards and limited numbers of registered pesticides to select from make the task challenging.

Although many tactics have been devised to manage resistance, little has been done in actual practice to accomplish this goal. However, in order to manage resistance, one must be able to manipulate or control those factors which contribute to resistance. These factors include the genetic make up of the pest, its reproductive potential, its behavioral and ecological capabilities, as well as the chemical and its method of application.

Resistance management should be aimed at conserving susceptibility by reducing frequencies of resistant alleles, decreasing the dominance of resistance and minimizing fitness of resistant genotypes (20). The most promising tactics for accomplishing this include: (i) Integrated Pest Management; and (2) Chemical Strategies

1. Integrated Pest Management

Integrated Pest Management is defined by FAO as a pest management system that, in the context of the associated environment and the population dynamics of the pest species, utilizes all suitable techniques and methods in as compatible a manner as possible and maintains the pest populations at levels below those causing economically unacceptable damage or loss. IPM is the selection, integration and implementation of pest control based on predicted economic, ecological and sociological consequences (2). In IPM, various combinations of methods are utilized in a compatible manner to obtain the best control with the least disruption of the environment (7).

IPM now offers the opportunity for such reductions in chemical selection pressure by introducing greater reliance on multiple interventions involving natural enemies, insect diseases, cultural practices, host plant resistance and other non-chemical measures.

Proper use of insecticides in pest management system - It is important to determine how insecticides can be used most effectively and harmoniously in pest-management programs. Two major principles will promote this objective:

- Substitute treat when necessary for employed routine treatment.
- Recognize that 100% control of pests is not required to prevent economic loss.

In the pest management era the use of insecticides can be categorized in three ways:

- Carefully timed suppressive applications aimed at a weak point in the insect's life cycle.
- Emergency applications reserved for epidemic situations in which all other control measures are inadequate and the insect populations exceed the economic threshold.

- Preventive treatment with highly selective insecticides (Physiological – behavioral – Ecological selectivity).

Extension of IPM system - The problem of transfer of IPM technology represents the principal bottle–neck limiting progress of IPM world-wide. A knowledge of extension, its role methods is crucial to an IPM manager guiding a program towards its implementation as a fully operational, field based IPM system.

Extension may be provided by a number of different types of organization. It is usually provided by a publicly funded extension service run by ministries of agriculture as in Egypt, but can be complemented by private consultancy services. In general extension involves: (i) The transfer of technology; (ii) Provision of information and advice; (iii) Problem solving; (iv) Education and training; (v) Strengthening the organization base of farmers; (vi) Supplying inputs, credit as technical service

At the core of all extension work are processes of communication. Traditionally this communication was considered one-way process, a top-down approach from the extension service to the farmer. More recently bottom-up approach has been recognized (4). The communication process may take place at a number of levels as individual method (23), group methods (9), mass methods and communication networks (19).

Barriers to IPM progress (Anonymous 1993)
- Information material for training and educating growers is lacking.
- Research activities are limited and lack of qualified personnel.
- Scientific infrastructure is sometimes inadequate.
- Extension services are poorly equipped and understaffed.
- Grower's knowledge of pesticide use and hazards are frequently very poor.
- Existing legislation is insufficient or inadequately enforced. Large scale growers mutually affect small farmers who constitute the greater proportion of the agricultural sector and use primarily home labour and hand tools.
- Information on the expected price of a product is critical to any appropriate computation of cost/benefit.

Challenges for IPM (Dhaliwal and Heinrichs 1998)
General:
- Risk sharing and insurance to encourage farmers to use IPM programs.
- Improvement in communication between farmers and researchers
- Substituting of the prevailing "Top-down" training by "Bottom-up" approach.
- Educational programs in IPM for farmers in urgently needed through establishment of farmers field schools for IPM.
- Establishment of criteria for approval, funding, review and evaluation of extension IPM demonstrations.
- Development of model certification requirements for independent pest management advisors and assistance to certified individuals in establishing IPM consulting firms.
- Investigation of bank procedures for agriculturally related loans to determine whether excessive pesticide treatments are encouraged by conditions specified in the loans.
- A series of measures of good agriculture practice (GAP) is urgently needed to determine optimum dosage, number of applications and maximum interval between application and harvest.

Research
- Measure how differed IPM tactics contribute to long-term crop stability
- Research on the interactions of different pest control tactics
- Evaluate the widely accepted view that, host plant resistance and biological control are naturally complementary.
- Re-evaluate the view that, botanical pesticides are harmless to non-target organisms.

2. Chemical strategies of Resistance Management

Measures for resistance management will be recognized under three principal categories: (1) Management by moderation, (2) management by saturation, and (3) management by multiple attack (Table 1). The terms moderation and saturation in resistance management were introduced by Sutherst and Comins (24) to express the use of contrastingly low or high dosages such that the target population is either induced severe depletion of susceptible genes or is entirely annihilated. The term multiple attack is introduced to signify the application of multidirectional chemical selection pressure.

Table 1. Chemical Strategies of Resistance Management

1. Management by moderation
- Low dosages, sparing a proportion of susceptible genotypes
- Less frequent applications
- Chemicals of short environmental persistence
- Avoidance of slow-release formulations
- Selection directed mainly against adults
- Localized rather than areawide applications
- Certain generations or population segments left untreated
- Preservation of "refugia"
- Higher pest population threshold for insecticide application
2. Management by saturation
- Rendering R gene "functionally" recessive by higher dosage on target
- Suppression of detoxication mechanisms by synergists
3. Management by multiple attack
Mixtures of chemicals
Alternation of chemicals

In this respect, Clark *et al*. (5) stated that, pesticide mixtures, sequences or rotations have a clear role in resistant management strategies. Jian Chu *et al*. (18) also reported that, the effect of rotating and mixing fenvalerate and methyl po against *Plutella xylostella* depended on the fitness value of the resistant genotype and the mode of action of the pesticide mixture. However, Hurley *et al.* (17) developed a high dose refuge management plan to delay European corn borer resistance to new genetically modified corn. For refuge, farmers plant a traditional maize variety that allows susceptible insects to thrive and mate with resistant insects showing the proliferation of resistance. Generally Grafius (15) reviewed techniques for managing pesticide resistance, including high insecticides doses, alteration of insecticides, tank mixes, maximum rate/maximum amount of use, piperonyl butoxide and refugia.

1. Management by moderation

This approach recognizes that susceptible genes are a valuable resource that must be conserved, and it attempts to accomplish this through reduction of the selection pressure. This strategy tries to ensure that susceptible gene are never eliminated from the population. It works best when the susceptible trait is dominant over the resistant one. Management by moderation means limiting use of a pesticide. Moderation in concert with IPM practices such as the use of treatment thresholds, spraying only specific pest generations or growth stages, maintenance of unsprayed wild host reservoirs to act as refuge for genetically susceptible individuals, use of pesticide with shorter residual or lower toxicity … etc. Moderation should be used to the fullest extent that will provide commercially acceptable control.

2. Management by saturation

While management by moderation comes close to meeting environmental standards and is less destructive to biological control, it may not by appearing where high, value crops are involved. The term saturation here indicates the saturation of the defense mechanisms of the insect by dosages that overcome resistance. Management by saturation involve excessive, heavy or frequent use of pesticides that is designed to leave absolutely no survivors. The use of higher pesticides rates to control resistant individuals, is the least attractive resistant management approach. Saturation is generally a last resort, when there are no other effective alternatives. This strategy is most effective when the resistant gene is dominant and the target population is small, isolated, or living in a limited habitat (e.g. greenhouse).

2.1. Rendering Resistant Genes Functionally Recessive

Resistance develops rapidly if R gene is dominent, but is slowed considerably if the R gene is recessive (12). Management by saturation aims at rendering the R gene functionally recessive by applying dosages sufficiently high to be lethal to susceptible as well as heterozygous-resistant individuals. This approach may be applicable only where a high dose of a rapidly decaying pesticide is feasible, as with certain fumigants, or where a compound lacking significant mammalian toxicity, such as a juvenile hormone mimic or bacterial toxin, is available.

2.2. Suppression of Detoxication by Synergists

Synergists act by inhibiting specific detoxication enzymes and thus are capable of reducing or eliminating the selective advantage of individuals possessing such enzymes. The relatively high cost of the synergist, problems with formulations and the risk of reduction of the margin of mammalian safety have mitigated against its use (23). The ability of synergists as a means of inhibiting the evolution of resistance would obviously depend on the absence of an efficient, alternative mechanism of resistance in the target population.

3. Management by Multiple Attack

This group of chemicals aims at achieving control through the action of several independently acting forces such that the selection pressure by one of them would be below that required for development of resistance.

3.1. Insecticide Mixtures

The concept of using mixtures as an anti-resistance measure assumes that the mechanisms for resistance to each chemical group are different and that they exist at such low frequencies that they do not occur together in any single individual within a given population. Thus, insects that survive one of the chemicals in the mixture are killed by another. The components of the mixture must have approximately similar decay rates, or preferably possess short environmental stability. Use of the mixture would not be applicable if the mixture consists of a pair of compounds that display negatively correlated toxicity (3).

3.2. Insecticide Rotations

The concept of rotations of chemicals as an anti-resistance measure assumes that individuals that are resistant to one chemical have substantially lower biotic fitness than susceptible individuals, so that their frequency declines during the intervals between applications of that chemical.

Characteristics of Chemical Strategies for Resistance Management

Saturation	Moderation	Multiple Attack
- High rates	- Low rates	
- Frequent applications	- Infrequent applications	
- Long residual	- Short residual	- Rotate treatments
- Apply before reproductive stage	- Apply after reproductive stage	- Use mixtures
- Eliminate refugia	- Preserve refugia	- Alternate with non chemical

Conclusion

Generalized recommendations for solving resistance problem would be difficult if not impossible to expect in view of the considerable genetic, biological and ecological diversity that exists in natural populations. Resistance delaying tactics are a vital component of integrated pest management. The essence of these tactics would be moderation in the use of pesticides but saturation and multiple attack should also prove useful under certain situations. The concept of use of insecticides in mixtures or rotations may be limited in many instances by economic or practical considerations. However, where control measures are applied on a large scale and are centrally coordinated, these concepts may present distinct advantages as means of delaying or averting the evolution of resistance, especially if supplemented by other integrated control measures.

Optimization of resistance management:

- Discovery of new types of toxophores
- Elucidation of R mechanism
- Estimation of biochemical markers and methods for R monitoring
- Quantification of dynamics of R in populations
- Break throughs in formulation and application technology
- Usage practices, education, voluntary compliance and regulation.

الملخص

عبد المجيد، محمد إبراهيم. 2003. السيطرة على مقاومة الآفات الزراعية لفعل المبيدات. مجلة وقاية النبات العربية. 21: 171–174.

يتم تقدير المقاومة بعدة عوامل تؤثر على مستوى الضغط الانتخابي وهى عوامل وراثية وبيولوجية وسلوكية وتطبيقية. وتعتبر الإدارة المتكاملة إحدى الوسائل الرئيسية المهمة المؤثرة في السيطرة على مقاومة الآفات لفعل المبيدات. وقد أخذ في الاعتبار في هذه المقالة الأساسيات والخطوط الإرشادية واستراتيجيات الإدارة المتكاملة للآفات، كما تمت الإشارة إلى الصعوبات والتحديات التي تواجه تقدم الإدارة المتكاملة للآفات. وهناك اتجاه آخر هام للتغلب على مقاومة الآفات لفعل المبيدات وذلك باستخدام بعض الإستراتيجيات المرتبطة بالتعامل مع المبيدات الكيميائية والتي تنقسم إلى ثلاثة وسائل: الأولى وتختص بإدارة الكيميائيات بالاعتدال من خلال استخدام جرعات منخفضة– استخدام مبيدات كيميائية ذات فترة ثبات قصيرة– خفض عدة مرات المعاملة– تجنب استخدام المستحضرات بطيئة الانطلاق إضافة إلى المعاملة الموضعية. وتختص الثانية بالإدارة عن طريق التشبع باستخدام المنشطات التي تعمل على إبطال مفعول نظم الهدم وفقد السمية. كما تختص الثالثة بالإدارة عن طريق الهجوم المتعدد أو المتضاعف من خلال استخدام مخاليط المبيدات وكذا استخدام المبيدات في دورات.

عنوان المراسلة: محمد إبراهيم عبد المجيد، قسم وقاية النبات، كلية الزراعة، جامعة عين شمس، 68 حدائق شبرا، الرمز البريدي 11241، القاهرة، مصر، البريد الإلكتروني: dimamt@yahoo.com

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