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Usage of Biorational Pesticides with Novel Modes of Action, Mechanism and Application in Crop Protection

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Abstract

This paper analyses and focuses on new classes of biorational insecticides to examine the specificity to harmful pests, selectivity to beneficial insects and their suitability to fit well into integrated pest management (IPM) programs. There is a great effort to reduce the risk of human exposure to pesticides and special demand for safer and more selective insecticides for natural enemies and non-target organisms. Of these efforts and demands, biorational pesticides are insecticides derived from natural materials such as animals, plants, bacteria and certain minerals, and are subjected to registration regulations. The recognized categories of biorational pesticides may be synthetic or natural compounds of microbial, plant protectant and biochemical (pheromones, hormones, natural growth regulators and enzymes) origins. Most biorational pesticides are nerve poisons acting at specific target sites in the insect's nervous system. Some insecticides act similarly to the old nerve poisons that result knock-down, rapid intoxication, lack of coordination, paralysis and death, and have higher affinity to insect receptors than to mammalian. The other insecticides affect specific systems, such as the molting processes, metamorphosis and the insect endocrinology system. Biorational pesticides are third-generation pesticides that are environmentally sound and closely resemble or are identical to chemicals produced in nature. The examples of biorational pesticides are the microbial pesticide *Bacillus thuringiensis* (Kurstaki), neonicotinoids, avermectins, phenlpyrazoles, spinosyns, pyrroles, oxadiazines and various groups of insect growth regulators including methoprene that is a synthetic chemical. Most of the biorational insecticides show effectiveness against different strains of resistant species, with no evidence of cross-resistance; hence these can play an important role in integrated resistance management (IRM) strategies. Most of the newer biorational insecticides are preferable to the conventional insecticides because of their specificity to target pests, effectiveness at low rates, selectivity to beneficial insects and their non-persistent characteristics in the environment. However, insect control using integrated pest management means by use of several techniques to reduce the favorable environmental factors that promote to the pests and their ability to thrive are ideal options.

Keywords

Biorational Insecticide, Reduced Risk Insecticide, Low Risk Insecticide, Newer Insecticide

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1. Introduction

For preventing proliferation of insect's fatalities on plants and to improve quality of environment and public health, pests control is essential. But the insect control operation through application of synthetic insecticides has not been very successful due to certain human, technical, operational, ecological and economic factors. Customarily, the landscape insect pest administrators daily view the pest management situations through the eyes of control or eradication option. Ideally, the best strategy would be to identify and remove only the pest, causing minimal disruption to the agro system

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(Sarwar et al., 2012; Sarwar, 2013; 2014). Pesticides vary in their toxicity and in their potential to cause undesirable ecological impacts. Until recently, insect pest administrators do not have the necessary tools to achieve this goal, but within the last decade or even within the last few years, many new and exciting products have been emerged or have greatly improved in efficacy (Sarwar, 2015 a; 2015 b; 2015 c). Pest control materials that are relatively non-toxic with only few ecological side-effects are sometimes called 'bio-rational' pesticides, although there is no official definition of this term. Some of biorationals, but not all, qualify for use on organic farms. The major categories of bio-rational pesticides include botanicals, microbials, minerals and synthetic materials. Some of the more commonly used and effective bio-rational pesticides are insect and mite growth regulators, *Bacillus thuringiensis* (Kurstaki), horticultural oils, insecticidal soaps, entomopathogenic nematodes and neem products. The advantage to using biological products is that these are less likely to negatively impact non-target organisms, including peoples (Lacey et al., 2001).

There are several meanings of biorational pesticides in current use, but the general description includes any pesticide of natural origin that has limited or no adverse effects on beneficial organisms or other components of the environment. This description lacks precision; it would exclude synthetic materials such as methoprene, and would have to acknowledge that pests which are a component of the environment. Generally, biorational pesticides are defined as pesticides derived from natural materials as animals, plants, bacteria and certain minerals. The biorational pesticides are placed into the categories of microbial pesticides, plant incorporated protectants and biochemical pesticides. It is important to note that the problem is recognized with the specific definition for biorational pesticides, and a committee is needed to appoint to deal with the issue. Also, these would regard synthetic materials such as methoprene that is a biorational pesticide because it acts in the same manner as a naturally occurring hormone of insects. Biorational pesticides are subjected to the registration, sales, transport, use, storage, and disposal provisions, while classical biological controls including parasites and predators are not subjected to these requirements. Strictly speaking, the use of biorational pesticides is not an alternative to conventional pesticide use; however, they are an alternative to the use of conventional pesticides such as organophosphates, carbamates and pyrethroids (Horowitz et al., 2009).

An active ingredient or formulation of biorational pesticides that effectively controls pests is derived from biological or has natural origins. According to Hara (2000), biorational or 'reduced risk' insecticides are synthetic or natural compounds that effectively control insect pests, but have low toxicity to non-target organisms such as humans, animals, natural enemies and the environment. Consequently, new types of insecticides have been developed by the agrochemical companies. Although these are mostly synthetic, yet they are more selective than conventional insecticides, hence safer and fit well into integrated pest management (IPM) programs (Casida and Quistad, 1998).

2. Use of Biorational Insecticides

Biorational insecticides give better control than conventional insecticides, not usually better sometimes equal; have broader spectrum of activity, usually a narrower spectrum of activity; are cheaper, usually more expensive; less toxic to workers or consumers; usually true to type, safer for the environment and for beneficial insects; and required for certified organic production surroundings. Biorational insecticides may be applied shortly before harvest without leaving excessive residues, are less persistence in environment and have reduced risks to non-target organisms. These act very quickly to stop feeding by pest insects, they may not cause death for hours or days, but they often cause immediate paralysis or cessation of pests feeding. Most biorational insecticides may have low to moderate mammalian toxicity. In the field, their rapid degradation and action as stomach poisons make them more selective in some instances for plant-feeding pest insects and less harmful to beneficial insects. Many biorational are not phytotoxic (toxic to plants), however, it is always best to test a new product on few plants first before applying on a large scale (Rajput et al., 2003; Khan et al., 2010; Ahmad et al., 2011; Sarwar, 2012).

3. Categories of Biorational Pesticides

Biorational pesticides come in many different formulations due to variations in the active ingredient's solubility, ability to control the pest and ease of handling and transport.

3.1. Biochemical Pest Control Agents

Biochemical pest regulator mediators comprise four common naturally well-designed classes that are designated underneath:-

3.1.1. Semiochemicals

These are chemicals released by plants or animals that amend the activities of receptors in organisms of alike or diverse kinds. They comprise pheromones, allomones, and kairomones. Pheromones are elements produced by an individual of one species that change the performances of others inside the identical species. Allomones are substances secreted by one species which alter the behaviour of a dissimilar type to the advantageous of the emitting species. Kairomones are compounds discharged by one species that change the behaviour of a different species to the advantageous of the receptor species.

3.1.2. Hormones

These are biological mediators manufactured in one portion of a creature and translocated to another part where they have controlling, behavioral, or regulating influences.

3.1.3. Natural Plant Regulators

These are compounds created by plants which have poisonous, inhibitory, stimulatory, or other amending influences on the similar or other species of plants. More or less of these chemicals are called plant hormones or phytohormones.

3.1.4. Enzymes

In this respect, enzymes are protein molecules that are the tools for manifestation for gene action and which catalyze biochemical reactions.

3.2. Plant Incorporated Protectants

Phytochemicals are botanicals which are naturally occurring insecticides obtained from floral resources. Bioactive compounds from the plant kingdom are easily biodegradable and have no ill-effects on non-target organisms. Several groups of phytochemicals such as alkaloids, steroids, terpenoids, essential oils and phenolics from different plants have been reported previously for their insecticidal activities (Canyonb et al., 2005).

3.3. Microbial Pest Control Agents

Microbial insecticides are products containing microorganisms or their by-products, which result in insect diseases. These biorational pesticides include (but are not limited to) bacteria, fungi, viruses and protozoans. The guidelines apply to all microbial pest control agents used as pesticides, including not only those that are naturally occurring, but also the improved strains. Pest control organisms such as insect predators, nematodes and microscopic parasites are not considered biorational pesticides, and are exempted from the requirements of these guidelines. Like botanical insecticides, they are of natural origin and have similar advantages and disadvantages. However, unlike botanicals, microbials have no effect on mammals. In fact, any given microbial will kill only a very limited group of insects (White and Johnson, 2010; 2012). The types of microbial insecticides are:-

3.3.1. *Beauveria bassiana*

Strains of this soil fungus attack a wide range of insects. Commercial formulations are labelled for control of many soft bodied sap feeders (e.g., aphids, whiteflies and mealybugs) as well as orthopterans (grasshoppers, locusts and mormon crickets).

3.3.2. *Bacillus thuringiensis* (B. t.)

This is probably the most common microbial ‘active ingredient’. This organism is incorporated into several products, most of which are used to control caterpillar pests. Specific strains of *B. t.* have been selected for their ability to control mosquitos, black flies and other organisms. For example *B. t.* strains ‘kurstaki’, ‘berliner’ and ‘aizawai’ are used for controlling larvae of many lepidoptera pests, while *B. t.* ‘tenebrionis’ is used against larvae of Colorado potato beetle, and *B. t.* ‘israelensis’ is used to control mosquito larvae. Be sure that the product chosen is labelled to control the pest the growers are targeting. Additionally, while some crops have been modified to express the insecticidal protein produced by *B. thuringiensis* these genetically altered plants are not considered in this publication.

3.3.3. *Bacillus popilliae* or *B. lentimorbus*

These microbes too, are formulated into several different products and they are used to control the larval stage (white grub) of Japanese beetle.

3.3.4. *Nosema locustae*

This microscopic protozoan is used in several products to control grasshoppers.

Because of the very selective nature of microbial insecticides, users must know what pest they have and read the label of the selected products to ensure a proper selection. In addition to using commercial products, it is often possible to collect diseased insects in the field. By grinding and spreading this ‘disease’, anyone may be able to produce his own insecticide.

4. Mode of Action of Biorational Pesticides

These compounds have achieved several currently desired goals of pest managers and the greater public demands. These are very selective, targeting just the pest, usually do not persist in the environment, much safer to handle and apply when compared to most chemical pesticides, and tend to preserve beneficial organisms. The most of the biorational insecticides have diverse modes of action, show effectiveness against different strains of resistant species, with no evidence of cross-resistance, has assisted in managing resistance to insect pests and they can play an important role in IRM strategies (Denholm et al., 1998). Most biorational pesticides are nerve poisons acting at specific target sites in the insect's nervous system. Some insecticides act similarly to the old nerve poisons that result knocking-down, rapid intoxication, lack of coordination, paralysis and death, and have higher affinity to insect receptors than to mammalian. The other insecticides affect specific systems, such as the molting processes, metamorphosis and the insect endocrinology system. All the biorational or low risk insecticides have relatively low detrimental effect on the environment and its inhabitants, and have little or no adverse consequence for non-target organisms, thus rendering them among important components in IPM program (Horowitz and Isaaca, 2004).

5. Scope of Biorational Pesticides

Efforts have been made to find biorational insecticides with novel modes of action and have no cross-resistance with the old insecticides. Biorational pesticides are a distinct group, inherently different from conventional pesticides. They are comprised of two major categories, the biochemical pest control agents (e.g., pheromones, hormones, natural plant growth regulators and enzymes) and the microbial pest control agents (e.g., microorganisms). Pesticides to be included in these categories must be naturally occurring, or if man synthesizes the chemical, and then it must be structurally identical to a naturally occurring chemical. Minor differences between the stereochemical isomer ratios (found in the naturally occurring compound compared to the synthetic compound) will normally not rule out a chemical being classified as a biorational unless an isomer is found to have significantly different toxicological properties from those of another isomer. Thus, application of active toxic biorational agents as an alternative control strategy results in an urge to look for environment friendly, biodegradable and easily available at affordable prices products for pests control.

6. Regulations of Biorational Pesticides

The philosophy and approach to the regulations of biorational pesticides shall require registrants to obtain clearance from the experts committee prior to the registration of the products. In regulating biorational pesticides, it shall be recognized that these kinds of pesticides are inherently different from conventional pesticides and will take due consideration that many classes of biorational control agents might pose lower potential risks than conventional pesticides. The most important inherent difference between biorational pesticides and conventional pesticides are target species specificity, generally non-toxic mode of action and natural occurrence of the biorational agents. These factors provide the basis for the expectation that many classes of biorational pest control agents pose a lower potential hazard than conventional pesticides and support the approach to testing needed for the registration of manufacturing product. Thus, the Environmental Protection Act in various states has framed a number of rules and regulations to check the application of chemical control agents in nature (Khanal, 2009).

6.1. Approach to Testing

To meet the intent of the above policy, the succeeding elements comprise the approach taken and factors often associated with biorational pest control agents or their use that significantly limit the agent's potential for human and other non-target organism exposures or hazardous. An application for registration shall contain the information on each ingredient, which is listed in the confidential statement of formula. Each biochemical including microbial toxins, shall be identified by the chemical name, structural formula, empirical formula, potency or other appropriate expression of biological activity or percentage by weight, the genus and species names of the organism from which the biochemical is separated or with which it is commonly associated, specificity or host range of the biochemical activity and mode of action. With respect to mode of action of the biochemical, the applicant should discuss any potential hazard to man, the environment, or non-target species. Other information needed include percentage composition (by weight) of each ingredient, whether the ingredient is an active ingredient, intentionally added or an impurity, the product name, the trade name and the common name, experimental or internal code number, the empirical formula, the molecular weight or the molecular weight range, and structural formula if it can be determined.

6.2. Manufacturing Process

Each product registration application shall be supported by an accurate and current description of the process used to manufacture or formulate the product. The description containing the information on basic manufacturing process for each biochemical derived from biological sources, the starting material, steps taken on both chemical and biological to ensure the integrity of the starting material and to limit the extraneous contamination in the unformulated biochemical shall be given due consideration. The procedures by which the manufacturer established the identity and purity of the seed stock from which the unformulated biochemical is produced shall be described, and the quality control methods and the techniques used to ensure a uniform or standardized product shall be reported. Information concerning analytical methods to verify certified limits is required to support the registration of each manufacturing use and end use product. There must be assurance, however, that the methods used and the data submitted are capable of demonstrating that the biorational pesticide used in the field is the same as that is submitted for registration. Each application for registration of a microbial pest control agent shall contain the product name and trade name if different, and the company code number may be given.

6.3. Information on Ingredients

Information on ingredients is required for the identification of bacteria, protozoa, viruses, or fungi in the product. This can comprise taxonomic position, serotype and strain, or any other appropriate designation. The precise test procedures and criteria used for identification i.e., the morphological, biochemical, analytical, physical, chemical, serological, or other identification means and the results of such tests should be provided. Further information needed is the natural occurrence of the organism, its relationship to other species (particularly those that are pathogenic), its history and a description of any unusual morphological, biochemical, or resistance characteristics of the organism if such characteristics are different from the classic description of the organism.

6.4. Toxicology Concerns

Biorational pesticides affect pest populations by controlling physiological processes, altering behavior, competing for space and nutrients, parasitizing and paralyzing the pest, or by replicating in an ineffective process to cause disease so that the pest is destroyed. The testing for registration of the product and the kinds of data developed must be sufficient to allow scientific experts to assess the potential hazards associated with the use of biorational pesticides. The major concerns with respect to toxicology are infectivity that is the potential for the microorganism to survive and replicate in a human host. Related concerns include persistence, invasiveness, colonization and other host-parasite interactions. Virulence-toxicity is the potential for direct injury at the cellular, tissue, or organ level. Other concerns included are the long-term effects associated with oncogenicity, carcinogenicity and teratogenicity. Hypersensitivity is an immune response leading to an abnormal sensitivity. Serious reactions include allergies and anaphylaxis. These concerns must be addressed in terms of the potential impact of these agents on the population as a whole particularly on those persons with altered defenses who might encounter these agents, and who represent a sub-population at higher risk. At present, viruses are of particular concern because they generally exhibit a greater incidence of genetic change than other living forms. Because this field is new, many problems related to toxicology and hazard evaluation would undoubtedly be encountered. It is recognized that for some biorational pesticides, there are no well-recognized and standard test methods for assessing the toxicological hazards to mammals. When problems arise, the registrant is urged to discuss the matter, so that alternative methods and protocols can be considered prior to the actual conduct of the tests.

Testing of biochemical agents for possible effects on humans and domestic animals is performed in a tier sequence. The potential for adverse effects can be ascertained by acute toxicity, irritation and hypersensitivity tests, short-term mutagenicity tests and by cellular immune response studies. When detrimental effects are found in the first tier of tests, additional studies at the tier II and III levels shall be required. The testing of microbial agents for possible effects on humans and domestic animals is also performed in a tier sequence. These tests consist of acute toxicity/ infectivity studies, cellular immune response studies, irritation, hypersensitivity, virulence enhancement, tissue culture, teratogenicity, mutagenicity, sub-chronic and chronic studies. Not all studies taken pertain to each organism at each tier.

6.5. Residue Analysis

The full set of residue chemistry guidelines for conventional pesticides may not always be applicable to biochemical pest control agents for the reason that biochemical agents occur naturally in the environment or are identical to naturally occurring biochemicals and have properties similar to their natural counterparts. Many biochemical agents are used at very low application rates (i.e., < 50 g active ingredient or less per hectare) and past experience indicates that biochemicals are relatively non-toxic. Consequently, the resulting residues of biochemicals in food or feed would be very low and the potential for adverse effects would be correspondingly low. Thus, it is expected that significant human dietary exposure will generally not occur from the use of biochemicals.

As with a biochemical agent, the use of a microbial agent on food, feed, or raw agricultural commodities requires that a tolerance, or an exemption from the requirement for a tolerance, be established. Certain environmental conditions such as high sunlight intensity, heavy rainfall, strong wind, low humidity and high temperature often greatly reduce the viability of the agent, and therefore, the residues of living organisms are apt to be small or relatively insignificant shortly after application. The purpose of non-target organism testing is to generate data necessary to assess potential hazard of biorational pesticides to terrestrial wildlife, aquatic animals, plants and beneficial insects.

6.6. Environmental Fate and Expression

The term environmental fate pertains to biochemical pest control agents, whereas, the term environmental expression pertains to microbial pest control agents. The purpose of environmental fate testing is to generate the data necessary to estimate the concentration of a biochemical pesticide and its degradates occurring in or on various media (i.e., soil, water, air) at intervals after pesticide application. Generally, these data would be submitted if adverse effects are observed in tier I environmental effect tests or if the biochemical is applied directly to water.

6.7. Product Performance Data Requirements

Efficacy data generally will be required only for products intended to control microorganisms infectious to man in any area (inanimate surface) where these microorganisms may present a health hazard, and uses of agents intended for control of fungal organisms that produce aflatoxins. Data on phytotoxicity to the target site i.e., crops or other desirable plants are considered a part of an efficacy evaluation and are desired.

6.8. Specific Provisions

The succeeding provisions apply to all biorational pesticides regardless of whether product performance data are or are not waived in accordance with the foregoing policy statement. The available information on host spectrum, the time required for achieving the desirable level of pest control or other product performance standard and the minimum effective dosage necessary to achieve the desirable level of pest control or other product performance shall be reported.

6.9. Product Performance or Efficiency Data

In general, efficacy data shall be required to support the issuance of an experimental use permit, and the extensions, renewals and amendments summaries of product performance data collected under an experimental use permit may be needed on a case-to-case basis for the purpose of making future decisions,

6.10. Product Label Guidelines

Public awareness about the unique qualities inherent in biorational pesticides is an integral element to the successful promotion of these agents for practical use. One of the more obvious vehicles available for reaching to the public is pesticide labelling. While biochemical agents are viewed essentially the same as conventional chemical pesticides with respect to label requirements, the labelling for microbial agents differs principally with respect to the ingredient statement. Also, current labelling guidelines prohibit claims as to the safety of a pesticide or its ingredients, including statements such as safe, non-poisonous, non-injurious, harmless, or non-toxic to humans or pets. This could be amended for biorational pesticides to allow claims as to lack of adverse effect on beneficial agents critical to IPM and crop production systems when supported by appropriate data. The lower degree risk inherent in biorational pesticides shall be discernible through the label signal words and the relative reduction of precautionary statements.

7. Promoting of Biorational Pesticides

Consistent with the mandate to protect public health and the environment, it is currently pursuing and promoting the development and use of biological and biologically derived control agents. It has been recognized that biorational pesticides are inherently different from conventional pesticides and that the fundamentally different modes of action of biorationals and the consequent lower risks of adverse effects from their use must be taken into account. Embracing this policy, the guidelines sought to reduce the burden of extensive data generation by the introduction of the tier testing concept. This departure from standard procedures is intended to function as a catalyst for development of additional innovative control agents consistent with the promotion of Integrated Pest Management (IPM) and the safe and effective use of chemical, biological and alternative methods to combat and control pests (Zalom et al., 2001; Workman et al., 2002).

8. Conclusion

As with any pesticide, it is important to choose an insecticide that fits the situation in which it is used. These products vary in their toxicity to nontarget organisms such as fishes, bees and natural enemies as well as their effectiveness at controlling specific insect pests. If used improperly, insecticides can harm peoples and the environment, so do not make the mistake of choosing that products. There have been efforts to develop biorational insecticides with selective properties to act on biochemical sites present only in the target arthropods and not in non-target organisms. The newer insecticides are not immune to evolution of resistance in the insect pests, and since their registration, several cases of resistance to those insecticides have been reported, but the development of diverse modes of action has assisted in managing resistance to insect pests. As most of the biorational insecticides have shown effectiveness against different strains of resistant insect species, with no evidence of cross-resistance, they can play an important role in IRM strategies. Biorational insecticides are promising alternatives for use in insect management tactics. However, each compound must be evaluated in terms of toxicity, effectiveness, environmental impacts and costs. Before using these biologicals, anyone might consult to Extension agent of local vicinity for information concerning technical and legal uses.

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