2020-05-28

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Science Publishing Group

https://doi.org/10.4236/ajps.2020.115054

American Journal of Plant Sciences, 2020, 11, 745-772
https://www.scirp.org/journal/ajps
ISSN Online: 2158-2750
ISSN Print: 2158-2742

Potential of Indigenous Pesticidal Plants in the Control of Field and Post-Harvest Arthropod Pests in Bambara Groundnuts (*Vigna subterranea* (L.) Verdc.) in Africa: A Review

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How to cite this paper: Tlankka, N.S., Mbega, E.R. and Ndakidemi, P.A. (2020) Potential of Indigenous Pesticidal Plants in the Control of Field and Post-Harvest Arthropod Pests in Bambara Groundnuts (*Vigna subterranea* (L.) Verdc.) in Africa: A Review. *American Journal of Plant Sciences*, **11**, 745-772.
https://doi.org/10.4236/ajps.2020.115054

Received: March 20, 2020
Accepted: May 25, 2020
Published: May 28, 2020

Abstract

Bambara groundnuts (*Vigna subterranea* (L.) Verdc.) is an important leguminous crop native in Africa and is mainly cultivated for its highly nutritious grains. However, bambara groundnuts production is constrained by many insect pests including aphids (*Aphids sp.*), leaf hopers (*Hilda patruelis*), foliage beetles (*Ootheca mutabilis*), pod sucking bugs (*Clavigralla tomentosicollis*), red spider mites (*Tetrunychus sp.*), groundnut jassids in the field and bruchids (*Callosobruchus maculatus*, and *Callosobruchus subinnotatus*) in the storage. Smallholder farmers usually apply synthetic pesticides to control those insect pests. However, synthetic pesticides are potentially harmful to the environment, non-targeted animals and human's health. Pesticidal plants such as *B. pilosa*, *L. camara*, *T. vogelii*, *V. amygdalina*, *L. javanica*, *T. diversifolia*, and *C. dichogamus* which are available in most parts of Africa where the crop is cultivated, possess bioactive chemicals which have insecticidal properties and have been revealed to be potential in the control of field and storage insect pests. Therefore, they can be used as an alternative to synthetic pesticides. Bambara groundnuts being one of the neglected crops, the insects affecting the crop have not been well explored in terms of their abundance and damage they cause to the crop in the field and on storage. Thus, in this review, the common arthropod pests of the bambara groundnuts and the potential of the bioactive compounds from the common plants with pesticidal properties have been described. It is recommended that the potential of these pesticidal plants to be investigated on bambara groundnut pests control on the field and on storage to optimize their use by smallholder farmers in insect control to reduce dependence on synthetic pesticides.

Keywords

Neglected Crop, Synthetic Pesticides, Bioactive Compounds, Insecticidal Properties

1. Introduction

Bambara groundnut (*Vigna subterranea* (L.) Verdc.) is an important leguminous crop indigenous in Africa [1] [2]. In many parts of Africa, it is ranked the third after peanut (*Arachis hypogaea*) and cowpea (*Vigna unguiculata*) in terms of consumption and socio-economic importance [3] [4] [5]. The grains are highly nutritious containing approximately 15% - 25% protein, 49% - 63.5% carbohydrate, 4.5% - 7.4% fat, 5.2% - 6.4% fiber, and 2% mineral thus, it is regarded as complete food [6] [7]. Moreover, bambara groundnut is highly tolerant to drought and temperature and it can grow and yield in poor soils [5] [8] [9] [10] [11]. Being a leguminous crop, bambara groundnuts have the ability to fix soil nitrogen of about 20 - 100 kg·ha^{-1} to the soil useful in crop rotations and intercropping with non-nitrogen fixing crops [11]. Bambara groundnut is mainly produced for consumption and it serves as a food security crop, eaten as freshly cooked pods or as dry grains incorporated into main dishes such as cooked plantains and cereals [12]. Moreover, bambara groundnuts serve as a source of income among smallholder farmers especially when the yields of other crops are low due to the prevailing drought and extreme temperatures and crop residues are used to feed livestock [11] [13] [14]. Although bambara groundnut has remained underutilized and under-researched [11]. However, currently, the crop has attracted research attention and cultivation by farmers mainly due to its climate resilience, unlike other legumes that are at risk due to climate change effects [14] [15].

The world production of bambara groundnut in 2016 was estimated by FAO to be 164,589 tonnes whereby the main production is from African countries such as Mali, Cameroon, Niger, Burkina Faso and Democratic Republic of Congo (DRC) [16]. In Tanzania, the bambara groundnuts are cultivated in Kagera, Mara, Mwanza, Shinyanga, Tabora, Singida, Dodoma, Rukwa, Iringa, Lindi, Ruvuma and Mtwara regions [12]. However, in Tanzania, the yield of bambara groundnut is 500 - 800 kg·ha^{-1} which is lower than the potential yield of 1500 - 2000 kg·ha^{-1} under proper crop management [17]. Despite the nutritional and economic potentials for the smallholder farmers, bambara groundnut production is constrained by insect pests including aphids (*Aphids sp.*), leafhoppers (*Hilda patruelis*) and bruchids (*Callosobruchus maculatus*, and *C. subinnotatus*)

[15] and, brown leaf beetles (*Ootheca mutabilis*), groundnut jassid (*Empoasca facialis*) [18], red spider mites (*Tetrunychus sp.*) [19], pod sucking bugs (*Clavigralla tomentosicollis* Stäl) [20].

In bambara groundnut farming, the use of pesticides is generally on a small scale mainly because bambara groundnut is a neglected crop or orphan crop (Hillocks *et al.*, 2012) leading to less application of agricultural inputs such as pesticides to maximize the potential productivity of the crop [3]. However, in an attempt to control pests, the smallholder farmers apply synthetic pesticides as the major insect control strategy and have always provided effective control against insect pests [21] [22]. However, synthetic insecticide has detrimental effects on the health of the pesticide applicators, consumers, and is not environmental benign [23] [24] [25] [26]. These undesirable impacts of synthetic pesticides have raised global concern paving a way to research plants with toxicity to the insect which may be used instead of synthetic insecticides. The use of pesticidal plants is a promising alternative to synthetic pesticides. Several studies revealed that, the pesticidal plant extracts are effective to control insect pests on crops [27]-[33]. Moreover, pesticidal plants are easily available, degradable in the environment and less toxic to human and non-targeted organisms [28], therefore they can be used by smallholder farmers to control insect pests in their crops including the bambara groundnuts with less detrimental effects to the environment, human health and to the natural enemies.

2. Review Method

We conducted a review of the literature related to the bambara groundnut pests as well as the pesticidal plants commonly used in Africa for different purposes but we mainly focused on pesticidal uses. A comprehensive review was conducted on the key pests constraining the bambara groundnuts production with the main focus on their distribution, damage symptoms on plants, and management strategies. Due to limited information on bambara groundnut pests, we tried to search for information on particular pests on different crops and specifically legumes. Concerning pesticidal plants, we searched documents related to their distribution, traditional uses, photochemistry, and research findings on their pesticidal potential. The primary source of information used in this review includes Google books, conference proceedings, research papers, and review articles and reports retrieved from the online databases such as Google Scholar and Google using keywords like "bambara groundnuts", "Insect pests + bambara groundnuts", Pesticidal plants," "Impacts of synthetic pesticides". More specific keywords such "pesticidal potential of *Bidens pilosa*, *Lantana camara*, *Tephrosia vogelii*, *Vernonia amygdalina*, *Lippia javanica*, *Tithonia diversifolia* and *Croton dichogamus"* were used to get the required detailed information. We managed to review 125 documents (109 articles, 5 online books, 5 conference proceedings, 6 institutional reports) related to bambara groundnuts, bambara groundnuts pests, legume pests, and pesticidal plants.

3. Review Findings

3.1. Key Arthropod Pests Affecting Bambara Groundnuts

Bambara groundnuts are relatively tolerant to insect pests and diseases [11]. However, some literatures have reported that the crop is affected by the wide range of insect pests in the field, storage, and fungal diseases such as Cercospora leaf spot (*Cercospora* spp.), powdery mildew (*Erysiphe polygoni*) and fusarium wilt (*Fusarium oxypolygoni*) [18]. In this review, the insect pests affecting the bambara groundnuts including aphids (*Aphis sp.*), leafhopper (*Hilda patruelis*), groundnut jassid (*Empoasca facialis*), and brown leaf beetles (*Ootheca mutabilis*), red spider mites (*Tetrunychus sp.*) [19], pod sucking bugs (*Clavigralla tomentosicollis* Stäl) [20] in the field and bruchids (*Callosobruchus macularus and C. subinnotatus*) on the storage [15] [18].

3.2. Aphids (*Aphis spp.*)

Aphids (*Aphis spp.*) (Hemiptera: Aphididae) are small sap-sucking insects widely distributed in Africa. There are about 5000 species of aphids but only 450 species have been recorded on crop plants [34]. Out of 450 species recorded on crop plants, it is only 100 species that are of agricultural importance [34]. Bambara groundnut is one of the crop infested by aphids [15] [18]. For instance, in Zimbabwe, aphids represent about 65% of the insect pest problem in bambara groundnuts [12]. Aphids damage plants in all stages of growth from the seedlings stage to flowering (**Figure 1**), pod formation, and seed filling [35]. They tend to form colonies in leaves, stems, and pods where they damage crops by sucking sap from the plant during feeding and also transmit disease-causing viruses such as rosette virus or through injecting deleterious toxins into the plants [35]. The heavily infested plants can wilt and turn yellow or die due to the removal of sap from the plant [12]. The main aphids control strategies in crops include cultural practices such as early planting, use of resistant varieties, physical control and application of chemical insecticides such as phosphamidon, dimethoate, thiometon pirimicarb. However, due to the undesirable effects of synthetic pesticides, its use is discouraged [36]. The biological control such as the use of natural enemies such as parasitic wasps, hoverfly larvae, lacewings, and ladybird beetles which predate on aphids help in suppressing the population of aphids [34]. Pesticidal plants, on the other hand, have provided promising results in aphid's control. For example, Mkindi *et al.* (2017) reported that pesticidal plants such as *Bidens pilosa*, *Lantana camara*, *Tephrosia vogelii*, *Vernonia amygdalina*, *Lippia javanica*, and *Tithonia diversifolia* were effective against aphids (*Aphis fabae*) on common beans. Furthermore, these pesticidal plants cause very little effect on beneficial arthropods as compared with synthetic pesticides [30]. Therefore, future research is needed to quantify the abundance of aphids on bambara groundnuts and the damage caused by them in different cropping systems and to test the effectiveness of the available pesticidal plants to be used as an alternative of synthetic pesticides in Tanzania.

Figure 1. Aphids on bambara groundnut plant (Source: Field photo).

3.3. Groundnut Leafhopper (*Hilda patruelis* Stal)

The groundnut hopper, *Hilda patruelis* Stal (Homoptera: Tettigometridae) are polyphagous sucking bug widely distributed in Africa [37] [38]. It is one of the important insect pests of bambara groundnuts severely affecting their productivity [18] [39]. They usually attack plants below the ground level or at the ground level [37]. During their feeding process, *Hilda* bugs tend to inject toxic saliva on the plants resulting in withering and ultimately dying of the plants. They are usually noticed by the presence of the colonies of black ants which tend to protect them [37]. The leafhoppers and ants coexist in symbiotic relationship where the leafhoppers produce honey-dew which provides food for the ants while ants protect the leafhoppers against predators [37]. The adult leafhoppers damage the crop by sucking sap from the stem, pegs, and pods resulting in wilting of the plants [40]. The affected plants turn yellow, wilt, and die due to sap-sucking by the hoppers [37] [41]. Although, it is regarded as a minor pest, however, sporadic infestation during the dry season may lead to significant loss of yield if left uncontrolled [37]. However, in Tanzania, there is a lack of information on this insect due to little research attention on bambara groundnuts as it is considered as an under-researched orphan crop [3]. Therefore, further research should focus on determining the abundance and assess the impact of *H. patruelis* on bambara groundnuts grown in different cropping systems and patterns.

3.4. Foliage Beetles (*Ootheca mutabilis, Ootheca bennigseni*)

Foliage beetles (*O. mutabilis*, and *O. bennigseni*) (Coleoptera: Chrysomelidae) are foliage eating insects that are widely distributed in southern and eastern Africa including Tanzania [42]. Leaf beetles are important insects affecting, common beans, cowpea, and bambara groundnuts [18] [42] [43]. They feed on root tissue and seedlings, make holes in the leaves of host plants (**Figure 2**), and often feed on flowers, resulting in crop losses usually when the crop is at the seedling stage. *Ootheca spp*. are also vectors of plant viruses [43]. The infestation by *Ootheca spp*. is most severe on young plants; however, sometimes it may

Figure 2. Foliage beetles on bambara groundnut plant (Source: Field photo).

persist up to post-flowering. The adult beetles feed on leaves reducing the photosynthetic activity of the plant and may even cause the death of the plants especially if there is a severe attack on the growing points [42]. In common beans, the yield losses of 18% - 31% attributed by foliage beetles in Tanzania have been reported (Abate & Ampofo, 1996). Unfortunately, in Tanzania, there is published information on the magnitude of the impact of this insect pest on bambara groundnuts.

3.5. Groundnut Jassids (*Empoasca fascilis*)

Groundnut jassids *Empoasca fascilis* (Homoptera: Cicadellidae) are small green insects widely distributed in Africa [38] [44]. *E. fascilis* is one of the important insect pests of bambara groundnuts in Africa [18]. The adults and nymphs pierce and suck on the lower surfaces of the leaf leading to the yellowing of the leaves [38]. Damage by many jassids on one leaf leads to yellow spots followed by crinkling, curling, bronzing, and drying of the plants [38]. A yield loss of 3.5% - 39.5% has been reported in soybeans depending on the susceptibility of the variety [45]. The jassids population growth is generally enhanced by dry and humid conditions. The management strategies include cultural practices such as intercropping with non-legume crops and the use of systemic insecticides. However, the use of synthetic insecticides kills the natural enemies which prey on the adult and nymphs regulating the population of jassids. Thus, future research is needed to look for strategies that have less impact on natural enemies such as the use of extracts from the pesticidal plants.

3.6. Pod Sucking Bugs (*Clavigralla tomentosicollis* Stäl)

Pod sucking bugs, *Clavigralla tomentosicollis* Stäl. (Hemiptera: Coreidae) are pods sucking bugs that are predominantly spread in tropics and sub-tropics of Africa [44]. It is one of the important pests of bambara groundnuts [20]. The nymphs and adults pierce and bugs suck the sap from the young pods leading to the deformation of seeds, necrosis, premature drying of the pods, and poor seed formation which ultimately results to low grain yield [42] [44]. They also feed on stems, leaves, and floral buds. [44]. The insect can cause grain yield loss ranging from 20% - 100% when left uncontrolled on susceptible crops especially during prolonged dry weather [46]. Cultural practices such as intercropping legumes including bambara groundnuts with cereals can reduce the bugs infestation [44]. The biological control such as the use of *Gryon fulviventris* parasitoid can control *C. tomentosicollis* in Africa [44]. Synthetic insecticides can also be used to control bugs, however, they may kill even beneficial insects such as parasitoids *G. fulviventris* [44]. Pesticidal plants such *Bidens pilosa*, *Lantana camara*, *Tephrosia vogelii*, *Vernonia amygdalina*, *Lippia javanica* and *Tithonia diversifolia* on the other hand have provided effective control of insect pests on common beans insect pests including *C. tomentosicollis* [29]. Thus, future research is needed to be conducted to test the effectiveness of these pesticidal plants to control pod bugs on bambara groundnuts.

3.7. Red Spider Mites (*Tetrunychus sp.*)

Red spider mites, *Tetrunychus sp*. (Acari: Tetranychidae) are highly polyphagous mites originated in Eurasia but they are now widely distributed worldwide [47]. Red spider mites affect a wide range of crops including tomato, cucumber, pepper, rose, strawberry, currant, peach, grapes [47], common beans [42] and bambara groundnuts [19]. The damage of crops by red spider mites depends on the ability of the plant to resist damage. On susceptible crop, spider mites feed on leaves undersides by extracting the plant's sap using their long needle-like mouthparts resulting in the formation of brownish spots and often form webs on plants leaves [42]. In severe infestation, the leaves dry and dry off resulting (**Figure 3**) in the wilting of the entire plant [44]. The loss of yield of up to 100% has been reported on infested tea [48] and tomato [49]. The infestation of spider mites population is influenced by environmental factors such as low relative humidity, high temperature, drought, and long sunshine hours [50]. [49] reported that spider mites are difficult to control. Farmers often use ineffective broad-spectrum synthetic pesticides to control spider mites resulting in pest resistance [49]. The use of broad-spectrum synthetic pesticides tends to kill the

Figure 3. Spider mites on bambara groundnut plant (Source: Field photo).

natural enemies which would regulate the population of the spider mites [44]. Moreover, predatory mites such as *Phytoseiulus persimilis*, *Amblyseius womersleyi* and *A. fallacies* (Acari: Phytoseiidae) are effective to control red spider mites under controlled structures and high relative humidity [44]. However, the synthetic insecticides applied also kills beneficial mites. Pesticidal plants, on the other hand, have been reported to reduce spider mites without or with little harm to the natural enemies. For instance, studies by [51] have revealed pesticidal efficacy of the *Lippia javanica* and *Solanum delagoense* on red spider mites on rapes and tomatoes [51]. It was found that both *L. javanica* and *S. delagoense* reduced mites by 66.5% and 55% respectively. Despite of the reported effectiveness of, *L. javanica* and *S. delagoense* on spider mites on rapes and tomato, however, there is no published information on their effectiveness on bambara groundnuts spider mites. Thus future research is recommended to investigate the efficacy of indigenous pesticidal plants on bambara groundnut spider mites.

3.8. Bruchids *Callosobruchus maculatus* (F.) and *Callosobruchus subinnotatus* (Pic)

Bruchids, *C. maculatus* and C. *subinnotatus* (Coleoptera: Bruchidae) are serious pests of grain bambara groundnuts in Africa [20] [52]. *C. maculatus* are widely distributed and believed to originate in Africa while *C. subinnotatus* is mainly localized in West Africa [53]. These two bruchids species often infest grain bambara groundnuts simultaneously. When these two species simultaneously infest bambara grains, they tend to exhibit interspecific competition where *C. maculatus* dominates over C. *subinnotatus* [54] [55]. It is reported that *C. maculatus* is the most destructive species enhanced by its shorter life cycle and high reproductive potential and it often infests a wide range of legume grains while *C. subinnotatus* infest only bambara grains [52] [55]. During co-infestation, *C. maculatus* can cause the extinction of *C. subinnotatus* in multiple generations [55].

Bruchids affect bambara groundnuts from the field to the storage. Being field to storage pests, their infestation commences in the field during the pod's stage whereby the females lay their eggs on developing seeds or pods or during the harvesting when the pods are left in the field to dry (Ajayi & Lale, 2000; Nyamador *et al*., 2016). Bruchids on stored bambara groundnuts grains, reduce the quality and quantity of grains, and reduce the seeds germination potential and market value of the grains. The grain loss of up 99% has been reported when grains of susceptible variety is left unprotected with insecticide [56]. The infestation on the storage is influenced by the level of initial infestation thus the proper strategy of protection of bambara groundnuts grains from bruchids infestation starts by preventing the pre-harvest infestation on the field and post-harvest infestation during storage [55]. Various strategies are applied to control bruchids such as cultural control measures, breeding for resistance, synthetic insecticides, and pesticidal plants [52]. The use of pesticidal plants has been reported to be effective control of storage insects it does not cause an undesirable impact on the health of consumers, applicators, and nor-target organisms [27] [33]. Thus, more research is needed to determine the efficacy of pesticidal plants in the control of bruchids in bambara groundnuts.

4. Prospects of Pesticidal Plants in Bambara Groundnut Insect Pest Control in the Field and Storage

Pesticidal plants contain a mixture of bioactive compounds that act as feeding deterrents, repellents on insects or they tend to interfere with insect development [57]. They have been used by farmers for decades for pest control in crops or livestock (**Table 1**) before and after the introduction of synthetic pesticides (Anjarwalla *et al*., 2016). Unlike synthetic pesticides that have a detrimental effect on the environment, non-target organisms, and humans, pesticidal plants serve as better alternatives to synthetic insecticides since they are friendly to the environment and the health of farmers and consumers [28] [58]. This review has explored the chemical compounds, potential in controlling insect pests in the field, and storage of seven selected candidate pesticidal plants including *Bidens pilosa*, *Lantana camara*, *Tephrosia vogelii*, *Vernonia amygdalina*, *Lippia javanica* and *Tithonia diversifolia* and *Croton dichogamus*.

Table 1. Common pesticidal plants found in Africa.

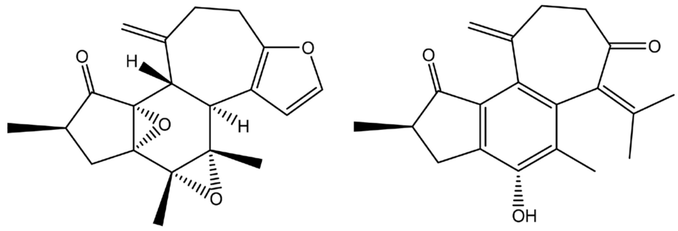
Pesticidal plan	Crop/insect controlled	Reference
Pyrethrum, *Chrysanthemum cinerariifolium*	Groundnut anthropods pests: *Helotrichia serrate*, *Peridontopyge* spp., *Macrotermes bellicosus*	[59]
Neem, Azadirachta indica	The Bean Weevil: *Acanthoscelides obtectus*	[60]
Black jack, *Bidens pilosa*	Common beans insect pests: *Ootheca mutabilis* and *O. bennigseni*, *Epicauta albovittata* and *E. limbatipennis*, *Clavigralla tomentosicollis*, and *C. hystricodes*	[29]
Mexican marigold, *Tagetes minuta*	Cabbage: *Brevicoryne brassicae*	[61]
Tickberry *Lantana camara*	Maize weevil: *Sitophilus zeamais*	[62]
Tobacco, *Nicotiana tabacum*	The Bean Weevil: *Acanthoscelides obtectus*	[60]
Fish poison, *Tephrosia vogelii*	Common beans insect pests: *Ootheca mutabilis* and *O. bennigseni*, *Epicauta albovittata* and *E. limbatipennis*, *Clavigralla tomentosicollis*, and *C. hystricodes*	[29]
Bitter leaf, *Vernonia amygdalina*	Cowpea beetle: *Callosobruchus maculatus*	[63]
Lippia javanica	Common beans insect pests: *Ootheca mutabilis* and *O. bennigseni*, *Epicauta albovittata* and *E. limbatipennis*, *Clavigralla tomentosicollis* and *C. hystricodes*	[29]
Mexican sunflower, *Tithonia diversifolia*	Cowpea beetle: *Callosobruchus maculatus*	[63]
Eucalpytus sp.	Cereals: *Sitophilus oryzae*	[64]
Garlic, *Allium sativum*	Maize: *Sitophilus zeamais*	[65]
Derris elliptica	Cabbage: *Brevicoryne brassicae*	[66]
Papaya, *Carica papaya*	Mustard *Lipaphis erysimi*	[67]
Croton dichogamus	Storage insect pests	[67]

4.1. The Chemical and Insecticidal Potential of *Croton dichogamus*

Croton dichogamus Pax is a naturally growing shrub belonging to the family Euphorbiaceae widely distributed in tropics and subtropics such as Kenya, Uganda, Ethiopia, Mozambique, Madagascar and Tanzania ([69] [70] **Figure 4**). In Africa, America and Asia croton species are used as traditional medicines in the treatment of various ailments such as fever, diabetes, dysentery, wounds, ulcers malaria, intestinal worms, inflammation, hypercholesterolemia, digestive problems, constipation, cancer weight loss and pains [71]. In Kenya and Tanzania, *C. dichogamus* is used as a dietary additive to milk and soup. The smoke from the Croton is inhaled during the treatment of respiratory infections. Moreover, it has been reported that the plant is also used to treat chest pains, malaria, arthritis, gonorrhea, and stomachache in Kenya [70].

The photochemistry of the plant is generally diverse possessing the compounds such as crotodichogamoin A and B (**Figure 5**), crotofolanes, halimes, crothalimene A and B, crotohaumanoxide, aleuritolic, depressin, casbane and sesquiterpenoid are isolated from the roots of *C. dichogamus* [69] [70]. Most of the croton species are rich in terpenoids [71], a compound with insecticidal properties [72] [73]. Silva *et al*. (2018) studied the effectiveness of the ethanolic extracts from the leaves and stems of *Croton rhamnifolius*, *C. jacobinensis*, *C. sellowii*, *and C. micans* against the diamondback moth (*Plutella xylostella* L) on kales. It was found that the *C. rhamnifolius* leaf had more lethal effect (LC = 14.95 mL^{-1}) than the stem (LC = 42.40 mL^{-1}) and *C. sellowii* stem was found to have the lowest lethal effect (LC = 1252 $\mu g \cdot mL^{-1}$). In Tanzania, the plant is used by agro-pastoral societies in Mbulu District as a pesticide for controlling storage insect pests, medication of teeth infections and urinary tract infection [68]. Despite *C. dichogamus* being used traditionally by agro-pastoral societies in Mbulu, proper application rates have not been established for optimized application. Therefore, future research is needed to establish its dosages for proper insect pest control.

Figure 4. The picture of *Croton dichogamus*, a pesticidal plant (Source: Field photo).



Crotodichogamoin A Crotodichogamoin B

Figure 5. Chemical structure of crotodichogamoin A and B from *C. dichogamus* roots (Aldhaher *et al*., 2017).

4.2. The Chemical and Insecticidal Potential of *Tithonia diversifolia*

Tithonia diversifolia commonly known as Mexican sunflower is a prolific flowering shrub belonging to the family Asteraceae originated from central and north America [74]. Currently, *Tithonia* (**Figure 6**) is widely distributed along with the farms, roads, rivers, and hills of humid and sub-humid tropics of Africa, Central America and South America [75] [76]. Extracts from the *T. diversifolia* plant is traditionally used as medicine for the cure of many ailments including wounds, skin diseases, stomachache, malaria, diabetes, sore throat, fever and liver pains [76] [77] and insect pests control [29]. The medicinal and insecticidal properties of the plant are attributed by the presence of phytochemical constituents including sesquiterpene lactones tagitinin A, taginin B, tagitinin C, tagitinin D and tagitinin H (**Figure 7**) [63] [74].

Several authors including Green *et al.* (2017) reported the insecticidal potential of *T. diversifolia* against cowpea bruchids *Callosobruchus maculatus*. It was revealed that the toxicity of crude extracts of *T. diversifolia* against bruchids was concentration-dependent. However, it was found that the crude extracts showed no significant effect on the oviposition despite the concentration. Other studies by [28] [29] found that the leaf extracts of the *T. diversifolia* was effective against the insect pest of common beans such as aphids (*Aphis fabae*), bean foliage beetle (*Ootheca mutabilis* and *O. bennigseni*) and flower beetle (*Epicauta albovittata* and E. *limbatipennis*). The application of *T. diversifolia* as pesticide reduces the cost incurred on expensive synthetic pesticides resulting in the high marginal rate of returns from farming. For example, the use of *T. diversifolia* is reported to provide the marginal rate of return of 5.32 USD/ha higher than 4.06 USD/ha obtained when synthetic pesticide is used [28]. The leaves of the *T. diversifolia* contain nutrients about 3.5% N, 0.37% P, and 4.1% K on dry matter basis so when used as green manure replenishes soil nutrients enhancing the growth and yield of the crops [75]. Moreover, foliar spraying of the extract from these plant as a pesticide it also provide additional nutrients to the crop in the form of foliar fertilizer [78], thus, resulting to high yield of the crop. Furthermore, plants are also used as animal fodder [79].

Therefore, the presence of the bioactive compounds in these plants, and proven pesticidal potential against arthropod pests of legumes [28] [29] [63]

Figure 6. The picture of *Tithonia diversifolia*, a pesticidal plant (Source: Field photo).

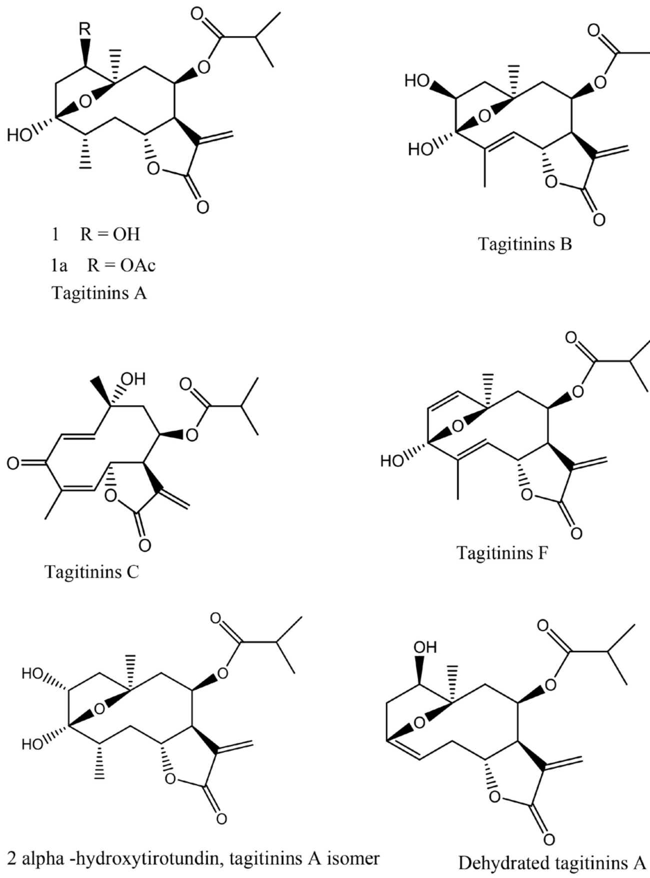


Figure 7. Chemical structure of sesquiterpene lactones tagitinin A, tagitinin B, taginin C taginin F and taginin 2 alpha-hdroxytirotundin, taginins A isomer and dehydrated taginins A (Green *et al.*, 2017; Miranda *et al.*, 2015; Zhao *et al.*, 2012).

gives the insight to investigate its effectiveness in the control of pre-harvest and post-harvest insect pest of bambara groundnuts.

4.3. The Chemical and Insecticidal Potential of *Lantana camara*

L. camara (Figure 8) is an ornamental plant in the family Verbenaceae originated from America. It is widely spread in tropical and subtropical regions

Figure 8. The picture of *Lantana camara*, a pesticidal plant (Source: Field photo).

including East Africa [80]. In many parts of the world, it is considered an invasive weed [80] [81] [82]. It is used in the preparation of the folk medicine for the cure of ailments diseases such as ulcers, rheumatism, tetanus, malaria, cancer, ulcers, cancer, eczema, high blood pressure, sores and measles among others [83] [84] [85] [86]. *L. camara* is regarded as toxic to livestock such as cattle, sheep, horses, dogs, and goats [30] [87].

The toxicity to animals is caused by the presence of pentacyclic triterpenoids (**Figure 9**) which damage liver and generalized weakness, diarrhea, vomiting and notorious to cause photosensitivity [88]. The toxicity in humans is undetermined but several studies have suggested that ingesting green unripe fruits are toxic to humans [88] [89]. However, other studies have reported that the ingestion of ripe fruits poses no risk to humans [88] [89]. Several studies have revealed the insecticidal property of *L. camara* against several insect pests of stored grains. For example, the study conducted in Kenya by Ogendo *et al.* (2003) reported the insecticidal potential of leaf powder from *L. camara* against maize weevil (*Sitophilus zeamais*). Their study revealed that after 21 days *L. camara* at the rate of 7.5% - 10% w/v resulted in 82.7% insect mortality. Moreover, another study by Rajashekar *et al.* (2014) reported the potential of *L. camara* in control of *Sitophilus oryzae* (L.) *Callosobruchus chinensis* (Fab.) and *Tribolium castaneum* (Herbst.). Despite the findings available, there is a need to conduct more studies to understand the potential of *L. camara* against different insect pests on different crops both in the field and on storage.

4.4. The Chemical and Insecticidal Potential of *Bidens pilosa*

Bidens pilosa L. is an annual herb originated from South America and widely distributed around the tropical and subtropical regions [90] [91]. The plant is regarded as a noxious weed in the agricultural fields [92]. In sub-Saharan countries, the young tender leaves (**Figure 10**) are consumed as a vegetable in times of food scarcity [92]. The medicinal role of the plant in many parts of the world such as Africa, Asia, and tropical America includes anti-inflammation, anti-bacterial infection, antioxidant, liver protection, regulating blood pressure and blood sugar has been extensively described by many authors [92] [93] [94] [95].

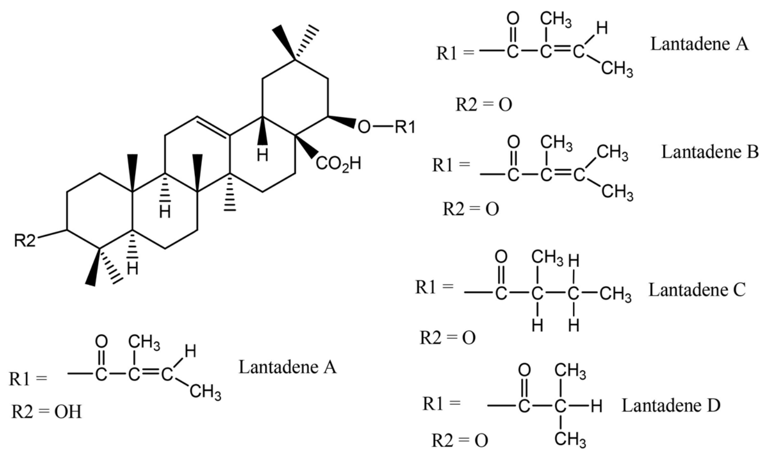


Figure 9. Chemical structures of Lantadene (Pentacyclic triterpenoids) (Mpumi *et al*., 2016; Sharma *et al*., 2007).

Figure 10. The picture of *Bidens pilosa*, a pesticidal plant (Source: Field photo).

The medicinal role offered by this plant is due to the presence of bioactive compounds. For stance, the antimicrobial and antimalarial function of *B. pilosa* is due to the presence of polyacetylenes in the plant [95]. Major bioactive compounds identified from leaves and flowers of the *B. pilosa* includes sesquiterpenes germacrene-D and β-caryophyllene and τ-cadinene [90] [93] (**Figure 11**). Several studies have revealed the anti-insect function of the plant. A study conducted by [96] revealed the insecticidal potential of essential oils from the leaves of *B. pilosa* against *Callosobruchus maculatus*. [97] investigated the toxicity of methanol and acetone extracts of *B. pilosa* against stored pests of kidney beans, the *Acanthoscelides obtectus* (Say), and *Zabrotes subfasciatus* (Boheman) (Coleoptera: Chrysomelidae).

Both acetone and methanol extracts were found to cause 100% mortality of A. *obtectus* and *Z. subfasciatus*. Moreover, a study conducted by [29] [32] revealed the insecticidal potential of *B. pilosa* against insect pests of common beans such as aphids (*Aphis fabae*), foliage beetles (*Ootheca mutabilis* and *O. bennigseni*), pod suckers (*Clavigralla spp.*) and flower beetle borers (*Epicauta albovittata* Gestro and *E. limbatipennis* Pic). Although the insecticidal functions of the plant

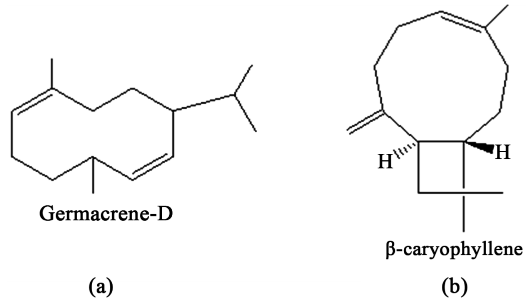


Figure 11. (a) Sesquiterpenes Germacrene-D (Yang *et al*., 2005) and (b) *β*-caryophyllene (Gertsch *et al*., 2008) from *B. pilosa*.

have been reported by many authors [29] [32] [96] however, it has not been sufficiently tested on bambara groundnut pests. Thus, future research is needed to be conducted to determine its efficacy on insect pests on bambara groundnuts.

4.5. The Chemical and Insecticidal Potential of *Tephrosia vogelii*

Tephrosia vogelii Hook. F. (**Figure 12**) is the herb belonging to the Family Leguminosae native to tropical Africa highly distributed in tropical America and South and Southeast Asia mainly cultivated as fish poison [98]. *T. vogelii* is also used as a pesticide to control pests on animals and crops on the field and storage and also enrich soil nutrients [99].

T. vogelii plant possesses diverse bioactive chemical compounds including three chemotypes (**Figure 13**). The chemotype 1 (C1) contains rotenoids required for pest control and chemotype 2 (C2) which do not contain rotenoids [99] [100]. However, it is reported that rotenoids (deguelin, tephrosin, *α*-toxicarol, and sarcolobine) differ in their effectiveness against insect pests. Rotenone is the most active rotenoid than deguelin, tephrosin while obovatin 5-methyl ether found in chemotype 2 is not active [100]. The Chemotype 3 (C3) is a hybrid of the chemical profiles of the Chemotype 1 and chemotype 2 [101]. Several studies have reported the insecticidal potential of the active chemical compounds of *T. vogelii*. For example, a study conducted by [62] revealed that *T. vogelii* leaf powder killed maize weevil (*Sitophilus Zeamais*) by causing 85.0% - 93.7% insect mortality in stored maize grain. It was found that the mortality of maize weevil was proportional to the exposure time and concentration. Closely related findings were reported by [102] when they investigated the potential of extracts from *T. vogelii* for the control of bruchids on stored legumes. Their study showed that the extracts had insecticidal potential against bruchid species (*Acanthoscelides obtectus*, *Callosobruchus maculatus*, and *C. chinensis*) on stored legumes. Moreover, the use of *T. vogelii* in controlling common bean pests has been reported to provide high marginal rate of return 5.62 (USD/ha) as compared with synthetic pesticide lambda-cyhalothrin pyrethroid (Karate) 4.06 USD/ha [28]. The low marginal rate of return (USD/ha) for synthetic pesticides is due to its high market price and ultimately high marginal cost than when *T. vogelli* was used. Despite the insecticidal and economic benefits offered when *T.*

Figure 12. The picture of *Tephrosia vogelii* a pesticidal plant (Source: Field photo).

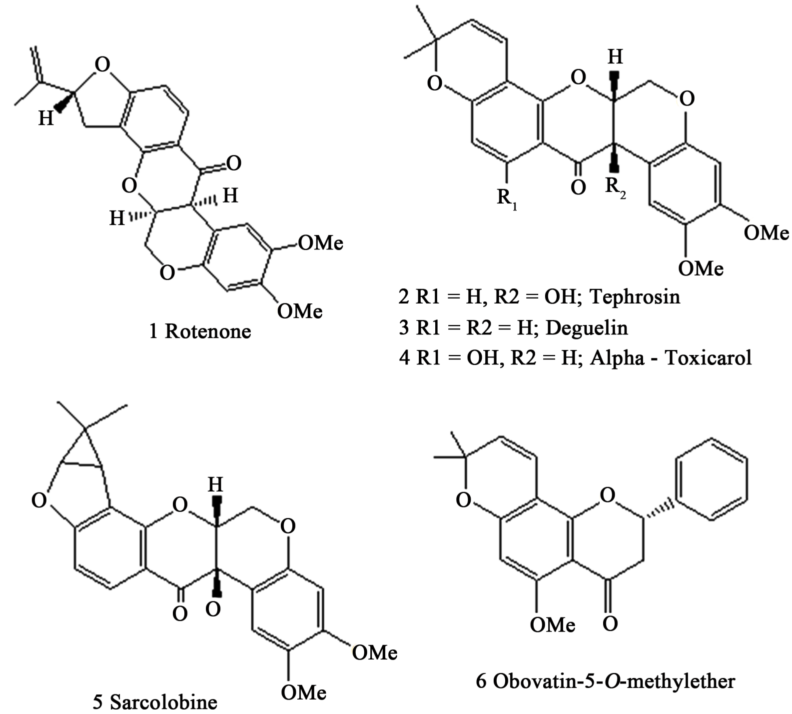


Figure 13. 1 - 5; *T. vogelii* Chemotype compounds and 6; *T. vogelii* Chemotype 2 (Belmain *et al.*, 2012; Stevenson *et al.*, 2012).

vogelli is used to control pests on crops such as common beans, however, there is limited information on its potential in insect control on bambara groundnuts. Therefore, future research is needed to determine its potential for bambara groundnuts insect control on the field and storage.

4.6. The Chemical and Insecticidal Potential of *Vernonia amygdalina*

Vernonia amygdalina Del, is a small perennial shrub (Figure 14) belonging to the family Asteraceae that is widely distributed in tropical Africa. It is commonly referred to as bitter leaf due to its bitter taste [103]. The bitter taste is attributed to the presence of anti-nutritional factors such as alkaloids, saponins, glycosides,

Figure 14. The picture of *Vernonia amygdalina*, a pesticidal plant (Source: Field photo).

and tannins [104] [105]. *V. amygdalina* has many traditional uses in African countries. In Nigeria, the leaves are used as a vegetable or as a spice in a soup whereby the bitterness of the leaves is reduced to the desired level by macerating in hot water [104] [106]. In Ethiopia, the leaves are used like hops in preparing tela beer [106]. The leaves are consumed mostly due to antioxidant potential [107] [108]. Moreover, in most African countries *V. amygdalina* is used as a folk medicine as remedies against ailments such as emesis, nausea, diabetes, loss of appetite, dysentery and other gastrointestinal tract problems, sexually transmitted diseases, diabetes mellitus [106] and antimalarial [109].

The phytochemical investigation of the leaves of *V. amygdalina* revealed presence of number of bioactive compounds such as sesquiterpene lactones including the vernolide and vernodalol (**Figure 15**) [108] [110], flavonoids such as luteolin, luteolin 7-O-glucosides, and luteolin 7-O-glucuronide, steroid glycosides, and vernonioside A, B, A1, A2, A3, B2, B3 and A4 [106] [108]. The sesquiterpene lactones found in *V. amygdalina* have insect antifeedant, antitumoral, antifungal, and cytotoxic properties [110]. Several studies have reported the insecticidal potential of leaf powders of *V. amygdalina* against *Callosobruchus maculatus* (F.) [111], beans weevil (*Acanthoscelides obtectus*) [112] and maize weevil (*Sitophilus zeamais*) [113] and field insects of common beans (*Aphis fabae*), bean foliage beetle (*Ootheca mutabilis*) and *O. bennigseni*), flower beetle (*Epicauta albovittata* and *E. limbatipennis*) and pod suckers (*Clavigralla tomentosicollis*, *C. schadabi* and *C. hystricodes*) in a study conducted in Tanzania and Malawi [29]. However, despite its potential in controlling insects in other crops such as common beans, future research is needed to test the efficacy of *V. amygdalina* extracts in controlling field and storage insect pests of bambara groundnuts.

4.7. The Chemical and Insecticidal Potential of *Lippia javanica*

Lippia javanica (Burm F.) Spreng (**Figure 16**) is an erect woody perennial herb belonging to the family Verbenaceae naturally growing in the bushes, along the roadsides, hillsides, and farms [114] in central, eastern, and southern Africa and the Indian subcontinent [115] [116]. In many African countries and Indian

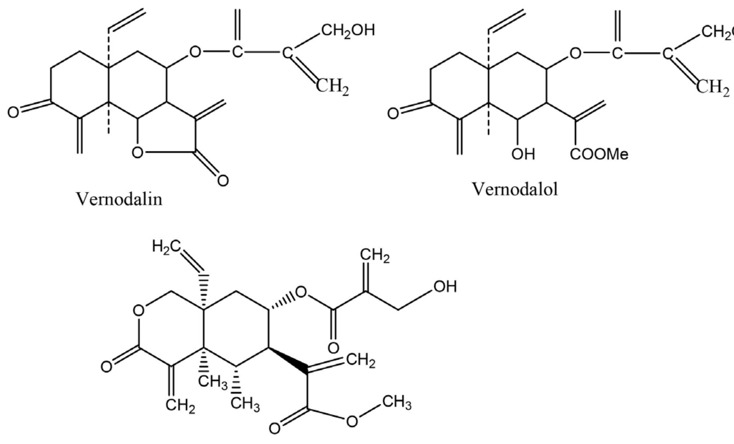


Figure 15. Structure of compounds isolated from *V. amygdalina* (Farombi & Owoeye, 2011; Green *et al.*, 2017).

Figure 16. The picture of *Lippia javanica*, a pesticidal plant (Source: Field photo).

subcontinent, *L. javanica* are traditionally used as herbal tea due to its ethno-medicinal properties for the cure of ailments like colds, cough, fever, malaria, repelling mosquitos, healing wounds, diarrhea, chest pains, bronchitis, and asthma and skin diseases [117]. In Kenya, the leaves and twigs are used as food additives whereas in India, leaves are used as a leafy vegetable. In Botswana, South Africa, and Zimbabwe, the leaves, stems, and twigs are used in preparations of the herbal tea [115].

The phytochemical analysis of *L. javanica* revealed the presence of camphor as the major component with minor components such as camphene, *α*-pinene, eucalyptol, Z, and E *α*-terpineol, linalool, cymene, thymol, 2-carene, caryophyllene and *α*-cubebene [28]. The camphor (**Figure 17**) a monoterpenoid commonly found in *Cinnamonum camphora* is reported to have the insecticidal potential [28] [32] [118] [119] [120]. Several authors including [28] [29] [32] reported the insecticidal property of *L. javanica* against field insects of common beans such as aphids (*Aphis fabae*), bean foliage beetle (*Ootheca mutabilis* and O. *bennigseni*) and flower beetle (*Epicauta albovittata* and *E. limbatipennis*). Another study conducted in Zimbabwe revealed that the aqueous leaf extracts of *L. javanica*

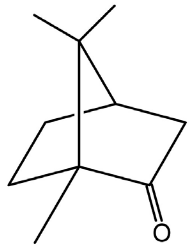


Figure 17. Chemical structure of camphor (Yim *et al.*, 2014).

have acaricidal activity against cattle ticks and acute oral toxicity in mice [121]. Their study found that the acaricidal effect was dependent on the dose of the extract and exposure time. A study by [122] as well revealed the effectiveness of aqueous extracts of *L. javanica* leaves against the cowpea aphids. Their study demonstrated that 10% w/v extracts from the dried leaves powder significantly reduced the aphids infestation on cowpeas. Furthermore, the leaf powders demonstrated insecticidal potential against storage insect pests of maize and cowpeas including *Sitophilus zeamais*, *Callosobruchus maculatus*, *Prostephanus truncates*, *Tribolium spp*., and *Sitotroga cerealella* [33]. Although *L. javanica* contains bioactive compounds proved with insecticidal potential, however, it has not been evaluated against insect pests of bambara groundnuts. Therefore, future research is needed to investigate its potential against the pre-harvest and post-harvest insect pests of bambara groundnuts.

5. Conclusion

The production of bambara groundnut is constrained by arthropod pests such as aphids, leafhoppers, leaf beetle's groundnut jassids, pod sucking bugs, and red spider mites on the field and bruchids on the storage. The use of synthetic pesticides for pests control is common in agriculture but it is associated with undesirable effects on the environment, human health, and non-target organisms. This review has established the potential for the use of pesticidal plants as an alternative to the use of harmful synthetic pesticides. Given the diverse bioactive compounds possessed by pesticidal plants such as *Croton dichogamus*, *Bidens pilosa*, *Lantana camara*, *Tephrosia vogelii*, *Vernonia amygdalina*, *Lippia javanica*, and *Tithonia diversifolia* and the promising results shown by these plants against the field and storage insects of legumes (e.g. Common beans), it is, therefore, suggested that the efficacy of these plants to be tested against bambara groundnut field and storage pests to establish proper usage by smallholder farmers.

Acknowledgements

The authors acknowledge the financial support received from the Centre for Research, Agricultural Advancement, Teaching Excellence and Sustainability in Food and Nutrition Security (CREATES-FNS) through the Nelson Mandela African Institution of Science and Technology (NM-AIST). We also acknowledge the McKnight Foundation's Collaborative Research Program (CCRP) through the University of Greenwich for additional financial support in our study.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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