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PERSPECTIVES ON THE USE OF BIOPESTICIDES IN PEST CONTROL

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ABSTRACT
Protecting against pest infestation is a necessity for plants' subsistence. In an effort to prevail,plants developed defense systems with various complexities. Comparatively favored systems were used for plants whose defensive systems were not as complex. The "biopesticide" refers to a product which contains active ingredients such as,, microorganisms, botanicals, and semiochemicals. The main allelochemicals used as biopesticides are alkaloids, rotenone and rotenoids, pyrethrum, pyrethrin and pyrethroids, neem, and azadirachtin, essential oils, and some vegetable oils. Biopesticides are, ecologically, a safer alternative. The purpose of using biopesticides is to reduce the number of synthetic pesticides used, in addition to encouraging development of sustainable agriculture. These perspectives will be substantiated by implementing new pest control strategies.
KEY WORDS: *biopesticides, allelochemicals, pest control.*

INTRODUCTION

Present-day plant protection processes are mainly carried out by the action of various chemical pesticides (insecticides, fungicides, herbicides). Although those provide fast and efficient responses, the negative effects they wield upon the environment and non-targeted outweigh the benefits in the long run. The excessive use of chemical pesticides initiates soil and water resources pollution, destroys the insect communities, and causes pathological changes in birds and mammals. In addition, they cause negative effects on human health, by decreasing the quality of the environment and food (Zarins et al, 2009; Luchian et al, 2019; Datcu et al, 2020). An ecologically safer alternative is controlling pests through biopesticides.

Biopesticides are products that contain microorganisms, botanicals, and semiochemicals as active ingredients (CE Regulation 1107/2009). It was observed that some plants repel pests from houses, fields, and stored food. The botanic research alongside studies concerning pest relations in parallel with the chemistry of natural substances, reveal that the repellent behaviors are related to the existence of compounds biosynthesized by plants. The compounds are mainly associated with secondary metabolism (Alexan & Ianovici, 2018; Boboescu & Ianovici, 2018; Ciobanu & Ianovici, 2018; Gavrilă et al, 2020).

Some of them (allelochemicals, for example) are implicated in interspecific chemical communication while others are associated with defense molecules (Grudnicki & Ianovici. 2014).

The biopesticide market is underdeveloped to a greater extent in comparison with the synthetic pesticides one. Microorganisms represent the main part of the biopesticides market, while botanicals and semiochemicals are still a small part of the world-wide industry (Regnault-Roger et al., 2005a).

OVERVIEW OF BOTANICALS AND SEMIOCHEMICALS BASED BIOPESTICIDES

Botanical based biopesticides

An ”active botanical substance” is composed of one or more plant matters obtained by exposing plants or same species plant parts with processes such as pressing, grinding, distillation, crushing, and/or extraction. The process can subsequently include concentration, purification, and/or mixing, providing that the chemical nature of the compounds is not modified or intentionally altered by the chemical or microbial processes (definition according to the Active Botanical Substances Guide Accepted in the European Union). Advancements in the comprehension of the allelochemical systems of plant movement provide new points of view in the utilization of these substances for crop assurance. Active botanicals substances are not harmless in themselves, so it is necessary to assess that they do not lead to harmful effects. The approach to toxicity assessment depends on the intention to utilize the biopesticides at appropriate levels of exposure in accordance with the existence of documentary information, such as medicinal use. In the event that the necessary information is unattainable, the data derived from the active substances chemical synthesized can be used in the same manner rendering scientifically justified deviations. If the botanicals contain components with known toxic attributes, the overall exposure to the component in question must be assessed and compared with the health-based reference values (EU Regulation 1107/2009).

Semiochemicals based biopesticides

Semiochemicals (pheromones and allelochemicals) are emitted by an organism and cause a behavioral and physiological response on individuals of the same species or of different species, beneficial for the one who releases it (allomones) or the one who receives it (kairomones) (Howse et al., 1998). For the purpose of plant protection, they are combined with distribution devices or as seed treatment products. Semiochemicals can be allelochemicals produced by individual species which alter the behavior of other individual species. Interspecific effects such as allomones benefit the emitter species while kairomones benefit the recipient species, alternately synomones benefit both species. Intraspecific effects for example, pheromones, cause alterations in the behavior of individuals of the same species (Sante, 2014). Together with allelochemicals, the plant's defense allomones act to repel pests and parasites or to undermine their biotic potential (Strebler, 1989). A wide variety of species is exposed to their: phytophagous insects, nematodes, pathogenic microorganisms, and other alopathic plants (Regnault-Roger et al., 2005a).

MAIN ALLELOCHEMICALS USED AS BIOPESTICIDES

1. Alkaloids

Alkaloids are less used due to the effectiveness of chemically synthesized pesticides. Some are actively used by farmers from developing countries in the same manner that has been practiced across a long period of time. Similarly, they are utilized in organic agriculture. A part of them is associated with specific synthesized insecticides. Despite the additional alternative beneficial uses such as berberine, which is phototoxic, they are genotoxic (Philogene et al., 1982).

Nicotine is very stable in its levogyre form and it is neurotoxic for insects, mammals, and birds. It represents an imitator of acetylcholine in the postsynaptic binding of receptors and interferes with the transmission of signals in the nerves. This causes stimulation followed by depression of the vegetative system and muscles. The lethal oral dose is in the range of 50-60 mg (Lauwerys, 1990). It is also toxic to birds. This limited toxicity is used as pesticides.

Nicotine was, without a doubt, one of the first molecules used as insecticides. Since 1960, aqueous extracts from tobacco were used against insects that squeeze and produce lesions in cereals. The active molecule, nicotine, from the plant was isolated in 1828, and in 1904 it was synthesized (Ware, 2000).

In this day and age, nicotine is mainly used in complex mixtures as sulfates in alkaline solutions in addition to combinations with soaps, fumigants or as contact aerosols in greenhouses (Weinzeirl, 1998). Various countries, namely China and Bolivia, use nicotine in the function of rice field protection by immersing nicotine stem cells in plantations as well as a spraying method in the protection of potato crops.

Veratrine is a mixture of alkaloids [veracevine, cevadine, sabadine, 3-O-vaniloilveracevine and veratridine (Copping, 2001)], extracted from an endemic plant from Balkans, *Veratrum album L.*, as well as from a plant belonging to Liliaceae family from Venezuela, *Schoenocualon officinale* Sch. & Champ. ,known as Indian caustic bailey or sabadilla. These alkaloids, "such as" or soemthing besides likepyrethrins, have a neurotoxic action by slowing down the closure of Na^+ channels and deregulating membrane depolarization. They maybe "initially"cause paralysis, which is followed by death (Bloomquist, 1996). They have been used against locusts, cattle lice, and houseflies. Currently, compounds are only used marginally, mainly in organic farming, against thrips (Thacker, 2002).

2. Rotenone and rotenoids

Rotenone inhibits cellular respiration and the energetic metabolism at the mitochondrial respiratory chain level. Despite being harmless for mammals, it is active against cold blooded animals, suchlike amphibians, fish, and reptiles. Although there were few recorded accidents at the enzymatic inhibition level, rotenone was considered for a long time to have a moderate level of toxicity on mammals. However, there were observed cases of chronic toxicity leading to degradation of the kidneys and liver (Weinzeirl, 1998). Recently, a hypothesis has been issued regarding the link between rotenone and Parkinson's disease (Betarbet et al., 2000). Rotenone resides for 3 to 5 days on the leaf side after application and biodegrades easily. Rotenone utilized independently is not harmful to honey bees, yet is deadly when mixed with pyrethrin (Copping, 2004).

Alongside nicotine, rotenone is one of the oldest insecticides used worldwide. The use of crushed Fabaceae roots for catching freshwater fish by the native South American populations was uncovered since 1665 and reported that these extracts were added in insecticides soaps in 1848 (McEwen & Stephenson, 1976). The active ingredient, belonging to flavonoids, was isolated by Geoffroy in 1895 from *Lonchocarpus nicou*, an American Fabaceae and was named “nicouline”. Similar research was conducted in 1902, by Nagai, who used the roots of *Derris elliptica* (roten in Japanese) and named the compound rotenone (Dajoz, 1969). This compound had major commercial importance until 1940, but, just like many other plant-based insecticides, its use declined at the end of the Second World War (Philogene et al., 2005).

Rotenone is used today in organic agriculture by itself or associated with other ingredients, such as pyrethroids, synergistic (piperonyl butoxide), sulfur, or copper (BCPC, 2006). It controls a wide variety of arthropod pests, including aphids, thrips, moths, beetles, and spider mites. It is recommended for the control of ticks on animals, lices, and against the Colorado potato beetle, *Leptinotarsa decemlineata* (Say); an insect that has developed resistance to many insecticides (Weinzeirl, 1998).

3. Pyrethrum, pyrethrins, and pyrethroids

Pyrethrum is a mixture of 6 esters, pyrethrin I and II (in the largest amount), cinerine I and II, and jasmoline I and II (Fournier, 1988). Pyrethrin I is the most toxic ester. It alters neural transmission by slowing down the closure of Na^+ channels during the recovery phase of the action potential of neurons. The insect consistently shows hyperactivity, followed by convulsions. Pyrethrins are extremely toxic and act quickly on insects. On the other hand, they have relatively low toxicity to mammals (oral LD_{50} between 1280 and 3920 mg kg^{-1} for rats and between 273 and 796 mg kg^{-1} for mice).

A massive intoxication with pyrethrum leads to tremors followed by convulsions, the lethal quantity for man was estimated being between 50 and 100 grams (Lauwerys, 1990). Pyrethrum is rapidly hydrolyzed in the digestive tract, although it is more toxic by inhalation or intravenously. Respiratory or skin allergies occur frequently a few hours after contact. Toxicity is specified for non-target species, especially fish and bees. However, the high degree of instability in light, air, and moisture considerably reduce the risks associated with use.

Even if the production cost is high, it is a natural insecticide used worldwide at a large scale (Regnault-Roger & Philogène, 2005). It is recommended for insects and mites' control on fruits, ornamental plants, house plants, greenhouse crops, and fields, in addition to stored goods and domestic or farm animals. It is applied mainly in combination with piperonyl butoxide, a synergist that inhibits detoxification (Copping, 2004). In France, pyrethrum and pyrethrins combined with the same synergist are also marketed together with rotenone or a microorganism, *Bacillus thuringiensis* (Couteux & Lejeune, 2006). Pyrethroids, compounds derived from pyrethrum and synthesized to be more photostable, are currently key molecules in plant protection.

4. Neem and azadirachtins

Neem is, in fact, a mix of over 100 limonoid compounds as azadirachtin, salanine, nimbine, and their analogs. All of the compounds have further ways of action. Moreover there have been many reported effects of neem against insects. Salanine results in food rejection and lack of appetite, and azadirachtins are the sole compounds with a major role in insects` growth inhibition (Schmutterer, 1990). This fact ensues from the ecdysteroids synthesis inhibition, which causes a perturbation in insects` molt and reproductive processes. Azadirachtin acts on an outsized kind of insects: balm of Gilead sawfly *Neodiprion abietis* (Harris), thrips, mining leaf moths, aphids, caterpillars. pine false webworm (*Acantholyda erythrocephala* L.) (Copping, 2004).

The usage of neem (*Azadireachta indica*) extracts as insecticides is traditionally Indian practice. The development of this insecticide is hampered by (i) commercial cultivation of the plant; (ii) extraction of active ingredients; (iii) development of persistent wording and period.

Presently, neem is found in numerous countries: New Zealand, Canada, Italy, Germany, the United States of America. It is quite presumptively one in all the foremost promising botanical insecticides that are to be employed in environment-friendly agriculture (Philogene et al., 2005).

5. Essential oils

Essential oils distinguish themselves from other vegetable oils by volatility. Essential oils are prepared by specific processes as dry or vaporous distillation as well as other mechanical processes (Guenther, 1972). Essential oils are produced in superior plants; 17500 aromatic species belonging to a limited number of families (Myrtaceae, Lamiaceae, Lauraceae, Asteraceae). Their components belong at two main chemical families; terpenoids (mono- and sesquiterpenes) and, to a lesser extent. phenylpropanoids (Bruneton, 1999). The biological impact of essential oils on pests limits their reproductive potential, due to their insecticide activity and the inhibition of their reproductory cycle (Regnault-Roger & Hamraoui, 1994a). A portion of them such as, rosemary (*Rosmarinus officinalis*) oil, thyme (*Thymus vulgaris*) oil and eucalyptus (*Eucalyptus saligna*) volatile oil, have proprieties that inhibits feeding (Regnault-Roger & Hamraoui, 1994b) or rejection activities (Tapondjou et al., 2003). Those activities depend on the phytochemical profile and on the entomological species sensibility.

Despite the heterogeneous chemical composition, essential oils have remarkable properties that led to their while use in aromatherapy, within the perfume industry, cosmetology, and the chemical industry.

Recently, their use in plant protection developed (Regnault-Roger, 1997), majorly in North America, due to an exemption on pesticide regulation. *Cymbopogon nardus* volatile oil, which removes mosquitoes and flies, and garlic oil (*Alium sativum*), an intimidating compound for several insects, are currently marketed for horticulture and greenhouses, further as for domestic use within the United States and also the United Kingdom (Copping, 2004).

6. Other vegetable oils

The particular oils contain large and heterogenous fatty acids, saturated or unsaturated, with medium or long carbon chains, esterified, and fatty acids esters with high molar weight. Their toxicity results from some physical and chemical properties. Their volatile compounds become toxic by inhalation, although contact toxicity suffocates insects by forming an impermeable film over the cuticle. Some compounds get through the cuticle, destroying the cell membrane and decoupling oxidative phosphorylation (Weinzeirl, 1998). Some fatty acids, such as oleic acid (C_{18}), have their insecticidal activity, while undecylenic acid (C_{11}) has lower toxicity, but intensifies the activity of other insecticidal compounds by potentiation (Regnault-Roger & Caupin, 1994). Repellant behaviors were also observed. *Melinis minutiflor* oil, extracted with various organic solvents (methanol, chloroform, hexane, or acetones), is rich in eicosanoid, linoleic methyl ester, and hexadecanoic acid and can remove the cattle tick *Boophilus microphus* (Castrejon et al., 2004). At normal spraying rates, plant oils are nontoxic for mammals. Beyond their pest control ability, plant oils are used as ingredients in agrochemical formulations because of their chemical and physical properties. They have multiple roles: additives, solvents, dispersants, or synergetics. These roles alongside their use in spraying reduce the number of pesticides released in the atmosphere and, therefore, reduce the pollution caused by crop protecting treatments, without reducing their efficacity (Gauvrit & Cabanne, 2005).

Plant oil emulsions were used for a long time against pests, but it was not until 1920 when they became prosperous, because of their secondary effects on *Citrus sp.* and high prices (Balachowsy, 1951).

In the present circumstances, oils are essential because they decompose rapidly in the environment and have no adverse effects on organisms other than insects. Thus, it benefits from the rule of exemption from the regulation of insecticides in the United States. In the United States, some oils are used to protect apple plantations, especially in areas where *Dysaphis plantaginea* (Passerini) and *Panonychus ulmi* (Koch) pests have become resistant to organophosphates, carbamates, and pyrethroids (Weinzeirl, 1998). Rapeseed oil (obtained from *Brassica napus* and *B. campestris*) is currently marketed as an insecticide for the control of corn pests but is also used in orchards, vegetables, melons, olives, soybeans and numerous other crops as well as for houseplants and ornamentals. Jojoba oil (extracted from *Simmondsia californica* Nutt.) is used as an insecticide for controlling *Bemisia spp.* and *Trialeurodes vaporariorum*, and since 1998 has been used as a fungicide against mold (Copping, 2004).

PAST PROSPECTS OF BIOPESTICIDE USAGE

Observing the reality that some plants had more complex defensive systems than others, people developed a technique based on using plants as pesticides. Historically, botanicals were first used as pesticides. They are mentioned in Chinese, Greek, and Roman antiquities, additionally in India, were the usage of *Azadirachta indica* Juss, (the Neem tree; Meliaceae) was mentioned in Veda, a manuscript written in old Sanskrit, dating at least 4000 years (Philogene et al., 2005).

It is relatively difficult to estimate exactly when and where plants or plant extracts were used systematically in the protection of other plants or, more generally, in agriculture. In the 18th century, several publications used plant-based formulas to control harmful insects (Balachowsky, 1951). At the end of the 19th century, methods were put into common practice including the use of toxic plants or minerals, oils, tar, sulfocalcic sprays, boiled water, and so forth (Pesson, 1990). The integration of scientific and empirical observations led to the development of extracts from plants.

The first botanicals and allelochemicals used as pesticides were obtained from affordable products. Insects were more targeted than pathogens because they could be easily identified (Regnault-Roger et al. 2005a, b).

The development of botany as an insecticide resulted from two parallel methods:

i. Observation of traditional uses of plants and extracts for the protection of cattle herds and crops, followed by verification of the effectiveness of these practices along with identification of active molecules. Examples for this category are the activity of nicotine extracted from tobacco (*Nicotiana tabacum*) and rotenone from the Fabaceae (*Lonchocarpus nicou* and *Derris elliptica)*.

ii. A scientific screening of plant families collected during prospecting campaigns followed by biological tests acquire active molecules. Rianodine, an alkaloid extracted from *Ryania* sp. and marketed in the United States in 1945, is the result of these prospects made in collaboration between Rutgers and Merck Universities in the early 1940s (Copping, 2001).

CURRENT PERSPECTIVES IN USING BIOPESTICIDES

For the companies that intend to commercialize a pesticide, the registration costs in developing countries are very high as a result of the toxicologic and ecotoxicological standards. In the European Union (UE), the costs are estimated at 30 million euros (Boquet et al., 2005). Due to the fact that biological researches demonstrated the environmental and toxicological benefits that biopesticides have in favor of synthetic pesticides and in view of the narrower markers due to specificity and selectivity, biopesticides manufacturer hope for an easier procedure of reglementation, which will lead to a bigger profit.

An easier procedure exists in the United States of America. The registration of biopesticides is the subject of a particular procedure stated in statute 40 in the CFR (Code of Federal Regulations) applied to FIFRA (Federal Law on Insecticides, Fungicides, and Rodenticides). According to EPA, semiochemicals could be classified as biochemical biopesticides when controlling pests by non-toxic mechanisms (EPA, 2004). Thereby, many natural extracts from plants and allelochemicals are viewed as GRAS (generally safe). They are included in list 25b. named for the specific section of FIFRA and are marked as low-risk pesticides (EPA, 2007). They are exempt from FIFRA standards. Encompassed in this list belong oils from plants (mint, cinnamon, rosemary, geranium, garlic, thyme, soy), monoterpenes (geraniol, eugenol), and common acids identified in Krebs cycle (malic, citric). This exemption became advertising for promoting the products. For example, EcoSmart Technologies (Franklin, TN, USA) commercializes rosemary oil as an active ingredient under the EcoPCO and EcoExempt IC names.

In the European Union, Council Directive 91/41 /EEC (http://eurlex.europa.eu) also called the Plant Protection Products Directive (PSD, 2006), deals with the marketing of plant protection products and which became strict in 1994. This directive seeks to homogenize the EU documentation standards required for the regulatory approval of plant protection products. It triggered the revision of 835 active ingredients for which formulations were registered in 1993. The Directive includes the elimination of pesticides that have been authorized for a long time in the Member States despite obvious toxicity or ecotoxicity. Thus, by strengthening the criteria in demanding the production of safe products, it is attainable to harmonize the safe marketing of active substances for plant protection in the European Union.

Directive 91/414 / EEC provides a positive list of active substances (Annex 1). This inclusion in Annex 1 conveys that the active substance has been shown to not present unacceptable risks to humans or the environment. Before a substance can be considered to be listed in Annex 1, information is collected on: the identification of the active substance for the plant protection product, the description of the chemical, and physical properties, the effects on the pests pursued and the risk assessment for acceptable to workers, consumers, the environment and non-target plants or animals.

FUTURE PERSPECTIVES

Selecting compounds which have been studied in the interest of preventing or diminish disease prevalence is the basis of modern agronomy. This approach has its` roots in the use of traditional methods which are based on Mendel`s laws. The development of biotechnology enabled a great impact on genetic selection techniques.

Companies that are specialized in biopesticides production strive to improve the formulations: stabilization of the extracts and consistent chemical pattern that meets the quality standards of the product sold. These requirements can be fulfilled by selling identical synthesized molecules in every area of the natural molecule (i.e. organoleptic properties, purity degree, and the absence of residual solvents). P-methane-3,8-diol, a repeller for mosquitos and horse flies, first identified in lemon eucalyptus *Eucalyptus citriadora* is listed on the market as a chemically synthesized active ingredient for commercial use (Mosi-Guard, China) (Copping, 2004).

The approach of combining biology with chemistry could actualize a solution to the problem that biopesticides confront in commercial development. The successful development of pyrethroids, commercialized in the 1970s, is an illustration of the synergism between biology and chemistry. Those derivates, products of chemistry, synthesized after a natural model (pyrethrum) and light stabilized, have a very vague resemblance with the natural compounds and their way of action. Despite their chemical background, they are labeled as ”green products” because they are, in essence, derived from a natural compound. Taking into consideration their enhanced efficiency and minimized harmful effect compared to other synthesized pesticides, they are key products in integrated pest control. They undeniably contributed to the alter of botanical insecticides perception.

A further promising approach in plant protection is the stimulation by elicitors of plant resistance, as long as it produces plant synthesized molecules for their protection. Even though this method of protection is insufficient when the plant is strongly attacked, introducing these natural and nontoxic substances leads to the diminishing of chemical pesticide treatments. Improving in this domain is necessary for fulfilling current and future needs.

CONCLUSIONS

All of the previously mentioned alternative practices based on plants` allelochemicals have in view reducing the number of synthetic pesticides used to protect crops, reducing environmental hazards, and promoting sustainable agriculture. It is now a deep-rooted concern of scientists to develop methods of crop protection that are also beneficial to the environment. This must be accompanied by a clear and effective policy at the economic and judicial level, in addition to research with applied as well as fundamental issues. Advancements in the knowledge of organism biology and ecosystem complexity have made it possible to develop and implement new pest control strategies that take into account environmental protection, which in turn will strengthen the prospects for environmentally friendly agriculture and sustainable development, both of which are necessary for the survival of humanity.

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