SUSTAINABLE USE OF BOTANICAL PRODUCTS IN PLANT PROTECTION AS A PROMISING PANACEA TO INTEGRATED PESTS MANAGEMENT AND CONTROL: ISSUES, CHALLENGES, BENEFITS AND FUTURE PROSPECTS

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Abstract

The overzealous and indiscriminate use of most of the synthetic pesticides has created different types of environmental and eco-toxicological problems. Recently, in different parts of the world, attention has been paid towards exploitation of higher plant products as novel chemo-therapeutants in plant protection. Botanical pesticides can be recommended as an eco-environmental friends and sustainable strategy in the management and control of agricultural pests. Because of their biodegradability, systemicity after application, easy preparation, eco-friendly and low-cost alternatives to agrochemicals, capacity to alter the behavior of target pests and favorable safety profile, it is hoped that plant-based pesticides would no doubt play a significant role in achieving evergreen revolution. This present review therefore underscores the issue, challenges, constraints, benefits, sustainable utilization and potential of botanical pesticides in the field of agricultural plant protection.

Keywords: Botanicals, pesticides, pests, diseases, and prospects.

1. Introduction

One of the main problems in agricultural production is crop destruction by pests which are mainly insects (Tilmand *et al.* 2002 and Basiounly *et al.* 2010). At present, a common way to control insect pests is the use of synthetic pesticides, which of course have a negative effect as they are not natural eco-environmental friends (Van Der Gaag, 2000). In general, plant insect pests, diseases and weeds impose a serious threat to crop production in Nigeria. Population of weeds, insect pests and diseases has increased over the years especially due to introduction of monoculture farming in the country (Emosairue and Ubana, 1998). Traditionally, Nigerian farmers have been relying heavily on pesticides for the control of various weeds, insect pests and diseases, thus, leading to the high importation of these products and their price have become so high that it is becoming impossible for local farmers to afford (Nwanze, 1991; Schwab *et al.* 1995; Van den Berg and Nur, 1998; Okrikata and Anaso, 2008). These challenges have created the need for alternatives to synthetic pesticides, but nevertheless, inadequate infrastructure for research and extension remains a constraint to the advancement and continuity of such important activity in the country (Bugaje *et al.* 2007). Although synthetic-chemical pesticides can be used to control some pests economically, rapidly and effectively but most of them cause serious negative impacts, such as toxicity and residual effects to humans, plants, foods and other living things. More so, there is also a problem of induction of insect/pathogen resistance resulting to ineffectiveness of pesticides; harmful effects to non-target beneficial organisms and unbalanced ecosystem due to pollution of soil, water and environment (Deedat, 1994 and Gupta and Shyam, 1996).

Considering the problems associated with using synthetic pesticides due to their negative influence, notably environmental degradation including, insect resistance developing in insect pests, influence on human health, and socioeconomic costs, we can ask the question: Is there any alternative for these compounds? Anew approach to control insect pests includes searching for compounds that specifically affect the physiological processes of insects and do not influence other groups of animals or plants.

Botanical pesticides are an important group of naturally occurring, often slow-acting crop protectants that are usually safer to humans and the environment than conventional pesticides and with minimal residual effects (Pavela, 2009). Moreover, thanks to the fact that botanical pesticides contain mixtures of biologically active substances, no resistance is developed in pests and pathogens. Therefore the use of plant pesticides has been recommended ever more as a suitable alternative of plant protection with minimum negative risks (Isman, 2006 and Pavela, 2007).

The challenge to sustainable use of plant protection products is a long-term one. It involves helping farmers to properly control/manage pests in such a way that they do not only minimize immediate risks from dangerous pesticides but also reduce the possibility of accumulating future stocks. Synthetic pesticides pose a threat to sustainable development especially in agricultural fields; the adverse impact of persistent organic pollutants (POPs), as many of the pesticides are known to cause environment problems and raise serious health concerns. POPs do not degrade easily, but remain intact in the environment for a long period of time. The pollutants disperse easily across wide geographic areas, retain their toxicity and have a tendency to accumulate in the fatty tissues of organisms (FAO, 2007).The use of plant insecticides has a long-term tradition in Europe; the first known written references to the application of plant extracts against pests came from Rome and date back to about 400 B.C. (Dayan 2009). At present, several dozens of plant insecticide are used worldwide, based on various extracts, especially of the families *Rutaceae, Lamiaceae, Meliaceae* and *Asteraceae.* Moreover, bio-insecticides are a large group of substances derived from natural sources, such as animals, plants, bacteria, and certain minerals, seem to be an excellent alternative to synthetic insecticides (Chowański *et al*. 2014). These compounds often have lower toxicity to non-target organisms than synthetic insecticides and they are effective at low concentrations and are readily biodegradable, which allows for avoiding the problems of environmental pollution. Recently, in different parts of the world, attention has been paid towards exploitation of higher plant products as novel chemotherapeutics for plant protection because they are mostly non-phytotoxic and easily biodegradable (Isman, 2006). Currently, different botanicals have been formulated for large scale application as bio-pesticides in eco-friendly management of plant pests and are being used as alternatives to synthetic pesticides in crop protection.

Laboratory and field research in Nigeria have proved that botanicals could be economically feasible, technically effective and environmentally friendly alternatives to synthetic pesticides (Oruonye and Okrikata 2010). Yusuf *et al*. (1998) observed that powders of leaves of *Azadiracta indica, Melia azaderach, Zingiber officinale, Eucalyptus camaldulensis, Ocimum basilicum, Capsicum frutescens* and wood ash of *Khaya senegalensis* are effective in the control of maize weevil (*Sitophilus zeamais*) in stored maize. Abdul-azeez (2009) applied cashew nut shell extract on cowpea pods infested with aphids and reported that the treatment has promising insecticidal effects on the aphids.

Although plant pesticides have been studied in many laboratory tests (Chandler 1951 and Morgan 2009), numerous scientific articles, reviews and chapters book have been written on this subject matter but very few studies are available that present results from practical use, and there is a great lack of biological efficiency comparisons of several products on multiple pest species at the same time. Sequel to that, this paper is intended to provide an in-depth literature with regards to the sustainable application of natural products mainly of plant extracts (botanical pesticides and botanical insecticides) in management and control of the menace poses by pests and diseases on vital agricultural crops which subsequently incur threat to national food security and greener revolution.

2. The Concept of Botanical Pesticides

Botanical pesticides (derived from biochemical pesticides) have a proven track record and long use as simple extractives for pest control and have spun off important groups of synthetic pesticides from phytochemical leads such as pyrethroids and neo-nicotinoids. The new environmental movement has provided a favorable environment for the rebirth of botanical insecticides. Public resistance to adoption of Genetically Modified Organisms (GMOs) is another factor favouring alternative control measures such as bio-pesticides, bio-control and other methodologies. The assertion, that people have extracted compounds from plants to use as botanical insecticides for thousands of years is evidence, dating back to 400 B.C., that compounds harvested from *Chrysanthemum* species were used to manage insect pests (Silva-Aguayo, 2009).

Botanical insecticides are usually harvested by macerating (soaking and separating) plant materials (stem bark, root, leave, flower, seeds) in the active ingredient and distilling (evaporating and condensing) the specific active compounds. Botanicals may be considered organically-approved products depending on the extraction method and formulation (i.e other ingredients included in the product). The advantage of using botanical insecticides is their short persistence and little or zero bioaccumulation in the environment due to rapid degradation. Research with a number of experimental botanical pesticides such as piperamides and alpha-terthienyl, shows they are degraded in the environment in hours or days. However, this short persistence can also be deemed a disadvantage since multiple applications may be needed to achieve adequate pest suppression (Nnamonu and Onekutu, 2015).

Botanicals include crude extracts and isolated or purified compounds from various plants species and commercial products (Liu *et al.* 2006). Not unlike pyrethrum, rotenone and neem, plant essential oils or the plants from which they are obtained have been used for centuries to protect stored commodities or to repel pests from human habitations and use as fragrances, condiments or spices, as well as medicinal uses (Isman & Machial, 2006). Quantitatively, the most important botanical is pyrethrum, followed by neem, rotenone and essential oils, which are typically used as insecticides (e.g. pyrethrum, rotenone, rapeseed oil, quassia extract, neem oil, nicotine), repellents (e.g. citronella), fungicides (e.g. laminarine, fennel oil, lecithine), herbicides (e.g. pine oil), sprouting inhibitors (e.g. caravay seed oil) and adjuvants such as stickers and spreaders (e.g. pine oil) (Isman, 2006).

Despite many advantages, the botanical pesticide market has a number of major challenges confronting its propagation. Although there has been growth, but it has not grown in a comparable way to the botanical medicine market in recent years. The major hurdle is costly toxicology testing for new products which may have limited Intellectual Property (IP) protection and a relatively small market size. Other challenges include economical supply of plant product, quality control and lack of stability. Though, there is, as well, competition from other bio-pesticide and bio-control agents, the Environmental Protection Agency (EPA) has granted reduced registration requirements to a variety of traditionally used insecticide products on its 25B exempt list in the USA. This is the main area where there has been growth in botanicals in developed countries, but some new products are also emerging from developing countries (Nnamonu and Onekutu, 2015).
Botanical pesticides include the followings;

2.1Essential Plant Oils

Essential oils are usually obtained via steam distillation of aromatic plants, specifically those used as fragrances and flavourings in the perfume and food industries respectively, and more recently for aromatherapy and as herbal medicines. Plant essential oils are produced commercially from several botanical sources, many of which are members of the mint family (*Lamiaceae*), citrus family (*Rutaceae*) etc. The oils are generally composed of complex mixtures of monoterpenes, biogenetically related phenols, and sesquiterpenes (Nnamonu and Onekutu, 2015).

There are several examples of essential oils like that of rose (*Rosa damascene*), neem (*Azadirachta indica*), citrus (*Citrus sinensis*), patchouli (*Pogostemon patchouli*), sandalwood (*Santalum album*), lavender (*Lavendula officinalis*), geranium (*Pelargonium graveolens*), etc. that are well known in perfumery and fragrance industry. Other essential oils such as lemon grass (*Cimbopogon winteriana*), eucalyptus (*Eulcalyptus globules)*, rosemary (*Rosemarinus officinalis*), vetiver (*Vetiveria zizanoides*), clove (*Syzygium aromaticum*) and thyme (*Thymus vulgaris*) are known for their pest control properties. While peppermint (*Mentha piperita*) repels ants, flies, lice and moths; pennyroyal (*Mentha pulegium*) wards off fleas, ants, lice, mosquitoes, ticks and moths. Spearmint (*Mentha spicata*) and basil (*Ocimum basilicum*) are also effective in warding off flies. Similarly, essential oil bearing plants like *Artemesia vulgaris, Melaleucaleu cadendron, Pelargonium roseum, Lavandula angustifolia, Mentha piperita,* and *Juniperus virginiana* are also effective against various insects and fungal pathogens (Isman, 2000).

i. Neem Oil

Neem or neem oil is extracted from the seeds of the neem tree, *Azadirachta indica*, which is a native of India. The neem tree supplies at least two compounds that kill insects (azadirachtin and salannin), along with an unknown number of other unidentified compounds that have fungicidal activity. *Azadirachtin* acts as an insect feeding deterrent and growth regulator. The treated insect usually cannot molt to its next life stage and dies within a few days. Azadirachtin acts primarily as a repellent when applied to a plant and may kill an insect within 24 hours. Neem has some systemic activity in plants (Schmutterer, 1990).

Currently registered neem products for ornamental pest control claim to be active against various sucking and chewing insects (Stark and Walter, 1995). As a plant extract, neem can be extracted and formulated in different ways, and different insects will react in different ways to the same product. Thus, effectiveness varies among products. Neem is most effective against actively growing immature insects. Neem oil (70%) is used to manage powdery mildew but is less effective on black spot and other leaf spot diseases.

Neem insecticides are effective against many caterpillars, flies, whitefly, and scales, and are somewhat effective against aphids. Neem may not show signs of efficacy for 3–7 days, and it can degrade within 3–4 days. Multiple applications are generally needed to obtain good management of the targeted pests. Neem is regarded as nontoxic to vertebrate animals and has been shown to minimally affect many beneficial insects such as bees, spiders, and ladybugs (Schmutterer, 1990).

ii. Citrus Oils--Limonene and Linalool

Citrus oils, which are extracted from oranges and other citrus fruit peels are used extensively as flavorings and scents in foods, cosmetics, soaps, and perfumes. The oils can also be refined to make the insecticidal compounds; d-limonene and linalool. Both compounds are generally regarded as safe for mammals by the United States Food and Drug Administration.

Limonene and linalool are contact poisons (nerve toxins) that may be synergized with other naturally occurring active compounds. They have low oral and dermal (skin) toxicities. Both compounds evaporate readily from treated surfaces and have no residual activity. They have been registered for use against fleas, aphids, and mites but they also kill fire ant workers, several types of flies, paper wasps, and house crickets. Commercial products (usually containing "d-Limonene") are available as liquids, aerosols, shampoos, and dips for pets. Skin or eye contact can be irritating to some animals, but symptoms are usually temporary. It is wise to also use these products cautiously as they minimize phytotoxicity to sensitive plants (Bogran *et al*. 2006).

2.2 Pyrethrum/Pyrethrins

Pyrethrins are highly concentrated compounds extracted from the daisy-like flower of *Chrysanthemum cinerariafolium*, commercially grown in Kenya. When the flower is grounded into powder, the product is called a pyrethrum. Synthetic insecticides that mimic the action of pyrethrins are known as pyrethroids (e.g. bifenthrin, cyfluthrin, and permethrin). Many insects are susceptible to low concentrations of pyrethrins. The toxins cause immediate knockdown or paralysis on contact, but insects may metabolize them and recover if a synergist is not used. Pyrethrins break down quickly, also have a short residual, and have low mammalian toxicity, making them among the safest insecticides in use.

Pyrethrins are easily broken down by stomach acids in mammals, so toxicity to humans and pests is very low. However, toxicity can occur when significantly more products is applied than specified on the label. Pyrethrins should not be sprayed around ponds or other bodies of water, as they can kill fish. Pyrethrins may be used against a broad range of pests including ants, aphids, roaches, fleas, flies, and ticks. They are available in dusts, sprays, and aerosol "bombs," and they may be mixed with synthetic pesticides or other natural products (Nnamonu and Onekutu, 2015).

2.3 Horticultural Oils

Horticultural oils were used for insect control as early as 1763 and are still popular today. Such control agents are often petroleum-based. However, plant-based oils considered acceptable in organic farming are also available. Horticultural oils work by disrupting insect feeding and egg laying when the pest is entirely coated. Eggs covered with oils are prevented from gas exchange, which suffocates the developing pest. Horticultural oils have minimal phyto-toxic (poisonous) effects on plants when used properly. Application timing, plant species, temperature, and oil type all contribute to the level of effectiveness and risk of phyto-toxicity. Phytotoxic effects are easily noticed by the browning or "burning" of the leaves or new growth on the stem (Nnamonu and Onekutu, 2015).

2.4 Hot Pepper

Products made with hot pepper contain *capsaicin*, a compound that gives certain peppers their "heat property." Low doses of capsaicin are often combined with paraffin and sold as "hot pepper wax" insect and animal repellents. The flavor does not affect the taste of fruits or vegetables that have been treated (Antonious *et al*. 2006 and Antonious *et al*. 2007).

2.5 Insecticidal Soap

Insecticidal soaps are made from plant oils (cottonseed, olive, palm, or coconut) or animal fat (lard, fish oil). They are made from the salts of fatty acids, which are in the fats and oils of animals and plants.

The mode of action of insecticidal soaps is still debatable. They may physically disrupt the insect skin or cuticle, block insect breathing holes (i.e. spiracles), or act as nerve toxins. Soaps act on contact and must be applied directly to the insect to be effective. Any soap residue that remains on plants has no insecticidal effect. Soaps are useful against soft-bodied pests like aphids, some scales, psyllids, whiteflies, mealybugs, thrips, and spider mites (Baldwin, 2008).

2.6 Traditionally Used Botanical Insecticidal Products

Other traditionally used botanical insecticide products include nicotine, rotenone, ryania, sabadilla and pyrethrum. Although nicotine and tobacco have a long history of use and have effective contact and ingested insecticides, they also have extremely high mammalian toxicity and are candidates for regulatory phase out. Tobacco is still used in some greenhouse applications as of today. Rotenone is the trade name of the insecticide derived from extracts of the tropical legumes *Derris* and *Lonchocarpus*. The main active principle, the isoflavonoidrotenone, is moderately toxic to mammals due to poor absorption and rapid metabolism, but is highly toxic to insects and fishes due to its rapid uptake and inhibition of respiratory electron transport. Rotenone has been widely available as plant extract at reasonable cost and used as a dust on horticultural and ornamental crops, but its use has been phased out recently in the US and Canada during regular re-evaluation. But hitherto, it is still being used in some other countries (Nnamonu and Onekutu, 2015). Sabadilla is the seed extract of the neo-tropical lily *Schoenocaulon officinale* which contains veratridine alkaloids which have a neurotoxic mode of action. The extract has low mammalian toxicity and is a useful contact insecticide against a number of agricultural insects such as lepidoptera, leafhoppers, and thrips.

Ryania is an extract from the South American shrub *Ryania spp.* containing the diterpene, alkaloid, ryanodine, which is a contact and ingested insecticide against horticultural and ornamental crop pests. It exerts its toxicity by blocking Ca^{2+} ion channels. The market for these botanicals is relatively small.

3. Other Greener Cultural Alternatives to Synthetic Pesticides

3.1 Trap Plants

Some insects, if given a choice, will opt to feed on one type of plant or another. For example: maggots prefer radishes over corn and tomato worms prefer dill over tomatoes. Therefore, certain plants can be strategically placed so that they lure harmful insects away from plants you wish to protect. These are commonly referred to as "trap plants." Once the trap plant has become infested, the target insect can be picked off and dropped in soapy water or the entire plant can be pulled up and disposed off.

3.2 Companion Planting

Some plants possess the natural ability to repel certain types of insects. Companion planting is the practice of strategically placing insect-repelling plants next to crops that will benefit from their natural properties. For example, planting garlic among vegetables helps fend off Japanese beetles, aphids, the vegetable weevil, and spider mites; basil planted near tomatoes repels tomato horn worms; and marigolds inter-planted with cucurbits (i.e., zucchini, cucumbers, etc.) discourage cucumber beetles.

3.3 Crop Rotation

Planting different kinds of vegetables in each different section of your garden plot each year will help reduce pest infestation. In the fall, some insects lay their eggs in the soil a couple of inches below the surface. The eggs hatch in the spring and immediately begin the search for their food source. Many insects will feed on only one or types of vegetables. Thus, if the plant they prefer to eat is located several feet or yards away, the insect must migrate to the source. Many will die along the way or fall prey to birds and other insects. Also, certain families of plants (e.g., potatoes and peppers - nightshade family) attract the same pests. In addition, many crops predominately absorb a particular nutrient from the soil. By rotating your crops each year, the soil in a particular section of the garden will have the opportunity to rest and regenerate.

3.4 Diversified Planting

A common practice among home gardeners is to plant a single crop in a straight row. This encourages pest infestation because it facilitates easy travel of an insect or disease from one host plant to another. By intermingling different types of plants and by not planting in straight rows, an insect is forced to search for a new host plant thus exposing itself to predators. Also, this approach corresponds well with companion planting.

4. Constraints, Challenges and Improvement of Botanical Pesticides Utilization

The use of botanical pesticides such as neem materials has some constraints. Jaryum *et al.* (2000) observed residual bitter taste on the grains treated with neem seed powder. It was therefore reported that neem products are most suitable for seed protection than on stored farm produce for consumption. Anjorin (2006) also reported the constraints of using botanical pesticides because it is laborious and time consuming processing such as grinding of bark or leaves of a tree into powder and the usage of crude and household materials like pestle, mortar and containers which often become stained, tasty and contaminated. Majority of the natural extracts users (83.3%) indicated insufficient supply of commercial formulation as their main constraints to the use of botanical pesticides. Other challenges include inadequate modern processing facilities (Okwete, 2006) which are necessary for efficient isolation, purification and compounding of natural products into pesticides and drugs. The process of simplification and purification of the active ingredients are often slow and cumbersome and may lead to loss of activity. Dayan *et al.* (1992) found that it is often difficult to standardize their dosages due to variation in their diverse growing conditions, varietal differences, age of sample at harvest, extraction methods and storage conditions.

Nevertheless, establishment of quality standards for botanical products involves numerous interwoven practical, scientific and legal issues. Infrastructures such as specialized research laboratory and storage facilities for botanicals raw materials and products need to be put in place. There is need for collaboration with the Government and its agencies such as National Agency for Food and Drug Administration (NAFDAC), Standard Organization of country and the farmers in order to establish and maintain such facilities. Standard formula of extraction technique of crude, semi-purified or purified botanical pesticide products should be originated and introduced in order to produce more consistent botanical pesticides globally. Proper identification of botanical products used as bio-pesticide is imperative. Economics is an important factor, as the cost of these standards is often prohibitive (Hameed *et al*., 2012).

5. Benefits of Effective and Sustainable Utilization of Botanical Pesticides

The imperative of using botanical pesticides in agricultural pest management can never be overemphasized. Because, botanical pesticides are easy to prepare, biodegradable and low cost alternative to synthetic pesticides, host specificity, conventional techniques or methods of application. More so, they are ideally suited for integration with most of other plant protection measures used in Integrated Pest Management (IPM) programs, no fear of environmental deterioration or pollution and hence eco-friendly. Also there is no problem of toxic residue and permanent control of pest or long persisting effects among others.

6. Future Prospects

Biotechnology facilities, scientific laboratories and National Pharmaceutical Research Institute (NIPR) and the science & technological-oriented universities are necessary to be explored and engage in extensive exploitation, so as to boost the botanical products research and utilization. It is imperative that commercial botanicals formulations should be produced and made available for use instead of the current crude preparation. Crude formulations often degrade rapidly and therefore applied frequently and precisely. Certified commercial botanical pesticides on the long run involve minimum labour requirements and can be formulated for stability under ultraviolet rays. Care is however needed to be taken to ensure its even distribution, unrestricted availability and high quality so that it will get to the farmers at the most affordable rate.

Conclusion and Recommendations

The present review underscores the need for sustainable use of botanical pesticides in an integrated pest management and control as they are cheap, easy to prepare, eco- friendly and low-cost alternatives to agrochemicals. Reports on negative effects of synthetic pesticides and environmental risks resulting from their indiscriminate applications have been reported and this renewed interest towards botanical pesticides as an eco-chemical approach in pest management. In the context of agricultural pest management, botanical pesticides are well suited for use in organic food production and may play a great role in the production and protection of food in developing countries. The current trends of modern society towards 'green consumerism' desiring fewer synthetic ingredients in food may favour plant-based products which are 'generally recognized as safe' (GRAS) in eco-friendly management of plant pests as botanical pesticides. In this regard, the importance of recruiting botanicals in plant protection or pest control is imperative.

This study recommends that farmers should be enlightened on the critical use of right pesticides and other protective measures in order to satisfy the criteria of effective plant protection. Plant protectionists should also include in their research, the development of crop resistant varieties to pests and diseases. Natural plant chemicals will play a significant role in the future for pest control in both industrialized and developing countries. Biodiversity-rich countries should quickly bio-prospect their traditionally used flora to document pesticidal plants in order to check future cases of bio-piracy and establish their sovereign right on the botanical pesticides developed from such plants.

Competing Interest

The entire authors declared no any conflict of interest at whatever form.

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