2016-01-26

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Scientific Research Publishing Inc.

http://dx.doi.org/10.4236/ajps.2016.71015

American Journal of Plant Sciences, 2016, 7, 138-151
Published Online January 2016 in SciRes. http://www.scirp.org/journal/ajps
http://dx.doi.org/10.4236/ajps.2016.71015

The Toxicity, Persistence and Mode of Actions of Selected Botanical Pesticides in Africa against Insect Pests in Common Beans, *P. vulgaris*: A Review

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Received 18 December 2015; accepted 23 January 2016; published 26 January 2016

Abstract

Common beans are affected by many insect pests such as bean leaf beetle, aphids, legume pod borer and bean beetles. Traditional and cultural practices such as site selection, crop rotation, intercropping and seed selection, sowing date are used to reduce the infestation of insect pests of common beans in the field and in storage rooms. Natural enemies such as predators, parasitoids and pathogens can control the insect pests. Synthetic pesticides such as cypermethion, carbaryl, and lambda-cyhalothrin have reported to be effective, but are toxic to people, destroy natural enemies and contaminate the environment. Botanical pesticides are the promising alternatives. This review paper explains toxicity, persistence and mode of actions of active ingredients of botanical pesticides. Rotenone from *T. vogelii* has the oral lethal dose (LD_{50}) of 132 - 1500 mg/kg to mammals. It delays the electron transport chain in mitochondria of the insects and limits the cellular energy production. Azadirachtin is antifeedant and growth disruptor of insects. It has low toxicity to mammals. The oral LD_{50} in mammals is greater than 3540 mg/kg. Azadirachtin displays strong effects on chemoreceptors of the insects. Pyrethrins are axonic poisons and have repellent effects to insects. It is less toxic to mammals with the LD_{50} of about 1500 mg/Kg. It attacks the nervous systems of insects. Sesquiterpene lactones from *T. diversifolia*, Pentacyclic triterpenoids from *Lantana camara*, Vernodalin, Vernodalol and Epivernodalol from *V. amygdalina* have repellent and feeding deterrents chemicals which discourage the insects from feeding the crop. Most active ingredients of botanical pesticides have short life span in the environment.

Keywords

Toxicity, Persistence, Botanical Pesticides, Mode of Actions, Half Life

How to cite this paper: Mpumi, N., Mtei, K., Machunda, R. and Ndakidemi, P.A. (2016) The Toxicity, Persistence and Mode of Actions of Selected Botanical Pesticides in Africa against Insect Pests in Common Beans, *P. vulgaris*: A Review. *American Journal of Plant Sciences*, **7**, 138-151. http://dx.doi.org/10.4236/ajps.2016.71015

1. Introduction

Currently, synthetic pesticides are used in controlling crops insect pests and have usually provided strong defense against insect pests [1]. Synthetic pesticides have paid off and contributed to increase in crop yields of up to four times the value of the applied pesticides [2]. Synthetic pesticides work quickly, and are not labour intensive [3]. Besides of being used widely, they are strong in controlling insect pests. However, their availability is unreliable in distant rural areas, because they are diluted to ineffective concentrations by dishonest traders, they are toxic to people and contaminate the environment [4]. Also, synthetic pesticides and their metabolites have high persistence in soil, water and crops themselves and therefore affect environment and the health of human being during preparation, application and the consumption of crops. These constraints of synthetic pesticides have led to increased interest in the application of botanical pesticides for crop protection in the field and during storage [5].

Botanical pesticides are naturally occurring chemicals extracted from plants [6] [7]. They are also called natural insecticides [6]. Botanical pesticides are cheaply available and easy to prepare and use [8], environmentally friend, difficult to contaminate farmers during preparation and use and therefore, safer than synthetic pesticides. Also they are friend to the health of human beings because they are less persistent in the environment, less toxicity and less harmful to beneficial insects [8] [9]. The active ingredients of botanical pesticides degrade rapidly in sunlight, air, and moisture and are readily broken down by detoxification enzymes [6] [7]. Commercially, botanical pesticides are cheap and in this case are viable to small-holder farmers and the growing economy of Africa.

In agricultural practices, the insect pests affecting the bean production include: bean stem maggot, *Ophiomyia spp*, bean foliage beetles, *Ootheca spp*, aphids, *Aphis fabae*, flower beetles, *Mylabris variabilis*, leaf eating caterpillars and legume pod borers [10]. The insect pests affecting the bean production in northern part of Tanzania include; bean stem maggot, *Ootheca*, beetle, flower beetle, leaf eating caterpillar, pod borer and aphids [11]. Insect pests reduce crop production yield because they consume plant tissues such as pod suckers, accelerating leaf senescence and contaminate the entire crops in the field which lead to poor food quality [12] [13].

It is estimated that, about 30% - 40% of crop loss in preharvest and postharvest worldwide is due to pests [14]. Therefore, insect pests limit much of the productivity gain made through agricultural innovations. Most small-holder farmers in sub-Saharan Africa in which the use of modern technology is poor, overcome the problem of crop loss through insect pests by the use of traditional methods [15] [16]. This includes mixing more than one crop in the farm field at the same time [17] which is known as intercropping. In northern part of Tanzania, small-holder farmers practice both intercropping and monocroping system [18]. Common beans, for example, are either intercropped with maize or grown alone for nutritional values such as protein, iron and zinc supplements and for good health including brain development [19] [20]. However, these traditional methods employed by small holder farmers to control insect pests of common beans are less effective. Therefore, the use of botanical pesticides is a promising means for controlling insect pests in common beans. But also there is limited scientific information of the toxicity, persistence and mode of action of botanical pesticides active ingredients for proper use to control insect pests in common beans.

This review paper concentrates on common practices used to control insect pests of common beans, the toxicity, persistence, and mode of action of some of active ingredients of botanical pesticides including *Tephrosia vogelii*, *Vernonia amygdalina*, *Tithonia diversifolia* and *Lantana camara*, Neem, *Azadirachta indica* and pyrethrum, *Chrysanthemum cinerariifolium* as the alternatives of controlling common bean insect pests in the farmers' field, and in storage rooms and increase the possibility of safe food and environmental friendly farming and storage practices [5].

2. Common Practices Used to Control Insect Pests of Common Beans in the Field

Field insect pests infestation is a very serious problem because life stages of insects cause economic damage and deteriorates the crops to be harvested and food products to be stored [21]. Field insect pests infestation cause products lose in the field and some insect life stages are carried up to the storage rooms in which the damage can be estimated up to 9% in developed countries and up to 20% or more in developing countries [22]. There are practices used to control the insect pests of the crop in the field. Those practices used by small-holder farmers include traditional, biological, synthetic and botanical pesticides application.

2.1. Traditional Practices

There are many traditional practices, whereby smallholder farmers use to reduce infestations of the insect pests in the farms. Those traditional practices are also called cultural practices. Cultural practices such as site selection, crop rotation, and cultivar and seed selection, proper sowing date can reduce the infestation of certain insect pests [23]. For instance, aphid infestation in wheat and common beans is reduced by early sowing time [24] and also, affect the population of bean stem maggot, *Ophiomyia sp*, bean foliage beetle, *Ootheca*, aphids and other arthropods attacking common beans in the field [25]. Apart from that, [26] reported that; planting in either late time or off-season lead to higher infestation of bean stem maggot in the farms grown common beans. In other agronomic studies, row spacing and plant density, weed control and stubble retention have been used to control bean stem maggot [27]. Other studies have reported that, sloping sites and border hedgerows which reduce wind speed promote aphid landing and affects aphids and *Ootheca species* distribution [28]. Increasing plant density from 22 bean plant/m^2 to 33 bean plant/m^2 was found to decrease common bean virus incidence transmitted by aphids by 10% - 20% [29]. Also [29] reported that; planting cereal border around faba bean field reduces the spread of non-persistently bean transmitted virus. However, cultural practices are not very effective although they are safe and cheap. Therefore, there is a need of conducting detailed study on the use of botanical pesticides for controlling insect pests in the farms of small-holder farmers.

2.2. Biological Control Methods

Biological control is defined as the reduction of pest populations (insects, mites, weeds and plant diseases) using other living organisms [30]. Insect pests are suppressed by naturally occurring organisms and environmental factors which are called natural enemies or natural control. Natural enemies of insect pests are known as biological control agents. Natural enemies are organisms which kill, decrease the reproductive potential, or reduce the number of another organism [30]. Those natural enemies include predators, parasitoids, and pathogens.

A predator is an organism that attacks, kills, and feeds on several or many other organisms in life time. Some predators are specialized, which means feeding on only one or few preys while most are generalized meaning that, feeding on variety of organisms [30]. Predators include spiders, lacewings, lady beetles, ground beetles, rove beetles, hover flies, and true bugs [30]. These organisms kill and feed in the insect pests affecting common beans. Ladybird beetles, family Coccinelidea, both adults and larvae feeds on aphids [31] and therefore reduce the population of aphids. Ladybird beetles are stronger, larger and usually more intelligent than the prey and therefore attack several hosts in a short period of time [32].

Parasitoids are insects which parasitize and kill other invertebrates. Many species of wasps and some flies are parasitoids. Some of species of parasitoids, when are in immature stage develops on or within a single insect host forming mummies and therefore killing the host [31]. Parasitoids are parasitic when are in immature stage and kill their hosts as they reach maturity [30]. Species of entomopathogenic fungi infest aphids through the cuticle and finally killing the host [32]. Apart from that, species in the *Braconidae* family develop as endopara- sitoids of aphids whereby the larva complete their development in the host [23]. Aphids are also controlled by spinosad. It is a biologically derived insecticide produced by the actinomycete, *Saccharopolyspora spinosa*, a bacterial organ isolated from soil [34].

Pathogens are important in biological control of many pests including insect pests, nematodes, mites and weeds [31]. Pathogen such as *Bacillus thuringiensis*, controls certain caterpillars, beetles and flies but does not affect other arthropods. Biological control is safe and eco-friendly. Therefore, detail studies are needed on toxicity, persistence and mode of actions of active ingredients of botanical pesticides for safety use by small holder farmers and support the present of natural enemies.

2.3. Chemical Pesticides

Worldwide, it is estimated that approximately 1.8 billion people engage in agriculture and most of them use approximately 5.6 billion pounds of synthetic pesticides to protect the food and commercial products that they produce [35]. Pesticide use in Africa accounts for only 2% - 4% of the global pesticide market [36]. Synthetic pesticides are reported to be effective, reliable against a wide range of insect pests, quick acting and easily tested for new insect pests [37]. Pesticides chemicals such as endosulfan, diazinon and lindane have been identified by several National bean programs and Research organizations to provide protection to germinating bean plants at a time when they are most vulnerable to attacks especially bean stem maggot [38]. Cypermethion, carbaryl, and Lambda-cyhalothrin have shown efficacy to control the pests in the field and in the storage rooms [39]. However, many of the synthetic pesticides such as endosulfan and lindane are either banned, or are expensive to small-holder farmers in Africa, and are persistence in the environment [40].

Also, according to the Stockholm Convention, among the 12 Persistence Organic Pollutants (POPs), nine are pesticides including aldrin, chlordane, dichlorodiphenyltrichloroethane (DDT), dieldrin, endrin, heptachlor, hexachlorobenzene (HCB), mirex and toxaphene [40]. Those POPs are associated with human health problems such as cancer. The study done by [40] reported that mothers who are exposed to lindane, can accumulate it into breast milk, o, p-dichlorodiphenyldichloroethane (DDD) can accumulate in maternal serum and total dichlorodiphenyltrichloroethane (DDT) can accumulate in the umbilical serum [40]. This reflects their potential placental and breast milk transfer to her child during pregnancy and lactation [40]. In response to the high costs and the negative side effects of synthetic pesticides to the health of human being [41], there is a need for studying botanical pesticides in detail which are affordable and have less or no health problems to the applicators, consumers and do not contaminate the environment to replace the synthetic pesticides.

2.4. Botanical Pesticides

Botanical pesticides have long been publicized as attractive alternatives to synthetic insecticides for pest management since they pose either little or no threat to the environment, to ecosystems and to human health [42]. In the middle of the 17th century, pyrethrin, nicotine and rotenone form pyrethrum, tobacco and *Tephrosia spp* respectively were recognized as effective insect control agents [6]. Hence, mankind has used plant extracts for thousands of years to the prevent diseases, treatment of disease, as insecticides to control microbial growth, weeds and many more functions [43]. Therefore, many plants which were used for medicinal purposes locally, also demonstrated potential as insect control agents [44]. Botanical products like tobacco extracts, neem oil and extracts, have found promising and useful for bean pests control [45]. Similarly, *Tephrosia vogelii*, *Azadirachta indica*, *Annona squamosa*, chilli paper, *Cupscum frutensces*, *Allium sativa* are reported to control insect pests of beans and cowpeas successfully [46]. *Aristolochia ringens* and *Alium sativum* have antifeedants, food poisons, contact poisons and repellents against *Sitophilus zeamais* [44]. Pesticidal plants such as Tobacco, *Nicotiana tabacum*, Neem, *Azadirachta indica*, Garlic, *Allium sativum*, Eucalyptus, *Eucalyptus camaldulemsis* and Mehogony, *Swietenia mehogany*, have been reported in controlling aphids attacking bean plants [47]. Normally, botanical pesticides comprise a mixture of bioactive compounds with many have advantages in terms of efficacy and short life span [48]. **Table 1** shows the toxicity of some active ingredients of botanical pesticides

The botanical pesticides are generally pest-specific and are relatively harmless to non-target organisms including man and natural enemies of insect pests [6] [49], and environmentally ecofriend, degrade rapidly in sunlight, air, and moisture, so they are less persistence in the environment, and are rapid in action to the insect pests, no adverse effect on plant growth, seed viability and cooking quality of the grains and are less expensive and easily available in the farmers natural environment [41]. Now it becomes necessary to search for the alternative

Table 1. Toxicity of certain botanical pesticides active ingredients (mg/kg).

Generic Name	Oral LD_{50}	Dermal LD_{50}	Signal Word
Pyrethrins	1200 - 1500	>1800	Caution
Rotenone	60 - 1500*	940 - 3000	Caution
Sabadilla	4,000	-	Caution
Ryania	750 - 1200	4000	Caution
Nicotine	50 - 60	50	Danger
d-Limonene	>5000	-	Caution
Linalool	2440 - 3180	3578 - 8374	Caution
Neem	13,000	-	Caution

*Toxicity varies greatly depending on type of solvent used as carrier; Source: [6].

means of insect pests control, which can minimize the use of synthetic pesticides. This work reviews the toxicity, persistence and mode of actions of some of botanical pesticides which are locally available plant materials in our environment.

3. Toxicity and Persistence of Some of Active Ingredients from Botanical Pesticides

Although botanical pesticides can be used as alternatives to synthetic pesticides but the toxicity of the chemical compounds extracted from botanical pesticides to insect pests and humans, persistence to the environment and mode of actions to insect pests are not clear [7]. Therefore, this part, intends to explain the toxicity and persistence of pyrethrin from pyrethrum, rotenone from *T. vogelii*, azadirachtin from *Azadirachta indica*, and some active chemical compounds from *V. amygdalina*, *L. camara*, and *T. diversifolia*. These botanical pesticides are selected, because are commonly found around our homes, along the roads, river banks and bush lands in northern part of Tanzania [11] and may be used as botanical pesticides.

3.1. Rotenone

Rotenone, **Figure 1** is contained in large amount in plant species especially *Tephrosia*, *Derris*, and *Lonchocarpus* [50]. All these plants are in the family fabaceae in Leguminosae. *Rotenone* (**Figure 1**) is used as natural insecticide, piscicide, and pesticide [7]. It is a relatively low toxicity insecticide for use in gardens but is highly toxic to fish and is sometimes used to eliminate unwanted fish from lakes [50]. It occurs naturally in the seeds, stems, leaves and the roots of plants in fabaceae family. It was the first described member of the family of chemical compounds known as rotenoids [51].

The LD_{50} of rotenone (**Figure 1**) for rats is 132 - 1500 mg/kg [6] [7]. In human being, rotenone is moderately toxic with an oral LD_{50} ranges from 300 to 1500 mg/kg [7] [51]. This compound (**Figure 1**) is highly toxic to fish and insects because it is lipophilic in nature [50]. The respiratory mechanism of fish is directly linked to water through the gills and in insect is directly exposed through trachea whereby rotenone is easily taken up through the gills or trachea into the bloodstream of fish, and insects respectively resulting to death [50].

However, rotenone is less toxic to mammals and birds since the route of ingestion is through the digestive tract whereby the compound is easily broken down to less toxic compounds before toxic quantities can enter the bloodstream [6] [7] [50] [51]. Rotenone is rapidly broken down by sunlight which is both an advantage and disadvantage [50]. Since it breaks down rapidly, it does not accumulate in the environment and less harmful to non-target organisms [6]. However, it must be re-applied at short intervals and is usually applied in the early morning or in the evening to avoid degradation of it by sunlight [7]. In water, the rate of decomposition depends upon several factors, including temperature, pH, turbidity of water and sunlight. The half life of rotenone is four days [6] [7] [50] [51]. The half-life of rotenone in natural waters ranges from half a day at 24˚C to 3.5 days at 0˚C [6]. However, there are limited scientific information about toxicity of rotenone to organisms and persistence of it in the environment. Therefore, detail studies are needed on the toxicity of rotenone to various animals and persistence of it in the environment for use it sustainably as botanical pesticide.

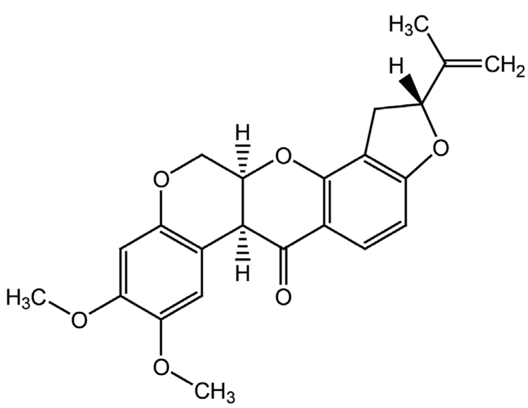


Figure 1. Chemical structure of rotenone.

3.2. Azadirachtin from Neem, *Azadirachta indica*

Neem tree is in Meliaceae family possessing bitter triterpenoids [52]. The active compound in the neem is azadirachtin which is found in the leaves, and also concentrated in the seeds [53]. It is a bitter, complex chemical compound which belongs to the limonoid group and it show strong biological activities among various insect pests [53]. This compound (**Figure 2**) is a feeding deterrent and growth regulator [51].

This compound (**Figure 2**) can affect about 200 species of insects by acting as antifeedant and growth disruptor. Azadirachtin has a toxicity and fascinating effect on insects (LD_{50} (*S. littoralis*), 15 µg/g) [53]. It has very low toxicity to mammals whereby the LD_{50} in rats is greater than 3540 mg/kg which make it practically non-toxic to mammals [53] and also has been reported to be non mutagenic [52]. Azadirachtin has been found to degrade rapidly under environmental factors such as UV radiation in sunlight, heat, air moisture, acidity and enzymes present in foliar surfaces [53]. The half-life of azadirachtin has been found to be between 48 minutes and 3.98 days under Ultraviolet (UV) light and sunlight and 2.47 days on leaf surface [6] [51]. Therefore, there is a need to use azadirachtin as environmentally compatible insecticides, with selective toxicity to targeted pests, low toxic to plants and mammals and environmental friendly desired stability.

3.3. Pyrethrin from Pyrethrum, *Tanacetum cinerariifolium* (*Chrysanthemum cinerariifolium*)

Pyrethrum is powdered, dried flower head of the pyrethrum daisy, *Tanacetum cinerariaefolium and* pyrethrins active compound from pyrethrum with six related insecticidal compounds which occur naturally [6]. There is pyrethrin I and pyrethrin II. The compounds related to pyrethrin I contain methyl group ($-CH_3$) and the compound related to pyrethrin II contain $-CO_2CH_3$ group [51] [52]. The general chemical formula of pyrethrin and the six related pyrethrin compounds are shown in **Figure 3** and **Figure 4**.

Pyrethrins are axonic poisons and have an insect repellent effect when present in little amount [6]. They are harmful to fish, but are less toxic to mammals and birds than many synthetic insecticides. In pure form, the rat oral LD_{50} is 1200 - 1500 mg/kg [51]. The technical grade of pyrethrum is less toxic to rat with the LD_{50} of about 1500 mg/Kg. Pyrethrins degrade easily when is exposed to the environment moisture, air and the sunlight [51]. The half-life of pyrethrins in the environment and field-grown bell pepper fruit is 2 hours or less [6]. However, there are limited scientific information about toxicity of pyrethrins compounds to various organisms and persistence of it in the environment. Therefore, detail studies are needed about the toxicity of pyrethrins compounds to various organisms and persistence of it in the environment for use it sustainably as botanical pesticide.

3.4. Sesquiterpene Lactones from *T. diversifolia*

Many classes of secondary metabolites which are isolated from the *Tithonia diversifolia* extracts include diterpenoids, flavonoids, sesquiterpene lactones (**Figure 5**) and chlorogenic acids derivatives [54] [55]. However,

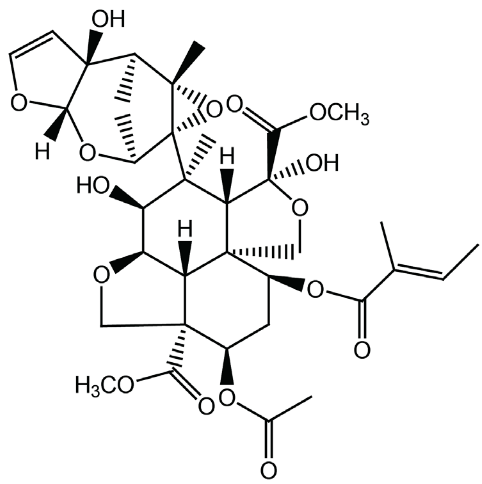


Figure 2. Chemical structure of azadirachtin.

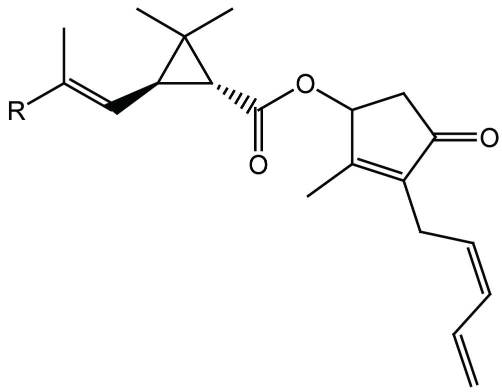


Figure 3. General chemical formula of pyrethrum, Pyrethrum I, R = CH_3, Pyrethrum II, R = CO_2CH_3.

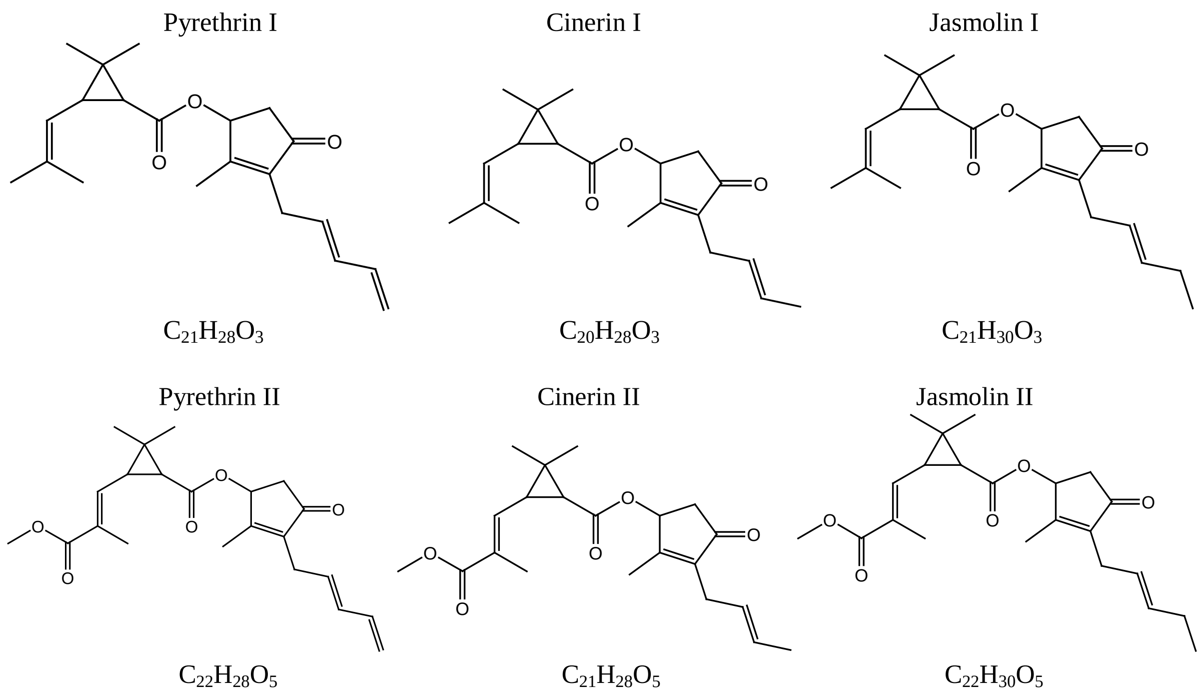
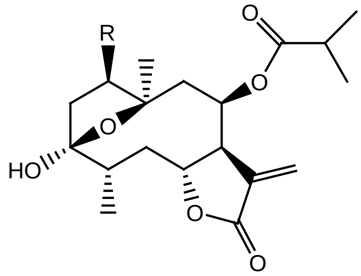


Figure 4. Chemical structures of the six related pyrethrin compounds.

the most abundant terpernoids in *Tithonia diversifolia* are sesquiterpene lactones [55]. But tagitinins compounds (**Figure 5**) which are in sesquiterpene lactones class are the most studied [56]. The sesquiterpene lactones and diterpenoids have biological activities [16] and contribute to inflammatory activity [55]. *T. diversifosia* is used as traditional medicine in constipation, stomach pains, indigestion, sore throat, liver pains and to treat malaria [57]. [56] reported that; the extracts of *T. diversifolia* of 10 mg/kg and 100 mg/kg administered to rats for 90 days were relatively safe with some toxicity observed at 100 mg/kg. However, the later can cause damage of the liver, the kidneys and, to a lesser extent, the heart [56]. The liver damage observed at higher doses of aqueous extracts of *Tithonia diversifolia* may result from the Chlorogenic acid, while kidney damage results from the Sesquiterpene lactones [55] [56]. However, no clear information about toxicity of these compounds from *Tithonia diversifolia*.

3.5. Pentacyclic Triterpenoids from *Lantana camara*

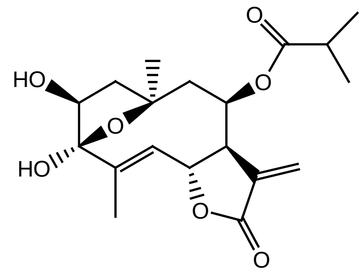
Lantana camara is recognized to be toxic to cattle, sheep, horses, dogs and goats [58]. The active ingredients causing toxicity of *Lantana camara* in grazing animals is pentacyclic triterpenoids [47] (**Figure 6**). It is one of



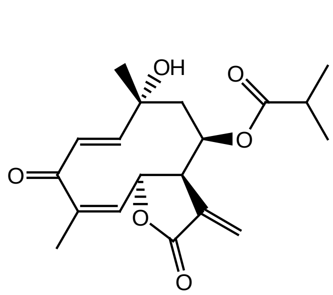
1 R = OH

1a R = OAc

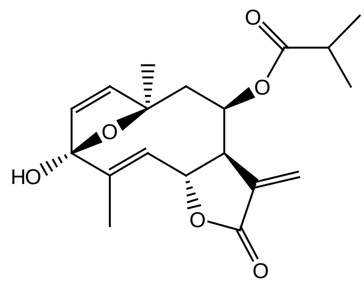
Tagitinins A



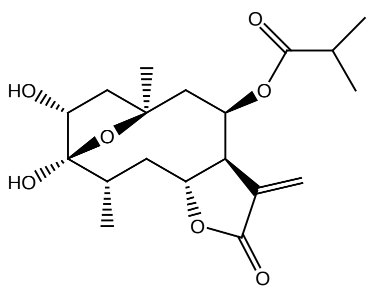
Tagitinins B



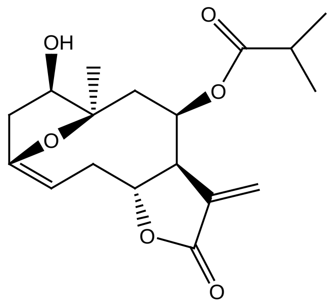
Tagitinins C



Tagitinins F



2 alpha -hydroxytirotundin, tagitinins A isomer



Dehydrated tagitinins A

Figure 5. Chemical structures of some sesquiterpene lactones from leaves of *T. diversifolia*. Source: [57].

terpernoids, which result in liver damage and photosensitivity [59]. The toxicity of *L. camara* to human being is undetermined, whereby numerous studies suggest that; ingestion of berries from *Lantana camara* can be toxic to humans [47]. [60] reported that; leaf extract of *L. camara* had excellent repellent, moderate toxic and antifeedant activities. However, other studies have found evidence which suggests that ingestion of *L. camara* fruit, poses no risk to humans and is in fact edible when ripe [47]. Studies conducted in India have found that; *Lantana camara* leaves can display antimicrobial, fungicidal and insecticidal properties [61]. *L. camara* has also been used in traditional herbal medicines for treating a variety of ailments, such as cancer, skin itches, leprosy, rabies, chicken pox, measles, asthma and ulcers [61]. *Lantana camara* has been tested as an alternative to fumigants in stored grains [62]. Therefore, there is a need of finding out more information about the toxicity of *Lantana camara* to the health of human being.

3.6. Vernodalin, Vernodalol and Epivernodalol from *V. amygdalina*

Vernodalin, Vernodalol and Epivernodalol (**Figure 7**) are sesquiterpene lactone compounds from the members of Asteraceae family. They are the major bioactive constituents isolated from *Vernonia* species [63]. Phytochemical

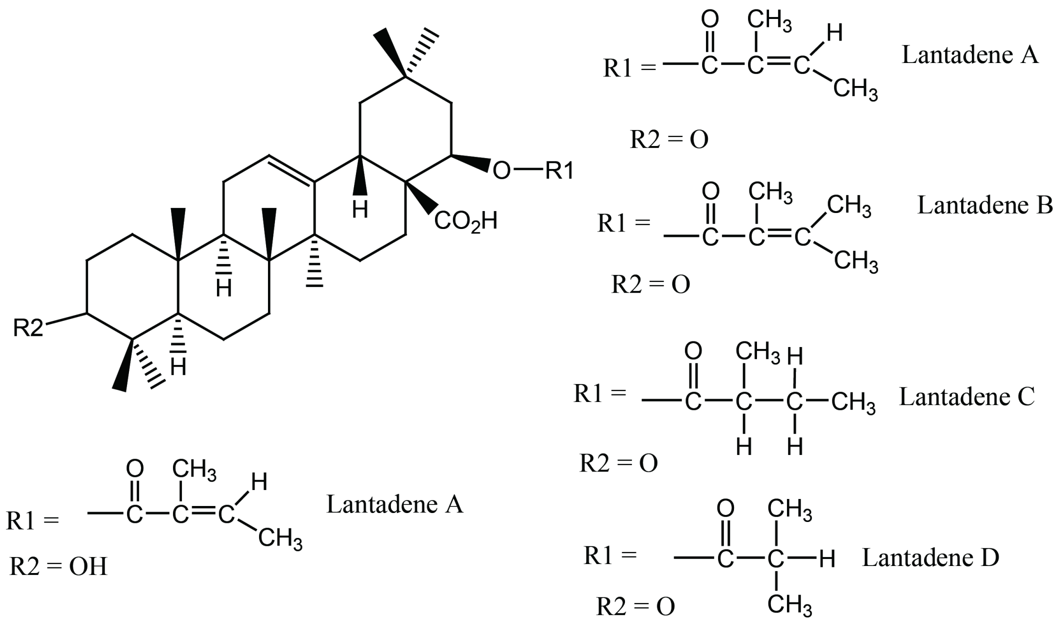


Figure 6. Chemical structures of Lantadenes (*Pentacyclic triterpenoids*). Source: [47].

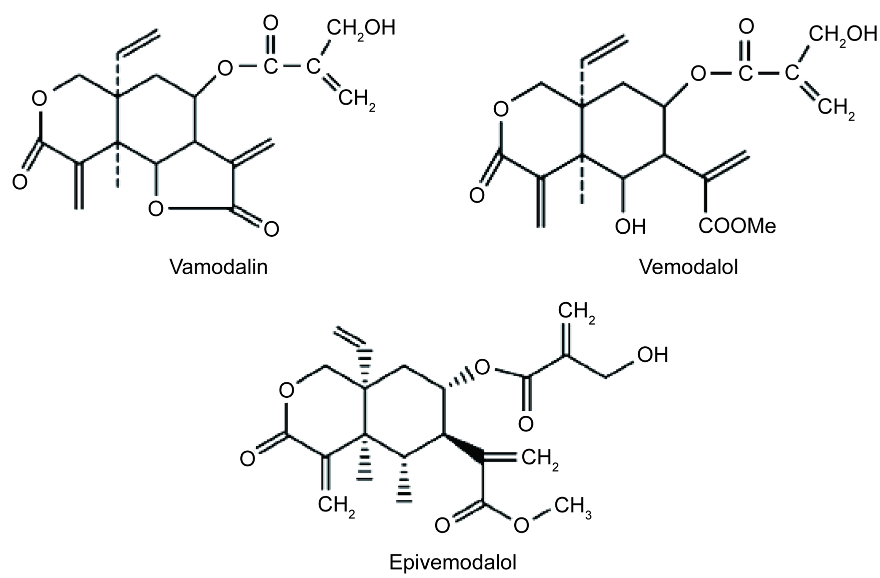


Figure 7. Chemical structures of isolated compounds from *V. amygdalina*. Source: [64] [65].

analysis of leaves of *Vernonia amygdalina* revealed the presence of important natural products vernolide and vernodalol [64] [65]. The toxicity of these compounds is very low to human being [42]. The LD_{50} was tested in mice and extrapolated to be 1265 mg/kg [63]. The possibility of using nontoxic deterrents and repellents as crop protectants is intuitively attractive [42] since have little effects to health of human being. These sesquiterpene lactones were found to be active on gram positive bacteria and vernolides has reported to show high antifungal activities [66]. Study on the efficacy of *V. amygdalina* on field insect pests in cowpea (*M. sjostedti* and *B. tabaci*) showed effectiveness when it was applied in two weeks interval after crop emergency [67]. These chemicals have deterrent and repellent properties toward insect pests.

Repellent and feeding deterrent chemicals from pesticidal plants discourage the insects from feeding it. Many compounds or extracts from medicinal plants which demonstrated antifeedant effects lack toxicity if ingested [42] [68]. Sesquiterpene lactone disappears in the environment in 90 days and the disappearance is faster when compared with synthetic pesticides [63]. However, there is little information about the toxicity, persistence and mode of action of *V. amygdalina* suitable for the protection of the environment from the botanical pesticides metabolites contamination.

4. Mode of Action of Active Compounds from Botanical Pesticides

Despite the suggestion, of using botanical pesticides as alternatives to synthetic pesticides but there are limited information about the mode of actions of the chemical compounds to insect pests. Therefore, this part intends to explain the mode of actions of pyrethrin from pyrethrum, rotenone from *T. vogelii*, azadirachtin from *Azadirachta indica*, and some active chemical compounds from *V. amygdalina, L. camara*, and *T. diversifolia.*

4.1. Mode of Action of Rotenone

Rotenone delay the electron transport chain in mitochondria of the insect pests and it is a contact and stomach poison [6] [7] [50] [51] [69]. It inhibits the transfer of electrons from iron-sulfur centers in complex I to ubiquinone and interferes with Nicotinamide adenine dinucleotide hydride (NADH) during the creation of usable cellular energy Adenosine triphosphate (ATP) [69]. In that case, Complex I is unable to pass through its electron to Complex Q, creating a back-up of electrons within the mitochondrial matrix. During this limiting process, cellular oxygen is reduced to the radical which is a reactive species. This reactive species can damage Deoxyribonucleic acid (DNA) and other components of the mitochondria [50].

4.2. Mode of Action of Azadirachtin

Azadirachtin displays strong antifeedant effects on chemoreceptors of the insects and discourage the insect pests to consume the plant [53]. If the insect pest continues in consuming crops sprayed with neem tree extracts, the azadirachtin blocks peptide hormone release, which results in severe growth defects and molting abnormalities [52] [70]. Finally, azadirachtin has a damaging effect on the tissues including the muscles, fat and gut of most of the insect [52].

4.3. Mode of Action of Pyrethrins

Pyrethrins attack the nervous systems of all insects and act like pyrethroids and DDT [6]. Axonic poison substances affect the electrical transmission of the impulses along the axon [51]. During their mode of action pyrethrins upset the sodium and potassium ion exchange process in insect nerve fibers and interfere the normal transmission of nerve impulses [6]. Pyrethrins delay the closure of voltage-gated sodium ion channels in the nerve cells of insects, resulting in repeated and extended nerve firings [51]. This hyperexcitation causes the death of the insect due to loss of motor coordination and paralysis. Sometimes insect pests may develop resistance to pyrethrum [6]. *Piperonyl butoxide* is paired with pyrethrin to prevent resistance by insect pests. It is synergist compound. Together, these two compounds prevent detoxification in the insect, ensuring insect death. Synergists make pyrethrin more effective, allowing lower doses to be effective [6]. Pyrethrins are effective pesticides because they selectively target insects rather than mammals due to higher insect nerve sensitivity, smaller insect body size, lower mammalian skin absorption, and more efficient mammalian hepatic metabolism [6].

4.4. Mode of Action of Active Ingredients from *T. diversifolia* to Insect Pests

The phytochemical analysis of *T. diversifolia*, revealed the presence of non-volatile fractions which are rich in flavonoids and sesquiterpene lactones whereas the essential oil contains mainly monoterpene hydrocarbons, such as b-ocimene, a-pinene and limonene [23]. The plant has been found to have insect feeding deterrent characteristics to insect pests [23] which have effect on chemoreceptors to discourage the insects from consuming bean plants. That is caused by the presence of 6-methoxyapigenin, sesquiterpene lactones, chologenic acids and tagitinins A, B, C and F, with diversiform, tirotundin, tithonine and sulphurein [23].

4.5. Mode of Action of Some Active Ingredients from *L. camara*

L. camara essential oil and leaves are composed of large amounts of sesquiterpene hydrocarbons, mainly *β*-caryophyllene [71], lantadene A, B and C which produce strong hepatotoxic response in rodents and the extracts have fumigant activity against *Sitophilus granarius* adults [72] [73]. Terpenoids, phenylpropanoids, and flavonoids are thought to be the main components which have biological activities in *Lantana camara* [60]. The leaves have repellent and antifeedant properties against insects [60]. Apart from that, *L. camara* active ingredients have acetylcholine inhibition property against insect pests [60]. It is known for its enzyme inhibition and therefore serves as an alternative to synthetic fumigants. However, there is limited information about the effectiveness, toxicity, and persistence of chemical constituents in *Lantana camara*.

4.6. Mode of Action of Active Ingredients from *T. diversifolia* to Insect Pests

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5. Conclusion

Currently, control of bean pests is achieved through the use of synthetic pesticides. But synthetic pesticides have been found to cause problems to the environment, ecology and to the health of human being. The promising alternatives, the botanical pesticides for instance the *Tephrosia vogelii*, *Cupscum species*, *Vernonia species*, *Tagetes minuta*, *Ocimum gratissimum*, Pyrethrum, *Azadirachta indica*, *Lantana camara* and *Tithonia diversifolia* can be considered to control the insect pests in the field and in the storage rooms. However, the toxicological and environmental properties of the compounds from botanical pesticides and the mode of action in insects should also be considered for the safety of our environment and the human health and insect resistance. It is known that most toxic mammalian poisons are natural products from plants although they are found to be cheap and easy available and to prepare, short life span and are ecofriendly to the environment and other animals.

Acknowledgements

This study was funded by McKnight Foundation through a grand from Bill and Melinda Gates Foundation given to The Nelson Mandela African Institution of Science and Technology (NM-AIST).

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