

Green Pesticides in Nigeria:An Overview

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Abstract
With Nigeria's burgeoning population, there is an ever-increasing need to step-up agricultural productivity. There has been an overzealous application of scientific techniques, such as chemical pesticides and herbicides, bringing its own set of problems, ranging from pollution of water resources to destruction of wildlife. In a bid to maximize crop yield from available arable land, many old, non-patented, more toxic, environmentally persistent and inexpensive pesticides are used extensively in Nigeria. The fate of these pesticides has become a source of concern particularly in the developing world where they are used indiscriminately. Protecting the environment is crucial in improving the lives of poor people in developing countries, because they pay a higher price when the environment turns against them. This paper examines first, the relationship between food security, agrochemicals and the environment and highlights some strategies for sustainable use of plant protection products. It further highlights the challenges hampering the use of green pesticides in Nigeria.
Keywords: agrochemicals, food security, green pesticides, sustainability

1. Introduction

There is no gainsaying the fact that without agrochemicals, food security may remain a mirage in developing countries. The first of the Millennium Development Goals (MDGs) is a pledge by the international community to halve the number of people in the world suffering from extreme hunger by the year 2015, a promise that puts agriculture at the heart of the development agenda. Protecting the environment is also one of the MDGs. Agriculture must therefore be sustainable. The linkage between the environment, on one hand, and food security, agriculture and poverty alleviation, on the other, is a critical concern of the MDGs and is set to become a major pivot of the emerging successor agenda to the MDGs, the Sustainable Development Goals (SDGs). The use of agrochemicals, including pesticides, remains a common practice especially in tropical regions and South countries. Cheap compounds, such as DDT, HCH, chlorpyrifos and lindane, that are environmentally persistent, are today banned from agricultural use in developed countries, but remain popular in developing countries. As a consequence, persistent residues of these chemicals contaminate food and disperse in the environment. Coordinated efforts are needed to increase the production of food with a view to enhancing food quality and safety as well as to controlling residues of persistent pesticides in the environment. The need to ensure the efficacy of pesticide products for their proposed use, while at the same time protecting pesticide users, consumers, crops, livestock and the environment cannot be overemphasized. This underscores the importance of recruiting 'green' pesticides and botanicals in plant protection or pest control. Green pesticides are the new paradigm in the agrochemicals and food security debate.

1.1 Background

World population is growing at an annual rate of 1.2%, i.e. 77 million people per annum. Six countries account for half of this annual increment: India, China, Pakistan, Nigeria, Bangladesh and Indonesia (Carvalho, 2006). According to the United Nations (UN) estimates, the population of the more developed regions (1.2 billion) will change little during the next 50 years, because fertility levels will remain low, even below replacement level. In contrast, the population of less developed regions is foreseen to rise from 4.9 billion in the year 2000, to 8.2 billion in the year 2050, assuming that some degree of decline in fertility will occur. Therefore, despite the projected increase of population growth rate occurring both in developed and developing countries, probably 95% of the global population increase will take place in the developing countries (UN, 2001, 2005). Regions with very modest gross domestic products (GDPs) such as sub-Saharan Africa, will register the highest population growth rate (UN, 2001).

Throughout the world, people get their daily supply of calories from different diets. In Europe and North America this supply is largely obtained from livestock products, while in many other regions, the calories supply is primarily obtained from cereal grains. Overall, 80% of the poor in developing countries live in rural areas and derive their livelihood directly from agriculture with diets that are deficient in micronutrients (minerals, vitamins, etc) and amino acids (FAO, 2002).

At the global level, significant progress has been made since 1960 towards improved nutrition and food security. Since then, world gross agricultural production has grown more rapidly than the world population, with an average positive production increase of food per capita (Klassen, 1995). Nevertheless, progress achieved has been very different between regions. While food security improved significantly in East Asia, it became very unsatisfactory in sub-Saharan Africa and South Asia where the number of people suffering from hunger dramatically increased (FAO, 2002). There are several causes of this such as regional conflicts, political instability and wars, droughts and shortage of water supply, abandonment of agriculture by migrant populations and increased desertification. These causes will likely remain in the near future. At the same time, more developed regions produce high quantities of food and generate surplus of food commodities. In spite of this, under nourishment exists in developed countries also (FAO, 2002; 2004). As stated by FAO, literally millions of people, including 6 million children under the age of five, die each year as a result of hunger. "Of these millions, relatively few are the victims of famines that attract headlines… and emergency aid. Far more die unnoticed, killed by the effects of chronic hunger and malnutrition, a 'covert famine' that stunts their development, saps their strength and cripples their immune systems" (FAO, 2002, 2004).

Agrochemicals are used extensively in Nigeria, but without much regulation. Monitoring and evaluation remains a challenge even when there is some form of regulation. With growing interest in environmental protection, earnest efforts are being made in laying down sound policy guidelines. The tripartite bond between agriculture, environment and food security is on the front burner in Nigerian policy enactments (FEPA, 1998; The New Nigerian Agricultural Policy, 2001).

2.0 The Concept of Food Security

Without necessarily being definitional, a discussion of the concept of food security becomes imperative because it has assumed the status of an "essentially contested concept" simply because the concept of food security has been used in various ways (Ojo and Adebayo, 2012). Whereas, food security in its most basic form is defined as the access by all people to the food needed for a healthy life at all times in simple language, a country is food-secure when majority of its population has access to food of adequate quantity and quality consistent with decent existence at all times. What is implied in this definition is that food must be available to the people to an extent that will meet some acceptable level of nutritional standards in terms of calorie, protein and minerals which the body needs; the possession of the means by the people to acquire (i.e. access) it and reasonable continuity and consistency in its supply (Davies, 2009). In other words, food security can be taken to mean access by all people at all times to sufficient food for an active, healthy life. Its central elements are: (a) availability of food and (b) possession of the ability for its acquisition. Food insecurity on the other hand, represents lack of access to enough food and can be either chronic or temporary. In chronic food insecurity, which arises from a lack of resources to produce or acquire food, the diet is persistently inadequate (Idachaba, 2004).

Food security should not be seen only from the perspective of availability either in quantitative or qualitative terms. Food hygiene and safety are usually given important consideration in order to protect the health of the people. Food, for instance, may be available but the source from which the food is produced or processed may be unhygienic. The chemical substances used to produce or preserve the food may also constitute health hazards. Health and safety considerations therefore become important in food security. For instance, given the general misuse of chemicals due to illiteracy and crass ignorance, particularly in developing countries, some chemicals used for treating livestock diseases and the indiscriminate application of pesticides to treat crop diseases or control pests and other agricultural parasites, may constitute harm to humans much later after the consumption of the agricultural products.

2.1 Challenges of food security in Nigeria

Attaining food security in its entirety poses a huge challenge in a country like Nigeria, as a result of a wide spectrum of problems (Eme *et al.,* 2014). More than 90 per cent of agricultural production in Nigeria is rain-fed with about 79 million hectares of arable land, of which 32 million hectares are cultivated (Nwajiuba, 2012, cited in FAO, 2012). Both crop and livestock production remains below optimum potentials. Despite a 7% growth rate in agricultural production (2000 to 2008), the growing population is dependent on imported staple food (e.g rice, beans) exemplified by increase in food import bill.

First and foremost, the primary cause of food insecurity in developing countries is the inability of people to gain access to food due to widespread poverty and unemployment, which also inhibits purchasing power and prevents assured access to food supplies. Secondly, global food prices have risen dramatically in the last few years and are forecast to rise further or become more volatile (Nelson *et al,* 2011, cited in, FAO, 2011). Food price volatility has exerted considerable pressure on global food security, and many Nigerians depend on the local market for their food supply and are therefore, vulnerable to high food prices. Related to high food prices is a high cost of input which limits yield and production levels that many times leads to sub-optimal input utilization. For instance, fertilizer consumption in Nigeria is one of the lowest in sub-Sahara Africa at 7lg per hectare (Abu, 2012, cited in, FAO, 2012). Thirdly, climate change affects food security significantly in unpredictable ways as a result of its detrimental effect on pests, crop production, animal husbandry, and humans.

Changing climatic conditions affect both the physical and the economic availability of certain staple food items. Their impacts on income-earning opportunities can affect the ability to buy food, the availability of certain food products, and price. Changes in the demand for seasonal agricultural labour, consequent upon changes in production practices, will in turn affect income- generating capacity. Fourth, farmers in Nigeria also have limited access to credit, and less than 10 per cent of irrigable land is being irrigated. Fifth, the global economy is knowledge-driven and food system efficiency is dependent heavily and directly on agricultural technological innovations and innovations in relevant sectors. Nigeria's adult literacy level is 54.5 per cent (NBS, 2009). However, the rural poor who are the active stakeholders in food availability account for 33.4 percent and are mainly involved in subsistence farming.

2.1.1 Increasing production to provide food security

The increase of food production per capita could be obtained by one of several means, or a combination of them, such as increasing the area of agricultural land, enhancing the yield of crops through the use of agrochemicals, organic fertilizers, biological controls, and improved soil and water management. Furthermore, using more productive plants and plant varieties resistant to pests, and promoting the use of genetically modified organisms (GMOs) resistant to pests and diseases could help. In all of these tentative solutions some experience has been obtained globally already. Results may be encouraging, but some are controversial.

Currently, the immediate response to the need for increasing production of food is a more intensive use of agrochemicals. Nigerian farmers in a bid to increase food production from available land, simply pour agrochemicals not paying attention to the detrimental effects of these on man and the environment. Agrochemicals include two large groups of compounds; chemical fertilizers and pesticides. The use of chemical fertilizers tremendously increased worldwide since the 1960s and largely was responsible for the "green revolution", i.e. the massive increase in production obtained from the same mass of land with the help of mineral fertilizers (nitrogen, phosphorus, potassium) and intensive irrigation. This has been the success story of rice, corn and wheat productions that increased worldwide (Borlaugh and Dowswell, 1993). This revolution was assisted also with the introduction of more productive varieties of rice and wheat (dwarf wheat).

Notwithstanding the increased production, massive use of mineral fertilizers caused serious contamination of aquifers, especially with nitrate, decreasing the quality of water for human consumption (Camargo and Alonso, 2006). This is the case for vast regions in developed countries such as France, as well as in other developing countries. Fertilizers of different types, such as phosphate and super phosphate fertilizers, produced from fosforite and phosphoric acid, raised problems of environmental contamination with heavy metals, such as cadmium and arsenic, and radio nuclides of uranium and thorium series. Furthermore, the excess of nitrate and phosphate fertilizers caused serious problems of eutrophication of water bodies in Europe, Thailand, Malaysia, etc. (UNEP, 2005).

The use of pesticides, including insecticides, fungicides, herbicides, rodenticides, etc., to protect crops from pests, helped to significantly reduce the losses and to improve the yield of crops such as corn, maize, vegetables, potatoes, cotton, as well as to protect cattle from diseases and ticks and to protect humans from malaria vectors. The world has known a continuous growth of pesticide use, both in number of chemicals and quantities, sprayed over the fields. Pesticides are poisons intentionally dispersed in the environment to control pests, but they also act upon other species causing serious side effects on non-target species. Residues of pesticides contaminate soils and water, remain in the crops, enter the food chain, and finally are ingested by humans with foodstuffs and water (Taylor *et al.,* 2003).

The application of different agrochemicals varies with regions of the world. For instance, in North America and Western Europe due to high costs of labour the chemical control of weeds is heavily done with herbicides, contrasting to East Asia and Latin America where herbicides are much less used. In the tropics, where insect pests and plant diseases are more frequent, pesticides are generally applied in massive amounts, both in small farms as well as in cash crops, i.e. industrial plantations such as banana, coffee, maize, cocoa and cotton. The residues of pesticides, especially the organochlorine and organophosphorous compounds, are found in soils, atmosphere and in the aquatic environment in relatively high concentrations (Carvalho *et al.,* 1997). Studies performed among people living in rural areas of some countries, such as Costa Rica and Nicaragua, indicated direct exposure of many workers to the chemicals and acute poisoning with effects on reproduction and central nervous system (Bretveld *et al.,* 2006). The population at large is exposed also to residues that are dispersed in the environment (Taylor *et al.,* 2003) Recent studies, carried out for example in coastal areas of Mexico, Nicaragua and Vietnam, show that aquatic species, such as clams and oysters, that are important components of the diet of riverine populations, may contain relatively high concentrations of DDTs, lindane, HCHs, endosulfan, toxaphene, chlorpyrifos amongst other crop protection chemicals (Carvalho *et al.,* 1997, 2002; Taylor *et al.,* 2003; Carvalho, 2005).

Another way of improving food security is through increasing the shelf life of foodstuff through irradiation of foods (IAEA, 2003). Actually, this procedure has been largely tested and demonstrated to be effective in delaying spoilage of potatoes, onions, fruits, and many other foodstuff. However, for the time being this treatment is not of wide public acceptance although it has the potential to replace many chemical additives used for the same purpose that are not totally safe for consumers (Macfarlane, 2002). Increased shelf life of food means also a more stable storage of banked food.

2.2 Agrochemicals - Pesticide problems and problem pesticides

The use of pesticides throughout the world has increased by 50% over the last 30 years, and 2.5 million tons of commercial pesticides are now applied annually. They are aggressively promoted by large companies and government groups making up a more than $35 billion a year industry.

The problem is, as our reliance on chemical pesticides increases (along with their cost), their effectiveness is declining. Crop yields lost to insects are greater now than they have ever been, even with increased toxicity. The issues include the following:

- Conventional pesticides create secondary pest problems. Chemical insecticides are rarely selective and kill a large number of insects, including the good ones. The environment created by indiscriminate insecticide use often allows other insects — not the initial pest but different insects seeking out food — to rapidly increase in number because no natural enemies (beneficial insects) remain to prevent the population explosion. In some instances, secondary pests cause greater damage than the insects that were initially the problem
- Conventional pesticides invoke resistance. Insect pests have a weird ability to develop resistance to conventional insecticides. Currently, there are more than 500 insect pest and mite species that have shown resistance. In fact, some of the most destructive pests found in the garden cannot be controlled with today's chemicals.
- The economics of conventional pesticide use. The combination of secondary pest outbreaks, insect resistance, government regulations, and legal battles over safety and the environment have made the cost of chemical insecticides to rise dramatically.

2.2.1 Current trends in the use of agrochemicals and food safety

There are two opposite trends in the use of agrochemicals, each one related to a geographic region. Developed countries, including European Union, USA and Canada, approved new laws restraining the use of agrochemicals. This legislation aims at protecting consumers through a more thorough toxicological testing of compounds and enforcement of lower concentration limits for the residues tolerated in food and water (Harris, 2002). For example, the maximum permitted concentration of pesticides in drinking water set by the EU is 0.1 ug/1 (Directive 80/778/EEC), challenging even the detection limits of current analytical methods (Barcelo and Hennion, 1997).

This move is driven by health concerns of the public and consumer associations that perceive the presence of pesticide residues in the environment as detrimental to life quality Results of scientific research support this point of view. Actually, it has been shown that even in low concentrations, the combined effect of xenobiotic chemicals causes suppression of immune response and hypersensitivity to chemical agents. In many cases, a relationship between organochlorine residues and breast cancer, and between PCBs and reduced sperm count and male sterility has been documented (EEA, 2005).

Developed countries go, therefore, in the direction of fewer chemicals and more "green products". Furthermore, new pesticides are less persistent in the environment (more environmentally friendly) than classic pesticides. These new pesticides, however, are more costly when compared with old chemicals, and generally cannot be afforded by developing countries.

Developing countries go in a different direction in these matters. They need to increase the agriculture production and the use of crop protection chemicals seems a simple way for obtaining better crop yields. Therefore, either they use chemicals that are cheap, such as DDT, HCH, BCH, because either their patents have expired and are easy to synthesize or they are even offered by developed countries. In this path the contamination of environment, exposure of the public, and residues in food are higher. Risks to public health are higher too (Carvalho, 2006).

2.2.2 Stored Product Pests

Throughout the whole of Sub-Saharan African, an estimated 25-40% of grain crop is lost in stores each year due to insects (Mulungu *et al.,* 2007). This is because of inadequate village level storage caused by poor storage structures and expensive, and therefore scarcely available storage chemical pesticides (Koona and Njoya, 2004). Little attention seems to be given to this astonishing fact of crop losses in stores due to storage pests. It is between harvest and consumption that the high losses occur to the individual farmers' grains (Nchimbi-Msolla and Misangu, 2002).

A considerable volume of information is available on losses to stored common beans from bruchid infestation. Bruchid damage reduces the weight, quality and viability of bean seed (Reuben *et al*., 2006). The degree of loss due to bruchid damage is quite variable and depends on the storage period and storage conditions. In Tanzania, for example, bean losses of up to 40% due to bean bruchids have been reported. It has been reported also that the damage increases as storage period is prolonged (Singh, 1990).

Synthetic pesticides have for long been effective and the most important in grain storage, however, there are several disadvantages accompanying their use. Most of the synthetic pesticides in use have persistent residues, which can hardly be removed during grain processing and are neither user nor environment friendly; can result in harmful residues in foodstuff and development of resistance in the target insect populations. Farmers treat their produce with synthetic insecticides during storage whereas majority of them still lack the knowledge on proper, safe and effective use (Mulungu *et al.,* 2012). These synthetic chemicals have become expensive; therefore, resource poor farmers fail to utilize them at the recommended dose rendering them ineffective and making pests control difficult and dangerous. Synthetic pesticides also may cause serious health hazards, insect pest resistance, resurgence, environmental pollution, ecological imbalance and residues in market produce.

The global problem of acute pesticide poisoning has been confirmed as extensive by a variety of independent estimates. Further, it is also recognized to be a problem confined to the developing countries. Inappropriate pesticide handling and application have been observed around the world and this has led to an annual poisoning of about three million people with acute symptoms, about 20,000 deaths and about 735,000 chronic illnesses (WHO, 1990). Pesticide poisoning has been discovered to occur more in developing countries, affecting women, children and infants (Goldmann, 2004). Most estimates concerning the extent of acute pesticide poisoning have been based on data from hospital admissions which would include only the more serious cases. The latest estimate by a WHO task group indicates that there may be 1 million serious unintentional poisonings each year and in addition 2 million people hospitalized for suicide attempts with pesticides. This necessarily reflects only a fraction of the real problem. On the basis of a survey of self-reported minor poisoning carried out in the Asian region, it is estimated that there could be as many as 25 million agricultural workers in the developing world suffering an episode of poisoning each year (Jeyaratnam, 1990). This article emphasizes the need to control the problem on a collaborative basis by all concerned, including national governments, agrochemical industries, international agencies, scientists and victims. High levels of pesticides residues arising from improper application and multiple sprays of sub lethal doses have been reported to be responsible for the poisoning and deaths of people in both rural and urban areas of Borno State and Nigeria in general (Gwary *et al.,* 2012). Whole families have been wiped out on consuming meals of beans. The scenario is quite simple: a man sprays a consignment of beans with chemical insecticides and stores them for sale after say, three months. A month later, his father-in-law dies and a huge sum of money is required for the burial and funeral rights. Out of ignorance or sheer desperation, he transports his beans to the market for sale. An unsuspecting family eats a meal of it and all family members are dead in a couple of days, clear symptoms and autopsy traced to the beans consumed.

2.3 The new paradigms

The last decade has seen new developments in food production: the genetic engineering of organisms, the organic-chemical-free agriculture and green pesticides.

Biotechnology and release of genetically modified organisms (GMOs), such as engineered soybean, maize and tomatoes, did promise a solution to food security needs and nutritional problems (Khush, 2002). According to the main biotechnology private companies (Aventis, Monsanto, Novartis, Zeneca, etc), these GMOs may be resistant to insect pests, to moulds, to frost, to dry conditions, etc, and could revolutionize agriculture (Pingali and Traxler, 2002). For example, soybean and other plants were modified to be tolerant to glyphosate, a common herbicide. The use of these GM plants renders the farmers dependent upon the use of more and more glyphosate. Interestingly, glyphosate is produced by the same company that produces the GM herbicide resistant plants.

Another paradigm has been the development of organic agriculture. Although started in the twenties, this has grown so much in the last 20 years that it corresponds to the use of a few millions of hectares already (Tamm, 2001). Organic agriculture respects the normal functioning of ecosystems, avoids the use of agrochemicals, and leads to food "free" of synthetic chemicals and, thus, more healthy, Notwithstanding the health value of better quality agriculture products, organic agriculture does not appear to have the potential for mass production of the amount of calories needed to feed humanity (Nnamonu and Ali, 2012). The development of organic agriculture may, therefore, contribute to improved food safety but does not help to cope with food security. It will be needed to increase agriculture production further. The successful control of hunger and under nourishment requires the control of population growth. Despite the conflicting views about the human carrying capacity of Earth, over population will not help to solve under nutrition. Furthermore, technology may not be able to provide in time miraculous solutions to feed a continuously growing population (Cohen, 2005).

3.0 Green pesticides

The concept of "Green Pesticides" refers to all types of nature-oriented and beneficial pest control materials that can contribute to reduce the pest population and increase food production. They are safe and eco-friendly. They are more compatible with the environmental components than synthetic pesticides. Thus in the present concept of green pesticides, some rational attempts have been made to include substances such as plant extracts, hormones, pheromones and toxins of organic origin and also encompass many aspects of pest control such as microbial, entomophagous nematodes, plant-derived pesticides, secondary metabolites from microorganisms, pheromones and genes used to transform crops to express resistance to pests. More recently, the encouragement of use of products from natural resources and even the extremely biodegradable synthetic and semi-synthetic products in pest management, has been considered to come under the umbrella of green pesticides (Koul *et al.,* 2008).

Natural products are an excellent alternative to synthetic pesticides as a means to reduce negative impacts to human health and the environment. The move toward green chemistry processes and the continuing need for developing new crop protection tools with novel modes of action makes discovery and commercialization of natural products as green pesticides an attractive and profitable pursuit that is commanding attention. However, it will be beyond the scope of this write up to discuss all of them at once.

The term "green" has become a trendy catchword, and is used with respect to pest control and pest control chemicals and equipment. This term does not appear to have specific regulatory boundaries, and many private enterprises are using it to push their products or agenda. Many individuals and groups advocate the use of natural pesticides and insinuate that since they are found in nature, and are not synthetically produced, they are therefore safer to use. Clearly, therefore, green pesticides encompass both synthetic and natural products and processes that eliminate or repel pests but are benign, friendly or harmless to the environment and ecosystem. Natural pesticides on the other hand are restricted to products that are from natural renewable resources, but not confined to benign, friendly or harmless products. For example, nicotine, rotenone, lead, mercury, arsenic etc., were once used as natural pesticides but are highly toxic. Another example of a toxic natural product is the poisonous snake venom. Therefore, the two terms should not be interchangeably used.

3.1 Types of green pesticides

3.1.1 Botanical Pesticides

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 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 favourable 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 biopesticides, biocontrol and other methodologies.

Botanical insecticides are usually harvested by macerating (soaking and separating) plant tissues high 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 (other ingredients included in the product). The advantage of using botanical insecticides is their short persistence and little 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. The diversity and redundancy of phytochemicals in botanical extracts is also useful. Redundancy, which is the presence of numerous analogues of one compound, is known to increase the efficacy of extractives through analogue synergism, reduce the rate of metabolism of the compounds and prevent the evolution of pesticide resistance when selection occurs over several generations. From a research discovery point of view, the number of insect deterrents derived from plants seems endless as co-adaptation appears to have produced a huge diversity of novel compounds across the plant kingdom and a remarkable redundancy of plant defences within each plant species. Research activities have provided application for behaviour modifying anti-feedants, essential oils with repellent fumigant and insecticidal action and a large number of agents with novel modes of action.

Despite many advantages, the botanical pesticide market has a number of major challenges and although there has been growth, 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. There is, as well, competition from other biopesticide and biocontrol 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.

Botanical pesticides include:

i. Neem: In addition to its categorization as a botanical, neem is also the source of a plant-derived horticultural oil. The neem tree is native to India and is the source of hundreds of products, including insecticides made from the extracts of the seeds and bark. The primary insecticidal extract is azadirachtin. When azadirachtin is used for pest management, it can act as an insect repellant, an anti-feedant (interferes with feeding), and growth regulator (interferes with molting and growth). When neem oil or neem soap is used, it poisons upon contact much like other soaps and oils. In some cases, neem can also be a systemic insecticide (when applied to the soil, the active ingredients are absorbed into the plant and transported to the growing tips and leaves).

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.

ii. Pyrethrum: a member of the class known as pyrethrins, is extracted from the seed of *Chrysanthemum cinerariaefolium* and has been used as an insecticide for over 100 years. Today these plants are grown primarily in Kenya. Pyrethrum is effective against a wide range of soft-bodied garden pests such as scales, whitefly, mealybugs, and thrips, but will not control mites. Pyrethrins are neurotoxins that attack an insect's nervous system and cause repeated and extended nerve firings. They may also have a repellant effect.

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 product is applied than specified on the label. Pyrethrins should not be sprayed around ponds or other bodies of water, as they can kill fish. Pyrethrum is a broad-spectrum insecticide that is toxic to beneficial insects. Pyrethrum can paralyze susceptible insects upon exposure, but also degrades in sunlight within hours. To get adequate management of some pests, repeated applications are needed. Pyrethrum products frequently contain a low hazard activator or synergist such as piperonyl butoxide or piperonyl cyclonene that substantially increases the effectiveness of the pyrethrum and reduces its cost (Pedigo and Rice 2008). Depending on the way these synergists have been manufactured, some pyrethrum products containing synergists may be allowed for use in organic agriculture.

iii. 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 phytotoxic (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 phytotoxicity. Phytotoxic effects are easily noticed by the browning or "burning" of the leaves or new growth on the stems.

iv. Dormant and summer oils: Dormant and summer horticultural oils can control egg, nymph, larva, and adult stages of overwintering leaf rollers, aphids, mites, and scales. Dormant oils are effective at controlling overwintering eggs and soft-bodied insects and can be used in the early spring before active plant growth begins. Only use dormant oils on woody trees and shrubs in dormant or delayed-dormant stages to avoid severely burning the foliage. Do not apply either type of oil during freezing weather because it will reduce the effectiveness of the oil properties and coverage of the application.

Summer oils can be applied to some woody plants (see the label for specific plants) during the growing season. Some horticultural oils can be applied in either summer or winter; however, the concentration used in summer is far lower than in the winter. To use summer or dormant oils, first dilute with water. (Commercial oil products contain emulsifying agents that allow them to mix easily with water.) Pests rarely develop resistance to oil sprays, and the products cause little or no harm to most beneficial insects. When oils are used correctly (as directed on the label), they are not hazardous to human health.

v. Traditionally used botanical insecticide 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 are 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. Rotenone is the trade name of the insecticide derived from extracts of the tropical legumes *Derris* and *Lonchocarpus.* The main active principle, the isoflavonoid rotenone, is moderately toxic to mammals due to poor absorption and rapid metabolism, but is highly toxic to insects and fish, 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. It continues to be used in other countries.

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 sp.* 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. (Johnson, Thor Ar *et al.,* 2003).

3.1.2 Natural pesticides

Living organisms that are used to manage pests are called biological controls or biological agents. When a microorganism is packaged and sold to control a pest, it is legally considered a biopesticide and is regulated as such (EPA, 2013). Multicellular organisms such as beneficial nematodes are an exception; although considered biological controls and packaged and applied similarly to other biological insecticides, they are not regulated as pesticides. When using biological insecticides, the instructions on the label must be carefully followed to avoid killing the organisms in the product, which would make it ineffective. The advantage of using biological products is that they are less likely to negatively impact non-target organisms, including people. As a result, several types of biopesticides have been considered as follows:

i. Bacillus thuringiensis: *Bacillus thuringiensis* (Bt) is a naturally-occurring bacterium that feeds on the larval stages of insect pests such as mosquitoes, Colorado potato beetles, and cabbage loopers. *Bt.* var. *kurstaki* feeds on Lepidopteran larvae, known as caterpillars, commonly found on vegetables and fruits. Under natural conditions when a caterpillar ingests Bt, the bacterium releases a toxin within the insect's gut, and the toxin degrades the stomach lining, causing the insect to die. While this process can take several days, feeding ceases within a few hours. If the bacteria are successful in reproducing within soft-bodied insects like caterpillars, the pests often become limp. Infected caterpillars can ooze Bt onto plant parts where other caterpillars can ingest the insecticide, continuing the cycle.

Commercial Bt products are formulations of the bacterial toxin and are nonliving. Bt can be sensitive to ultraviolet light (sunlight) and is most effective when applied in overcast conditions or late in the day. Most Bt products degrade within 24 hours regardless of sunlight conditions or temperature, giving them a very short period of effectiveness once they have been applied. Small and young caterpillars are most susceptible to Bt, so caterpillar development must be regularly monitored in order to time the application to coincide with newly hatched caterpillars. The immature insects must be feeding, as Bt is only effective when ingested. If temperatures are too cool or too hot, insects may stop feeding. Multiple applications are often needed for adequate management of the pest.

Different strains of Bt are effective against specific pests, care must be taken to choose the Bt product that targets the pest to be controlled. For example, *Bt.* var. *kurstaki* kills caterpillars, while *Bt.* var. *israelensis* is for mosquitoes and other fly larvae.

Similarly, the various *Bacillus* products available for purchase online and in garden stores should be checked for suitability in different areas. For example, *B. popilliae*, marketed as Milky Spore Powder, is only useful for managing Japanese beetles.

ii. Beauveria bassiana: *Beauveria bassiana* is a soil borne fungus that feeds on insects and can be used effectively to control thrips, aphids, whitefly, caterpillars, beetles, and subterranean insects like ants and termites. *B. bassiana* is applied to the target pest as a spore, which is the reproductive and dispersal structure of the fungus. Once the spores have contact with the insect exoskeleton, they grow hyphae (long, branching vegetative appendages) that secrete enzymes, which in turn dissolve the cuticle (outermost layer of the skeleton). These fungal hyphae then grow into the insect, feed on its body tissue, produce toxins, and reproduce. It takes up to seven days for the insect to die. If moist conditions (92 percent humidity or greater) are present during this time, *B. bassiana* will "bloom" and release more spores into the environment to repeat the cycle on other pest insects.

B. bassiana can be sensitive to sunlight, so it may be best to apply at the end of the day. The biggest disadvantage of this insecticide is that its spores will infect many non-target beneficial insects too. However, the strain used and sold commercially does not affect honey bees.

iii. Nematodes: Nematodes are multi cellular organisms commonly referred to as microscopic worms. Certain nematode species are considered beneficial, as they are very effective at managing soil-dwelling insect pests such as root weevils and cutworms, and can also control pests that pupate or hibernate in the soil such as codling moth larvae.

The two different types of nematodes used for insect control are cruisers and ambushers. Cruisers seek out their insect prey, while ambushers wait for insects to pass by. *Steinernema carpocapsae* and *S. scapterisici* are ambushing nematodes effective for managing mobile insects like crane fly larvae, fleas, and cutworms. *Heterorhabditis bacteriophora* and *S. glaseri* are cruisers used to manage slower-moving insects like root weevil and scarab beetle larvae. *S. riobrave* and *S. feltiae* nematodes do both ambushing and cruising. These species are effective at managing codling moth and fruit tree borers.

For both types of nematodes, the infectious juvenile stage attacks susceptible hosts by entering the insect body through openings such as respiratory spiracles. Once inside the body, the nematodes release bacteria that liquefy the innards of the insect, which thereby becomes food for the nematodes and enables them to multiply. A single or small number of nematodes can produce thousands more of their own kind in 2–3 generations. Once the nematodes have consumed the host insect, they disperse to infect other insects.

In commercial insecticide products, beneficial nematodes are often in the form of infective juveniles and housed on a sponge or encased in clay. They must be cared for, stored, and applied properly to be effective. While beneficial nematodes are commonly packaged similarly to other insecticides, they are not regulated by the EPA in the same way.

iv. Nosema: *Nosema* are protozoans (a diverse group of single-cell organisms which can be highly mobile), that have proven to be effective control agents for some insect pests. For example, *Nosema locustae* is used to manage grasshoppers. *Nosema* spores are added to bait (also called an attractant) which the grasshopper eats. The spores germinate and the protozoans feed within the insect's body cavity. As the protozoans reproduce, the insect's health declines. *N. locustae* is active only against young grasshoppers and can take 3–4 weeks to cause mortality. Infected grasshoppers generally feed less and produce fewer eggs. *Nosema* works most effectively in large-scale grasshopper management programs in contrast to home gardens where only small areas are treated, as grasshoppers can easily move into the target space.

v. Fermented microbes: Some microbes can be fermented to produce an insecticide such as abermectin, a fermented product of *Streptomyces avermitilis* used in baits for household insect pests. The best known home gardening product of this type is spinosad. Metabolites of *Saccharopolyspora spinosa,* a soil-inhabiting bacteria that is fermented, are the basis for this new class of insecticide. The fermentation process has been industrialized to produce commercial insecticides. Spinosad is composed of spinosyns A and D. The fermented product is very toxic to caterpillar pests such as cabbageworm, cabbage looper, diamondback moth, armyworm, and cutworm, as well as fruit flies such as spotted wing drosophila. Spinosad can act on a susceptible insect's stomach and nervous system. It is primarily ingested by feeding insects but can have some efficacy when sprayed directly on insects. Affected pests cease feeding and undergo partial paralysis within minutes upon exposure to spinosad, but it may take up to two days for the insects to die (Salgado et al. 1998). Spinosad is systemic in some plants.

Depending on the fermentation process and formulation, some spinosad insecticides are considered organic. Spinosad has low toxicity to many beneficial insects that prey on pests, and is nontoxic to mammals and other vertebrates, with the exception of some fish (e.g. slightly toxic to trout). Spinosad is toxic to bees for three hours after application, and should not be applied to blooming plants during the day. Because it is selectively toxic for many pest species and relatively safe to non-target species, spinosad has become highly desirable as an organic insecticide. However, its popularity raises concerns about the development of pest resistance. Therefore, the use of spinosad should be alternated with other products.

3.1.3 Mineral insecticides

Insecticides developed from elemental (mineral) sources mined from the earth are classified as natural products and often cost less than other processed or harvested insecticides. The toxicity of mineral-based insecticides depends on the chemical properties of the mined elements. Some mineral insecticides such as sulfur are registered for organic use and have relatively low toxic effects on people and non-target organisms. In contrast, lead arsenate is a natural mineral product that was cancelled as a pesticide in 1988 due to its toxicity and persistence in the environment.

i. Diatomaceous earth: Diatomaceous earth is a fine particle dust comprised of fossilized diatoms that is effective against slugs and soil-dwelling insects. Diatoms are small, usually single-celled phytoplankton commonly found in aquatic or moist environments. Diatoms are encased inside a cell wall made of silica, the same compound used to make glass. Diatomaceous earth works as a fine abrasive that disrupts the exoskeleton cuticle of a slug or insect and causes it to desiccate (dry out). It is used only in landscape areas that do not contain edible plants (e.g. ornamental gardens). To create an effective barrier for slugs, diatomaceous earth is applied in a 3-inch wide, 1-inch thick band around the habitats that slugs use. Applications are repeated after periods of rain. Note, however, that diatomaceous earth can also be toxic to beneficial insects such as predatory ground beetles and is highly toxic to bees if applied to blooms.

ii. Elemental sulphur: Elemental sulfur is a finely ground powder that can be applied either as a dust or a spray. This mineral is one of the oldest pesticides known, and reported pest resistance is rare. Sulfur acts as a metabolic disruptor (interferes with a chemical reaction, digestion, or the transport of substances into or between cells) to insects such as aphids, thrips, and spider mites. Most sulfur formulations have low toxicity to people but can be an eye and skin irritant. Sulfur is highly toxic to fish, so it is important to keep it away from water bodies.

Sulfur should not be used on a crop just before harvest if the crop will be preserved; sulfur can produce off-flavors in canned products, and sulfur dioxide can form, which may cause containers to explode. In addition, sulfur is phytotoxic to most crops if applied two weeks before or after the application of a horticultural oil.

iii. Iron phosphate: Iron phosphate is very effective at managing slugs and snails when combined with bait. Baited iron phosphate usually comes in pellet form. Scatter the product around the crop in need of protection and areas where slugs seek refuge, such as garden bed borders and rocks. Liquid formulations are also available. Follow label suggestions for subsequent applications.

Slugs that feed on iron phosphate will stop eating, usually seek a hiding place, and then die of starvation. Iron phosphate is considered relatively nontoxic and does not affect insects, birds, or mammals when applied in the recommended amount. Avoid over-application, as there is some evidence that iron phosphate baits can negatively affect earthworms. Because iron phosphate is nontoxic only in the labelled application amounts, it must be stored in a safe place away from pets and children.

iv. Kaolin: Kaolin is fine clay that is sprayed on plant foliage or fruit to deter feeding and egg laying of insect pests such as apple maggot, codling moth, and leafhoppers. It can also have some repellent properties that cause irritation to insects upon contact (Stanley, 1998). The effectiveness only lasts as long as the clay film covers the fruit or foliage to mask its chemical, visual, and tactile cues. Reapplication is necessary if rain washes the product off. Kaolin's toxicity to pests is additionally dependent on the insect being on the fruit or foliage during the entire time of pest susceptibility. Insect activity must be monitored to be sure that plants are protected during the required times. Kaolin is an organically-approved material.

v. Soap: Natural soaps are derived from plants (coconut, olive, palm, cotton) or animal fat (whale oil, fish oil, or lard) and have been used since the 1700s to control certain soft-bodied insects such as aphids. Soaps are fatty acids that can degrade or dissolve the protective layers of the insect cuticle, causing the insect to desiccate. Insecticidal soaps are considered nontoxic to humans and many beneficial insects, but selectively kill certain pest insects. Some soaps are approved for use in organic agriculture.

Insecticidal soaps are very effective for managing soft-bodied insects like aphids, scales, whitefly, mealy bugs, thrips, and spider mites. The soap must contact the insect's outer skeleton to be effective. Leaf-feeding insects are often found on the undersides of leaves, so the plant foliage must be fully covered. Results from the application of soap are usually seen in 1–3 days. Multiple applications are often needed to be effective. Insecticidal soaps are usually diluted with water before applying.

Household soaps should not be used as insecticides. Household soaps vary tremendously in composition, purity, and effectiveness, and thus have the potential to harm crops. For example, household soaps can be phytotoxic to some plants, resulting in leaf burn. Only soaps that are specifically registered and sold for use as insecticides should be applied to plants. The product label must be read for known phytotoxic effects and the product tested on a small portion of the plant to see if leaf burn occurs. Leaf burn symptoms usually develop within two days.

3.1.4 Essential oils as green pesticides .

Essential oils are defined as any volatile oil(s) that have strong aromatic components and that give distinctive odour, flavour or scent to a plant. These are the by-products of plant metabolism and are commonly referred to as volatile plant secondary metabolites. Essential oils are found in glandular hairs or secretory cavities of plant-cell wall and are present as droplets of fluid in the leaves, stems, bark, flowers, roots and/or fruits in different plants. The aromatic characteristics of essential oils provide various functions for the plants including (i) attracting or repelling insects, (ii) protecting themselves from heat or cold; and (iii) utilizing chemical constituents in the oil as defence materials. Many of the essential oils have other uses as food additives, flavourings, and components of cosmetics, soaps, perfumes, plastics, and as resins. Typically these oils are liquid at room temperature and get easily transformed from a liquid to a gaseous state at room or slightly higher temperature without undergoing decomposition. The amount of essential oil found in most plants is 1 to 2%, but can contain amounts ranging from 0.01 to 10%. For example, orange trees produce different composition of oils in their blossoms, citrus fruits, and/or leaves. In certain plants, one main essential oil constituent may predominate while in others it is a cocktail of various terpenes. In *Ocimum basilicum* (basil), for example, methyl chavicol makes up 75% of the oil, β-asarone amounts to 70–80% in Acorus calamus rhizomes, linalool, in the range of 50– 60%, occurs in coriander seed and leaf oils procured from different locations at different time intervals and is by far the most predominant constituent followed by p-cymene, terpinene, camphor and limonene. Interestingly 2-decenol and decanal were the most predominant constituents in leaf oil (Lawrence and Reynolds, 2001). However, in other species there is no single component which predominates. Most essential oils comprise of monoterpenes - compounds that contain 10 carbon atoms often arranged in a ring or in acyclic form, as well as sesquiterpenes which are hydrocarbons comprising of 15 carbon atoms. Higher terpenes may also be present as minor constituents. The most predominant groups are cyclic compounds with saturated or unsaturated hexacyclic or an aromatic system. Bicyclic (1,8-cineole) and acyclic (linalool, citronellal) examples also make the components of essential oils. However, intraspecific variability in chemical composition does exist, which is relative to ecotypic variations and chemotypic races or populations.

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*). The oils are generally composed of complex mixtures of monoterpenes, biogenetically related phenols, and sesquiterpenes. Examples include 1,8-cineole, the major constituent of oils from rosemary and eucalyptus; eugenol from clove oil; thymol from garden thyme; menthol from various species of mint; asarones from calamus; and carvacrol and linalool from many plant species. A number of source plants have been traditionally used for protection of stored commodities, especially in the Mediterranean region and in Southern Asia, but interest in the oils was renewed with emerging demonstration of their fumigant and contact insecticidal activities to a wide range of pests in the 1990s (Isman, 2000).

There are several examples of essential oils like that of rose (*Rosa damascene*), 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*), Eulcalyptus globulus, 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*, *Melaleuca leucadendron, Pelargonium roseum, Lavandula angustifolia, Mentha piperita, and Juniperus virginiana* are also effective against various insects and fungal pathogens. Studies conducted on the effects of volatile oil constituents of Mentha species confirms that they are highly effective against *Callosobruchus maculatus* and *Tribolium castanum*, the common stored grain pests. Essential oils derived from eucalyptus and lemongrass have also been found effective as animal repellents, antifeedants, insecticides, miticides and antimicrobial products; thus finding use as disinfectants, sanitizers, bacteriostats, microbiocides, fungicides and some have made impact in protecting household belongings. Essential oil from *Cinnamomum zeylanicum, Cymbopogon citratus, Lavandula angustifolia syn. L. officinalis, Tanacetum vulgare, Rabdosia meli- ssoides, Acorus calamus, Eugenia caryophyllata, Ocimum spp., Gaultheria procumbens, Cuminum cymium, Bunium persicum, Trachyspermum ammi, Foeniculum vulgare, Abelmoschus moschatus, Cedrus spp*. and Piper species are also known for their varied pest control properties. Citronella (*Cymbopogon nardus*) essential oil has been used for over fifty years both as an insect repellent and an animal repellent. Combining few drops each of citronella, lemon (*Citrus limon*), rose (*Rosa damascena*), lavender and basil essential oils with one litre of distilled water is effective to ward off indoor insect pests. The larvicidal activity of citronella oil has been mainly attributed to its major monoterpenic constituent citronellal (Zaridah *et al.,* 2003). Vetiver (*Vetiveria zizanioides*) essential oil obtained by steam distillation of aromatic roots contains a large number of oxygenated sesquiterpenes. This oil is known to protect clothes and other valuable materials from insect attack when placed in closets, drawers, and chests. Catnip (*Nepeta cateria*) essential oil is highly effective for repelling mosquitoes, bees and other flying insects. The most active constituent in catnip has been identified as nepetalactone. It repels mosquitoes ten times more than DEET. It is particularly effective against *Aedes aegypti* mosquito, a vector for yellow fever virus. Oil of *Trachyspermum sp*. is also larvicidal against *A. aegypti* and southern house mosquito, *Culex quinquefasciatus* Say (LC_{50} = 93.19–150.0 ppm) (Koul *et al.,* 2008).

3.2 Advantages and Disadvantages of green Insecticides

Green pesticides are cheap, effective and environmentally friendly. But like most good things, they have disadvantages also**.** The pros and cons are enumerated:

Advantages

- Plants producing the compounds are known by the farmer because most of the time they grow in the same general area.
- Often these plants also have other uses like household insect repellents or are plants with medicinal applications.
- The rapid degradation of the active product may be convenient as it reduces the risk of residues on food.
- Some of these products may be used shortly before harvesting.
- Many of these products act very quickly inhibiting insect feeding even though long term they do not cause insect death.
- Since most of these products have a stomach action and are rapidly decomposed they may be more selective to insect pests and less aggressive with natural enemies.
- Most of these compounds are not phytotoxic.
- Resistance to these compounds is not developed as quickly as with synthetic insecticides.

Disadvantages

- Most of these products are not truly insecticides since many are merely insect deterrents and their effect is slow.
- They are rapidly degraded by UV light so that their residual action is short.
- Not all plant insecticides are less toxic to other animals than the synthetic ones.

- They are not necessarily available all season long.
- Most of them have no established residue tolerances.
- There are no legal registrations establishing their use.
- Not all recommendations adopted by growers have been scientifically verified.

Plants to be used as green pesticides

There is a lot of publications with lists of plants possessing insecticidal properties. For example, in 1950, Heal *et al*., reported approximately 2,500 plants in 247 families with some sort of toxic property against insects. It is not enough that the plants are considered promising or even with proven insecticidal properties, it is necessary to conduct an analysis of the risks to the environment and to human health. Another example is that it may not be appropriate to recommend plants that are in danger of extinction. For these reasons and with the purpose of obtaining maximum benefit from a plant with insecticidal properties, but without degrading the ecosystem, the properties that an ideal insecticidal plant should have are listed below:

- It should be a perennial.
- It should have a wide distribution and be present in large numbers in nature. Otherwise it should be possible to be grown by agricultural procedures.
- The plant parts to be used should be removable: leaves, flowers or fruit.
- Harvesting should not mean destruction of the plant (avoid the use of roots or bark).
- The plants should require small space, reduced management and little water and fertilization.
- The plant should have additional uses (for example medicinal use).
- The plant should not otherwise have a high economic value.
- The active ingredient should be effective at low rates.

4.0 Strategies for sustainable use of plant protection products

Sustainable use, in the context of this review means minimising the hazards and risks to both man and his environment from the use of plant protection products without compromising the necessary crop protection property (Lale, 2002). Governments in developed countries and some developing countries have, for many years, operated a policy of 'pesticide minimisation'. Given the rate of increase in human health related problems such as cancer, genetic disturbances and damage to the immune system, which are caused in part by some of the toxic substances contained in pesticides, there is need for the Nigerian government to strategise and consider the effective regulation of these plant protection products (Oruonye and Okrikata, 2010). Research findings in Nigeria and other parts of the world prove that integrating botanical pesticides in our pest management system will promote safer agricultural practice. In Nigeria for example, botanical insecticides have been extracted from various plants including neem (*Azadiracta indica*), Pyrethrum *(Chrysanthemum cinarariaefoliun*), Tobacco *(Nicotiana tabacum*), Derris (*Derris elliptica*), Pawpaw (*Carica papaya*), Tomato (*Lycopersicon esculentum*), Cashew nut (*Anarcardium occidentale*), Garlic (*Allium sativum*), Aligator pepper (*Aframomum melegueta*), Curry leaves (*Hyptis sauvolens*), Onions (*Allium cepa*), Basil (*Ocimum basilicum*), Bitter gourd (*Momordica charatia*), Ginger (*Zingiber officinale*), Bitter leaf (*Vernonia amygdalina*), Siam weed (*Chromolaena odorata*) and pepper fruit (*Uvaria afzelli*). Their biological properties have been tested and found to include insecticidal and repellent effects against insect pests. Some have also been found to have antifeedant, growth regulatory, oviposition inhibitory, sterility inducing, antifungal and nematicidal properties (Abdul-azeez, 2009). Extracts of *Afrostyrax lepidophyllus* have been shown to have pesticidal activity (Nnamonu and Anyam, 2014).

4.1 Recommendations

The following strategies/policies which centre on identifying/discovering, advocating for and promoting the use of botanical pesticides under the framework of integrated pest management will no doubt enhance sustainable use of plant protection products in Nigeria: (1) The Nigerian government should consider making favourable laws and policies to govern the processing and use of selected botanical pesticides. (2) There should be a purposeful encouragement of indigenous private sector participation in the formulation, testing and marketing of botanicals. (3) As a matter of policy, the government should ensure that the period required to register botanicals is far less than that required to register conventional/synthetic pesticides. (4) Another important policy issue is the possibility of indiscriminate harvesting of botanical materials to meet a surge in demand. This could lead to environmental degradation and loss of biodiversity as is already happening in the case of neem in parts of South Asia (Ahmed and Stoll, 1996). To safeguard against this, a species of plant should not be promoted as a source of bio-pesticide until adequate arrangements have been made for its increased production (Lale, 2002). (5) The government should design a policy to encourage and protect local companies that may be involved in the processing and marketing of botanical pesticides so that the citizens could derive maximum benefit from these locally available resources. (6) Presently, many dangerous pesticides are being used in Nigeria for crop protection These classes of pesticides are either highly restricted or banned by law, but the laws are not enforced. The strict enforcement of such law followed by a planned policy to adopt and promote the use of green pesticides; which are comparably safer both to the applicator, food consumer as well as to the environment, will stem the tide of deaths associated with pesticide poisoning (Lale, 2002). (7) The Nigerian government should also promote aggressive enlightenment campaigns through the efforts of both public and private sectors to create high level awareness amongst the citizenry about the available alternatives to synthetic pesticides.

5.0 Conclusion

While pieces of evidence abound that botanical/green pesticides are generally safe and effective, their use in Nigeria as in other parts of Africa is still hampered by some challenges which include: (1) Most data on botanical pesticides are obtained from laboratory trials; field data are rare. (2) There is still hardly developed any appropriate technology for the application of botanicals, especially the oil and dust formulations (Lale, 2002). (3) Compared with synthetic insecticides, the effects of botanical insecticides are short-lived. So frequent applications are required to obtain a reasonable degree of crop protection. (4) Botanical pesticides formulations are yet to be available in usable forms to farmers in commercial quantities so as to serve as alternatives to synthetic pesticides. (5) There is the problem of farmers' acceptability of this seemingly new dimension/technology in pest control (Okrikata and Anaso, 2008). Advocacy for and implementation of integrated pest management strategies on field pests, stored product pests, structural pests and domestic pests is indispensable. Therefore, the discovery, advocacy, adoption and promotion of the use of green pesticides in an integrated pest management framework is most relevant and expedient.

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