Environmental Research 142 (2015) 549–562

Contents lists available at ScienceDirect

Environmental Research

journal homepage: www.elsevier.com/locate/envres

Review article

New environmentally-friendly antimicrobials and biocides from Andean and Mexican biodiversity

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ARTICLE INFO

Article history:
Received 10 March 2015
Received in revised form
6 August 2015
Accepted 6 August 2015

Keywords:
Biopesticides
Environmentally-friendly biopesticides
Antifeedant
Insect growth regulators
Insecticidal
Antibacterial
Antifungal activity
Secondary metabolites
Phytopathogens
Insect pest control
Biological activity.

ABSTRACT

Persistent application of pesticides often leads to accumulation in the environment and to the development of resistance in various organisms. These chemicals frequently degrade slowly and have the potential to bio-accumulate across the food chain and in top predators. Cancer and neuronal damage at genomic and proteomic levels have been linked to exposure to pesticides in humans. These negative effects encourage search for new sources of biopesticides that are more "environmentally-friendly" to the environment and human health. Many plant or fungal compounds have significant biological activity associated with the presence of secondary metabolites. Plant biotechnology and new molecular methods offer ways to understand regulation and to improve production of secondary metabolites of interest. Naturally occurring crop protection chemicals offer new approaches for pest management by providing new sources of biologically active natural products with biodegradability, low mammalian toxicity and environmentally-friendly qualities. Latin America is one of the world's most biodiverse regions and provide a previously unsuspected reservoir of new and potentially useful molecules. Phytochemicals from a number of families of plants and fungi from the southern Andes and from Mexico have now been evaluated. Andean basidiomycetes are also a great source of scientifically new compounds that are interesting and potentially useful. Use of biopesticides is an important component of integrated pest management (IPM) and can improve the risks and benefits of production of many crops all over the world.

1. Introduction

Although application of pesticides is necessary for modern agriculture, overuse often leads to ecological and environmental problems. Many modern pesticides are biodegradable, but others are persistent in the environment and contribute to the development of resistance in various organisms. In fact, many are easily degradable and readily metabolized, even though they are still responsible for environment problems. Although many pest organisms are controlled, many beneficial insects and microorganisms are eliminated. The effects of organophosphates, glyphosate, paraquat, diquat, maneb, and other ethylene bis-dithiocarbamates are complex (Alavanja et al., 2004; Lee et al., 2008; Hancock et al., 2008). Some of these pesticides degrade slowly and have the potential to bio-accumulate across the food chain and in top predators through consumption of contaminated biota (Bjermo et al., 2013; Frouin et al., 2013). In addition to those applied in agriculture, other persistent organic compounds arise from waste incineration, industrial chemical processes, unregulated disposal of textiles, building materials and burning of waste and vegetation (Antunes et al., 2012; Liu et al., 2013; Evenset et al., 2007).

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http://dx.doi.org/10.1016/j.envres.2015.08.004
0013-9351/

Inorganic materials such as obsolete electronic waste (e-waste) also contribute to this problem. Once released, these substances tend to accumulate in soils and sediments for a long period of time and are subject to partitioning, degradation and transport processes.

In addition to ecological effects on the environment, a number of these pesticides have been shown to have potential effects on human health. Cancer and neuronal damage at genomic and proteomic levels have been linked to exposure to pesticides (Whitehead et al., 2015; Margni et al., 2002; Snell et al., 2003). Numerous studies have been conducted to investigate the potential neuroprotective action of natural products in neurotoxin-based models of Parkinson's disease (Sudati et al., 2013). Although the association between pesticide exposure and Parkinson´s disease (PD) has been established (Hancock et al., 2008; Lee et al., 2008; Rhodes et al., 2013), the specific mechanisms involved in the damage to dopaminergic function have not yet been fully elucidated. One proposed mechanism suggests that pesticides could be the cause of neurodegenerative diseases through the inhibition of mitochondrial function. The structure of 1-methyl-4-phenyl-1,2,3,6-tetrahydropyridine (MPTP) is similar to that of paraquat. MPTP is an agent known to cause damage to mitochondrial complex I (Le Couteur et al., 1999) and to induce the destruction of nigral dopaminergic neurons with a consequent neurobehavioral syndrome in mice (Thiruchelvam et al., 2000). Recently an interesting contribution to the understanding of this phenomenon was made by Qi et al. (2014) who, through mathematical simulations, have shown that both paraquat and rotenone may affect all fluxes associated with dopamine compartmentalization and its breakdown metabolites. In other studies, oxidative stress has been shown to play a central role in Parkinson's disease; for example, Garrido et al. (2011) showed that the application of pesticides could induce Lewy body formation, dopaminergic neurodegeneration, decrease in striatal dopamine levels and disturbances in GSH homeostasis. In addition, changes in the expression pattern of genes associated with the development of PD as tyrosine hydroxylase, alpha-synuclein, Parkin, PINK1 or DJ-1, have been correlated with exposure to rotenone and MPTP (Rajput and Rajput, 2007).

The negative effects of persistent organic pesticides are drivers in the search of new sources of biopesticides that are more "environmentally-friendly" to the environment and human health. Biopesticides and biocides are derived from such natural materials as animals, plants, fungi, bacteria, and certain minerals (EPA) (http://www.epa.gov/pesticides/about/types.htm). Since the beginning of civilization, substances obtained from botanical and fungal sources have been employed for agriculture, medicinal, or other cultural uses. Plants and fungi from many families produce a broad spectrum of natural products known as secondary metabolites (SM). These organisms still represent a large source of novel active biological compounds with insecticidal, nematicidal, herbicidal, antiviral, antifungal, antifeedant and antibacterial activities (Cantrell et al., 2012).

Many plant or fungal compounds have significant biological activity associated with the presence of alkaloids, mono-, iridoid monoterpenes, sesqui-, sesquiterpene lactones, di- and triterpenes, flavonoids, naphthoquinones, anthroquinones, coumarins, phenylpropanoids, flavonoids, and other types of phenolics (Rios and Recio, 2005; Svetaz et al., 2013). As a rule these substances are more degradable than many persistent pesticides; they may eliminate or significantly reduce the risk of adverse ecological effects and of soil and groundwater contamination (Seigler, 1998). Of course, compounds or extracts from plants or fungi will ultimately have to be evaluated for safety, efficaciousness, and a set of enviornmental problems in their own right. Just because they are "natural" does not mean that their use will be completely free from problems!

Many phytochemical isolations are biodirected in order to find new botanical and mycological biocides rather than simply to isolate compounds with new chemical structures. Botanically- and fungally-derived compounds that exhibit resistance to attack by pests may serve as agrochemicals by taking advantage of their antifeedant, insecticidal, fungicidal, nematicidal, molluscicidal, repellent, and herbicidal activity. Other SM have toxicity toward weeds and bacterial and fungal phytopathogens. In many instances, SM from fungi have greater potency as biocides than those isolated from higher plants suggesting that they are a promising, but inadequately explored, source of bioactive compounds. Substances from lichens, mosses, liverworts, and ferns have been insufficiently examined, but the literature available suggests that they also may provide many new active compounds (Aqueveque et al., 2005; 2006; 2010a,b).

The impact of plant natural products (phytochemicals) on human health, the food industry and crop production is increasingly recognized (Tajkarimi et al., 2010). Many plants and fungi have served as medicines for humans. Natural products have the ability to inhibit or modify the activity of many enzymes including tyrosinase, acetylcholinesterase, and melanin oxidase, and may play a role in health promoting activities (Schinella et al., 2002; Arrebola et al., 2015; He et al., 2015). Plant, fungal and bacterial natural products can be used as drugs against many diseases such as cancer, neuro-degenerative diseases, bacterial–fungal pathogens, and inflammation among others. Many secondary metabolites (SM) possess antibacterial, antiviral, antifungal, antiparasitic and antioxidant properties. Today these substances also have great value as cosmetics and medicines. Many are used to flavor and preserve foods. Others are used as dyestuffs and fragrances.

Although the use of fungicides of synthetic origin for control of postharvest microorganisms in food plants has been limited because of the residues that remain in the products, antimicrobial agents from plants or bacteria either alone or in combination are added to food packaging materials to improve the shelf life of packaged products, control the growth of microbes and ensure that consumers obtain quality products without fungal or bacterial contamination. Some synthetic antimicrobial agents previously used for this purpose have been shown to be carcinogenic.

Many compounds of current interest have been known and studied for many years, but it is only with the advent new biotechnological (genomic, proteomic and metabolomic) approaches that their biosynthesis has been understood at a level to permit their engineering in crop plants. Plant biotechnology provides new methods for elucidation of the biosynthetic pathways leading to the SMs in plants and fungi and, further, new molecular methods offer ways to understand regulation and to improve production of SM of interest. Cell and tissue cultural techniques are advantageous in comparison to extraction of natural compounds from whole plants grown in the field as culture occurs under controlled conditions. Culture methods also avoid factors such as seasonal variation and lack of a suitable climate for cultivation. However, they are often limited by inadequate understanding of factors that initiate formation and accumulation of desired compounds and by cost.

Naturally occurring crop protection chemicals offer a means to meet the demand for increased food production produced by increases in global population. Regulation of traditional crop protection products in agriculture has been controversial (Seiber et al., 2014; Czaja et al., 2015; Exley et al., 2015), but use of biopesticides in modern agricultural practices based on integrated pest management (IPM) (Cantrell et al., 2012; Marrone, 2014; Singh, 2014; Seiber et al., 2014; Czaja et al., 2015; Exley et al., 2015) may help to resolve conflicts involving food production, human health and the environment. This concept has stimulated intensive research, leading development of a variety of new technologies