frontiers in Agronomy

REVIEW
published: 28 September 2021
doi: 10.3389/fagro.2021.725895

Invasive Alien Plants in Sub-Saharan Africa: A Review and Synthesis of Their Insecticidal Activities

Osariyekemwen Uyi[1,2*†], *Ludzula Mukwevho*[3†], *Afure J. Ejomah*[1] *and Michael Toews*[2]

[1] Department of Animal and Environmental Biology, University of Benin, Benin City, Nigeria, [2] Department of Entomology, University of Georgia, Tifton, GA, United States, [3] School of Biology and Environmental Sciences, University of Mpumalanga, Mbombela, South Africa

Despite the cornucopia of agricultural, economic and ecological ramifications of invasive alien plant species (IAPs) in sub-Saharan Africa, studies on their potential use as bio-insecticides have not received adequate attention compared to the burgeoning plethora of literature on their use in ethnomedicine. In the current study, we review the existing, but scattered literature on the insecticidal activity of different parts of some IAPs; specifically those invasive in sub-Saharan Africa but with published literature from Africa and elsewhere. From our literature survey, we found that 69 studies from four continents (Africa, Asia, North America and South America) reported the insecticidal activity of 23 plant species from 13 families (Asteraceae = 6 species; Solanaceae = 3 species; Apocynacee, Fabaceae and Euphorbiaceae 2 species each; Araceae, Bignoniaceae, Chenopodiaceae, Meliaceae, Mimosaceae, Myrtaceae, Papaveraceae, and Verbenaceae = 1 species each) that are invasive in, and alien to Africa. The highest number of published case studies were from India ($n = 19$) and Nigeria ($n = 15$). We found that varying concentrations of extracts or powders from different plant parts caused 50–100% mortality against a myriad of insect pests of agriculture and environmental importance. Our review discussed the prospects for exploiting IAPs as pesticidal plants in African countries especially among resource-poor small-holder farmers and locals to improve agricultural productivity and livelihoods. Finally, we highlighted safety concerns and challenges of using IAPs as bio-insecticides in Africa and formulates appropriate recommendations for future research.

Keywords: invasive alien plant species, Africa, botanical insecticide, insect pest control, resource poor farmers

OPEN ACCESS

Edited by:
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***Correspondence:**
Osariyekemwen Uyi
osariyekemwen.uyi@uniben.edu

† *These authors have contributed equally to this work*

Specialty section:
This article was submitted to Pest Management, a section of the journal Frontiers in Agronomy

Received: *16 June 2021*
Accepted: *27 August 2021*
Published: *28 September 2021*

Citation:
Uyi O, Mukwevho L, Ejomah AJ and Toews M (2021) Invasive Alien Plants in Sub-Saharan Africa: A Review and Synthesis of Their Insecticidal Activities. Front. Agron. 3:725895. doi: 10.3389/fagro.2021.725895

INTRODUCTION

Invasive alien plant species (IAPs) are among species whose naturalization threatens the biological biodiversity and functions of the ecosystem in their new geographic region (Richardson and Pyšek, 2012; Mostert et al., 2017; O'Connor and van Wilgen, 2020). These plants are among significant ecosystem drivers that degrades the quality of grazing, agricultural and natural lands (Richardson and van Wilgen, 2004; Davis, 2006). Due to the immense ecological and social pressures exerted by these plants, governments have announced the management of IAPs and millions of dollars are invested toward the management of these plants in South Africa and elsewhere in the world (McConnachie et al., 2010; Van Wilgen and Lange, 2011; Hoffmann and Broadhurst, 2016; Morokong et al., 2016; Hanley and Roberts, 2019).

Regardless of the efforts made toward minimizing the densities of invasion and the spread of these IAPs, follow-up treatments may be required to keep the populations of these non-native species at a level that prevents spread and harm to human health or the environment (Marais et al., 2004; Klein, 2011; Mukwevho and Mphephu, 2020). Although manual clearing of IAPs yields temporal relief on the intensity of invasion, continuous clearing alone favors the expansion of the invasion by species that are propagated vegetatively (Radtke et al., 2013). To minimize the further spread of IAPs through plant propagules, the cut plant materials from the above- and below-ground may be further processed to be used for socio-economic and ecological benefits in sub-Saharan Africa (Shackleton et al., 2007, 2018; Ngorima and Shackleton, 2019; Mugwedi, 2020).

The potential use of IAPs in ethnomedicine and various aspects of ethnobotany in Africa have received a great deal of attention (e.g., Omokhua et al., 2016, 2018a,b) however, studies on the use and potential of invasive alien plants as pesticidal plants to manage agricultural and environmental pests is only beginning to gain recognition (e.g., Midega et al., 2016; Mkindi et al., 2017; Stevensona et al., 2017; Uyi et al., 2018a,b). Since some IAP's contain some novel secondary phytochemicals, the harvested materials may be processed to be used against microorganisms, insects and weeds and other undesired plants (Deressa et al., 2015; Amir et al., 2017; Mkindi et al., 2017; Das et al., 2018; Zerihun and Ele, 2018; Mugwedi, 2020). Like other pesticides, biopesticides may repel insect pests, disrupt their development, affect reproduction or kill live organisms on contact (Mogg et al., 2008; Litt et al., 2014; Uyi and Adetimehin, 2018). Although different scientists consider IAPs as a threat to agriculture and biodiversity, dozens of IAPs have insecticidal properties that have been rigorously screened toward major pests, pollinators and wasps (including some parasitoids) around the globe (Isman, 2008; Mkenda et al., 2015; Mkindi et al., 2017; Stevensona et al., 2017).

Due to the cost of synthetic chemicals (Dougoud et al., 2019), impacts on non-target species (Theiling and Croft, 1988; Mulè et al., 2017), target pest's genetic drift (REX consortium, 2010; Khayatnezhad and Nasehi, 2021) and ecotoxicological impacts (Pimentel, 1995; Kankam, 2021), the United Nations (UN) promotes the use of environmentally safe products, such as aqueous extracts to minimize the impact of pests on crops (Phillips and Throne, 2010; Bommarco et al., 2013; Oliveira et al., 2014). Sustainable and eco-friendly biopesticides may be easily accessible by the resource-poor small-holder farmers and locals in countries where there is greater food insecurity, particularly in Africa (Sasson, 2012). Further processing of plant propagules also curbs the further distribution of IAPs through vegetative materials, hence also benefiting the livelihoods though reducing pressures by the agricultural pests on various crops. In this paper, we review the existing, but scattered literature on the insecticidal activity of different parts of some IAPs; specifically, those that are invasive in the sub-Saharan Africa. We discuss the prospects and opportunities for using IAPs as bio-insecticides of insect pests of agricultural and environmental importance. Finally, the paper highlights the safety concerns, research gaps, the challenges of using IAPs as bio-insecticides and formulates appropriate recommendations for future research.

METHODS

The information presented in this review was obtained from journal articles that are relevant to the topic. Only literature on insecticidal (not repellence) properties of IAPs that are invasive in Africa were included. Plant like *Azadirachta indica* A. Juss (Miliaceae) that have wide usage and is already well-established for over 100 years were not considered in this review. The scientific papers analyzed were obtained from different sources such as Google Scholar, Science-Direct, PubMed, SciFinder, and Scopus. Systematically used keywords include invasive alien plants, insecticidal, pesticidal, insect pest, efficacy, mortality, with the scientific name of each plant reported to possess insecticidal properties in journal articles. We used Boolean operators (and, or, not or and not) to combine or exclude keywords in our search to obtain a more focused and productive results. The literature search was conducted between June 2019 and April 2020, and more than 120 published papers were identified. Among the excluded research papers were those that assessed the insecticidal properties of forest trees, plants that have not been declared as invasive in Africa and studies that did not include control treatments. The mean percentage of insect mortality reported here was recorded from either of the text, tables, graphs and/figures. Among the information derived from the research papers was the country in which different studies were conducted, name of the IAP's, the harvested/used plant part(s), the formulations, the target insect, developmental stages at which the formulation was applied, and the percentage mortality reported after application of the formulation. Only articles that reported data with means, sample size and a measurement of variance (standard deviation, standard error or confidence intervals) for all treatments with a clear indication of replication were considered. The scoring system of 0–4 was used to rate the insecticidal properties of IAPs against insects in Africa. The percentage mortality of 1–25, 26–50, 51–75, and 76–100% were ranked as 1, 2, 3, and 4, respectively, but the formulation that recorded zero percent mortality was ranked as 0.

RESULTS AND DISCUSSION

Impact and Distribution of Invasive Alien Plant Species in Africa

Invasive alien plant species are identified as the plants that are intentionally or accidentally introduced to the regions beyond their native ranges (Richardson and Pyšek, 2012). Naturalized alien plant species are among significant ecosystem drivers that pose major threats to the native communities (e.g., plants and arthropods) in natural and agricultural ecosystems (Van Hengstum et al., 2013; Litt et al., 2014). The increase in the intensity of invasion aggravates the degree of threat to biodiversity and ecosystem function (Valone and Weyers, 2019). The distribution and problems of the IAPs reviewed in this paper are detailed in **Tables 1A–E**. Among the common impacts of the IAPs is the degradation of grazing land, competition with native species and cultivated crops for natural resources, supporting agricultural pests between cropping seasons, presenting health hazard to humans and poisoning of livestock

(Aigbokhan et al., 2010; Alagesaboopathi and Deivanai, 2011; Park et al., 2012; Van Hengstum et al., 2013; Litt et al., 2014; Shackleton et al., 2017; Dandurand et al., 2019; O'Connor and van Wilgen, 2020). Although there is sufficient literature that documents the impacts of these plants, the global efforts on mapping the distribution of the plants in their non-native ranges is insufficient (Witt et al., 2018).

The current distribution of invasive alien plants has been recorded for various plants invading the landscapes of different countries in Africa (Henderson, 2001; Shackleton et al., 2017; Witt and Luke, 2017; Witt et al., 2018, 2019; Catarino et al., 2019), whilst other studies also predicted the future distribution of these weeds (McConnachie et al., 2010; Taylor et al., 2012; Tererai and Wood, 2014; Obiakara and Fourcade, 2018). Further, surveys on the distribution of agents associated with these IAPs contribute to the continuous update on the change of the invasion intensities (Mukwevho et al., 2018). Despite the remarkable efforts by the Centre for Agriculture and Bioscience International (CABI, sometimes also referred to as CAB International) to describe the international distribution of IAPs, insufficient records of plant distribution in other African countries result in fragmented distribution maps.

Invasive Alien Plants in Africa With Reported Insecticidal Properties

From the literature survey, we found 69 studies across the globe that reported insecticidal activities of 23 plant species that are invasive in, and alien to Africa. The identified species were from 13 plant families and comprised six species from Asteraceae, three species from Solanaceae, two species from Apocynaceae, Fabaceae and Euphorbiaceae, and one species each from Araceae, Bignoniaceae, Chenopodiaceae, Meliaceae, Mimosaceae, Myrtaceae, Papaveraceae, and Verbenaceae (**Tables 2A–I**). These reports showing the insecticidal activities of alien plants that are problematic in Africa originated from Africa, Asia, North America and South America. The highest number of published case studies were from India and Nigeria with 19 and 15, respectively, whilst countries such as Algeria, Argentina, Brazil, Colombia, Chile, China, Egypt, Ethiopia, Ghana, Kenya, Malawi, Mexico, Pakistan, Sudan, Tanzania, Togo, Tunisia, Turkey, and the United States of America have less than 6 reports each. We hypothesized that the large number of research papers from India, Nigeria and other developing countries may be due to the fact that scientists in these countries are aware of the limited availability of synthetic insecticides by the resource-poor small-holder farmers; locals in these countries are keen on identifying IAPs to control and manage insect pests of agricultural, environmental and medical importance. Due the ecotoxicological effects and high cost of synthetic insecticides, the use of plants with pesticidal properties to control insect pests in agro-ecosystems among resource-poor small-holder farmers has been historically widespread and adopted in Africa (Belmain and Stevenson, 2001; Midega et al., 2016). Despite the widespread use of these biorational methods, pest control in some ecosystems in Africa continues to rely on the use of synthetic insecticides when alternative biopesticides are unavailable (Isman, 2006, 2015; Isman and Grieneisen, 2014). Although a plethora of empirical research has demonstrated the insecticidal properties of weeds in general, our literature found evidence that some invasive alien plants in Africa possessed insecticidal properties against a range of insect pests.

Several biological assays have been conducted to ascertain the efficacy of invasive alien plants against a myriad of insect pests with varying levels of insect mortality (**Tables 2A–I**). The survey demonstrated that leaf extracts were frequently used for bioassays, compared to other parts (i.e., roots, stems, inflorescences, fruits or seeds) of the plant (**Figure 1**). A majority of studies were conducted on members of the Asteraceae which represented 25 out of 69 studies and accounted for 38% of the total studies recorded in this review (**Figure 2**). Mean mortality rank of insect pests caused by the Asteraceae ranged from 50 to 100% (**Figure 3**).

Asteraceae Species With Insecticidal Properties

Six species in the family Asteraceae were reported effective against a number of insect pest species. In a laboratory and field study conducted by Xu et al. (2009), the acetone leaf extract of *Ageratina adenophora* caused up to 73% mortality in *Brevicoryne brassicae* after a 3-day exposure. Although the use of the essential oils of *A. adenophora* has been suggested for controlling aphids, ants and weevils in stored grains, there are no reports on the insecticidal use of this plant in invaded areas in Africa. Jaya et al. (2014) observed that essential oils from *Ageratum conyzoides* leaves caused 100% mortality against *Tribolium castenum*. Moreira et al. (2007a,b) isolated compounds including (5,6,7,8,3′,4′,5′-heptamethoxyflavone, 5,6,7,8,3′-pentamethoxy-4′, 5′-methylenedioxyflavone and coumarin) from the hexane extract of *A. conyzoides* leaves and tested the efficacy of the compounds against *Rhyzopertha dominica* and *Diaphania hyalinata*. Following a 24-h exposure, varying concentrations of the isolated compounds caused between 76 and 87% mortality in adults of *R. dominica* and 100% mortality in the larvae of *D. hyalinata* (Moreira et al., 2004, 2007a,b). The leaf extracts of *A. conyzoides* have also been reported to possess strong insecticidal activities (100% mortality) against the larvae of *Acanthoscelides obtectus*, *Musca domestica* and *Epilachna vigintioctopunctata* (Calle et al., 1990; Saxena and Sharma, 2005). Liu and Liu (2014) evaluated the larvicidal activity of the essential oil of *A. conyzoides* aerial parts against *Aedes albopictus*. The authors identified the principal constituents of the essential oils of *A. conyzoides* and concluded that the oils have insecticidal and larvicidal activities. Despite the burgeoning plethora of papers on the pesticidal activity of *A. conyzoides* against a myriad of arthropod pests (see Rioba and Stevenson, 2017), studies on the indigenous use of this plant in the control and management of insect pests are scarce. The increasing reports of the use of *A. conyzoides* in ethnomedicine for the treatment of a wide range of diseases in Africa (e.g., Nwauzoma and Dappa, 2013) suggest that the locals are exploiting the potential of the plant. Whether or not the plant has found use among the locals in its invasive range in Africa remains to be documented.

In a bioassay where *Cimex lectularius* adults were exposed to 2.0 g of *Chromolaena odorata* leaf powder, 70% mortality

TABLE 1A | Published reports on the impact of some invasive alien plants in sub-Saharan Africa.

Family/Species	Growth form	Native range	Distribution ranges in Africa*	Impact of the weed	Reference (s)
Apocynaceae					
Catharanthus roseus	Shrub/herb	Madagascar	BE, BO, BF, CA, CD, ET, GAB, GU, KE, MA, MO, NA, RW, SE, SL, SA, SW, TZ, TOGO, UG, ZA, ZM	Adapts to a wider range of ecological conditions such as watercourses, rocky outcrops, grazing lands, and along plantations. The milky sap contained on the vegetative parts of the plant makes the plant to be toxic	Henderson, 2001
Nerium oleander	Shrub	Europe, Asia	EG, KE, MO, NG, SA, ZM	The plant is toxic to humans and other mammals. The modes of toxicity/poisoning include direct ingestion or of the smoked food products, and inhalation	Henderson, 2001
Araceae					
Pistia stratiotes	Aquatic	South America	AN, BE, BO, BF, BU, CA, CAR, CH, CO, CD, EG, EQ, ET, GA, GAB, GH, GU, KE, LE, LIB, MA, MO, MOR, NA, NI, NG, RW, SE, SL, SO, SA, SU, SW, TOGO, TZ, UG, ZA, ZM	The water weed covers water bodies and thereby affects the lives of organisms inhibiting the waters. The weed clogs waterways and thus prevents movement of boats, blocks irrigation canals, disrupts fishing grounds and hydro-electricity production	Henderson and Cilliers, 2002; Macdonald et al., 2003; Witt et al., 2018
Asteraceae					
Ageratina adenophora	Herb	Argentina	AL, KE, NG, SA, UG, ZM	Outcompetes the native plant and crop species, thus affecting the diversity of plants, carrying capacity of grazing lands and yields of cultured crops. The weed is not palatable to grazers and dense thickens may restrict movement of stock and machinery	Tererai and Wood (2014)

Algeria (AL); Angola (AN); Benin (BE); Burkina Faso (BF); Botswana (BO); Burundi (BU); Cameroon (CA); Central African Republic (CAR); Côte d'Ivoire (CD); Chad (CH); Congo (CO); Egypt (EG); Equatorial Guinea (EQ); Ethiopia (ET); Gambia (GA); Gabon (GAB); Ghana (GH); Guinea (GU); Kenya (KE); Lesotho (LE); Liberia (LIB); Malawi (MA); Mozambique (MO); Morocco (MOR); Namibia (NA); Nigeria (NG); Niger (NI); Rwanda (RW); South Africa (SA); Senegal (SE); Sierra Leone (SL); Somalia (SO); Sudan (SU); Swaziland (SW); Togo (TOGO); Tanzania (TZ); Uganda (UG); Zambia (ZA); Zimbabwe (ZM).

was reported after 5 days (Uyi et al., 2018a). Depending on concentrations, the leaf, stem and root powders of *C. odorata* were reported to cause between 16 and 100% mortality against adults of the *Callosobruchus maculatus* (Uyi and Igbinoba, 2016; Uyi and Obi, 2017; Uyi and Adetimehin, 2018). In Nigeria, Lawal et al. (2015) reported that the leaf extracts of *C. odorata* displayed a strong insecticidal activity by causing between 33 and 93% mortality in *Sitophilus zeamais*. In a field experiment in Ghana, Ezena et al. (2016) reported that varying concentrations of the leaf extract caused between 36 and 77% mortality in nymphs and adults of the *Brevicoryne brassicae* and *Hellula undalis* and *Plutella xylostella*. Udebuani et al. (2015) tested the efficacy of *C. odorata* leaf extract against *Periplaneta americana* by exposing the adults to different concentrations of the leaf extract and reported 12 to 69% mortality. Sukhthankar et al. (2014) investigated the insecticidal activity of different concentrations of methanolic leaf extract of *C. odorata* against the larvae of *Anopheles stephensi, Culex quinquefasciatus* and *Aedes aegypti* and found up to 100% mortality in these larvae after 24 h of exposure. Similar to *A. conyzoides*, studies documenting the indigenous use of *C. odorata* are scarce (but see Cobbinah et al., 1999). The authors conducted ethnobotanical surveys on plants used for the protection of stored cereals in Ghana and reported that cowpea treated with *C. odorata* leaf powder were free of insect infestation for 4 months and that the locals attributed this to the insecticidal or repellent activities of *C. odorata*.

Tesfu and Emana (2013) studied the insecticidal properties of different parts of *Parthenium hysterophorus* powders against *Callosobruchus chinensis* over 48 h and found that the highest dose (2/50 g seeds) of inflorescence, leaf and stem powder caused 77, 73, and 57% mortality, respectively. The leaf, stem and root extracts of *P. hysterophorus* have been reported to be effective against *Ae. aegypti*; larval mortality of 40 to 100% was recorded after exposure to the aqueous leaf extracts of *P. hysterophorus* (Kumar S. et al., 2012; Amir et al., 2017). In an investigation of the insecticidal efficacy of the leaf extract of *P. hysterophorus* against the larvae of the rice moth, *Corcyra cephalonica*, Khan and Qamar (2015a) reported 81% mortality of larvae. In another experiment, Khan and Qamar (2015b) recorded 14.4% adult mortality in *P. americana*. Reddy et al. (2018) investigated the insecticidal activity of *P. hysterophorus* against *P. xylostella* and *Aphis craccivora* in a field experiment and found that *P. hysterophorus* leaf extract showed promising toxicity (LC50 = 1140.68 mg L^{-1}) to larvae of *P. xylostella* and *A. craccivora* (LC50 = 839 mg L^{-1}) after 96 h of treatment. The authors did not report any specific mortality rates. Although several studies (see references in **Tables 2A–I**) have recommended the use of *P. hysterophorus* as a pesticidal plant in its invasive ranges in Asia and Africa, there is no evidence to show that the locals especially the resource-poor small-holder farmers are exploiting it as yet.

In Nigeria and Tanzania, the leaf and stem bark extracts of *Tithonia diversifolia* have been reported to cause 100% mortality of adult *C. maculatus* (Obembe and Kayode, 2013; Green et al., 2017). Similarly, studies on the insecticidal activity of the leaf

TABLE 1B | Published reports on the impact of some invasive alien plants in sub-Saharan Africa.

Family/Species	Growth form	Native range	Distribution ranges in Africa	Impact of the weed	Reference (s)
Asteraceae					
Ageratum conyzoides	Herb	Americas	AN, BE, BO, BF, BU, CV, CA, CAR, CO, CD, EG, EQ, ET, GA, GAB, GH, GU, KE, LIB, MA, MALI, MO, MOR, NG, RW, SE, SL, SA, SU, SW, TZ, TOGO, UG, ZA, ZM	Alternate host to a number of economically important pests, namely pathogens (e.g., Tomato Yellow Leaf Curl Tanzania Virus and the Ageratum Yellow Vein Virus) and nematodes (*Meloidogyne javanica*, *Radopholus similis* and *Helicotylenchus multicinctus*). The plant releases the allelochemicals that inhibits the seed germination and growth of other species	Witt et al., 2018
Chromolaena odorata	Shrub	Central and South America	BE, CA, CAR, CD, CO, GH, GU, KE, LIB, MO, NG, SA, TZ, TOGO, UG, ZM	Displaces native plant species and alters the fuel loads which may increase proneness to wildfires. Reduces the productivity of rangelands and may cause serious health problems to livestock and people	Muniappan et al., 2005; Witt et al., 2018; Catarino et al., 2019; Mugwedi, 2020
Parthenium hysterophorus	Herb		BO, EG, ET, KE, MO, RW, SA, SO, SW, TZ, UG, ZM	The plant is allelopathic and suppresses the natural vegetation of the invaded landscapes. Severe reduction in the productivity of rangelands and has serious health hazards (dermatitis, hay fever, and asthma) to people, livestock, and wildlife	McConnachie et al., 2010; Witt et al., 2018
Tithonia diversifolia	Shrub	Mexico and Central America,	AN, BU, CA, CAR, CO, CD, EG, ET, GU, KE, MA, MO, NG, RW, SA, SW, TZ, TOGO, UG, ZA, ZM	The plant is allelopathic and has a significant impact on native vegetation. The evergreen plant reduces species diversity and the productivity of rangelands. Intensive invasions may contribute to the local extinction of valued native species	Obiakara and Fourcade, 2018; Witt et al., 2019
Xanthium strumarium	Herb	Central and South America	BO, BU, EG, ET, KE, LE, MA, RW, SA, TZ, UG, ZA	Rapidly forms large stands, displacing other plant species. Toxic to livestock and can lead to death if eaten	Witt et al., 2018

Angola (AN); Benin (BE); Burkina Faso (BF); Botswana (BO); Burundi (BU); Cameroon (CA); Central African Republic (CAR); Côte d'Ivoire (CD); Congo (CO); Cabo Verde (CV); Egypt (EG); Equatorial Guinea (EQ); Ethiopia (ET); Gambia (GA); Gabon (GAB); Ghana (GH); Guinea (GU); Kenya (KE); Lesotho (LE); Liberia (LIB); Malawi (MA); Mali (MALI); Mozambique (MO); Morocco (MOR); Nigeria (NG); Rwanda (RW); South Africa (SA); Senegal (SE); Sierra Leone (SL); Somalia (SO); Sudan (SU); Swaziland (SW); Togo (TOGO); Tanzania (TZ); Uganda (UG); Zambia (ZA); Zimbabwe (ZM).

extract of *T. diversifolia* against *S. zeamais* showed 43% mortality in adults (Obembe and Kayode, 2013). Babarinde et al. (2008) and Adedire and Akinneye (2004) demonstrated that the leaf powder of *T. diversifolia* caused 90 and 99% mortality of *S. zeamais* and *C. maculatus*, respectively. In a field experiment, Mkenda et al. (2015) showed that the leaf extracts of *T. diversifolia* significantly reduced the population of the nymphs/larvae and adults of *Aphis fabae*, *Ootheca mutabilis*, *O. bennigseni*, *Epicauta albovittata* and *E. limbatipennis*. The authors further showed that the control offered by the leaf extracts were comparable to lambda-cyhalothrin, a commonly used synthetic pyrethroid. Although without mortality figures, Mkindi et al. (2017) reported some insecticidal activity of *T. diversifolia* leaf extract against some important pests (*Aphis fabae*, *Ootheca mutabilis* and *O. bennigsen*, *Epicauta albovittata*, *E. limbatipennis*, *Clavigralla tomentosicollis*, *C. schadabi,* and *C. hystricodes*) of beans in Tanzania and Malawi. The authors reported that *T. diversifolia* offered effective control of key pest species that was comparable in terms of harvested bean yield to a synthetic pyrethroid. The leaf extract of another species of Asteraceae, *Xanthium strumarium* caused more than 82% mortality in green peach aphid, *Myzus persicae* (Erdogan and Yildirim, 2016). In Uganda, farmers used the leaf extract and powder of *T. diversifolia* for the management of field and stored product pests (Mugisha-Kamatenesi et al., 2008; Mwine et al., 2011). *Tithonia diversifolia* is known to contain sesquiterpene lactones and diterpenoids (Chagas-Paula et al., 2012), some of which have biological activities against insects such as termites (Adoyo et al., 1997). However, there is no specific information about which compounds are responsible for its insecticidal effect. Despite the traditional use of *Xanthium strumarium* in ethnomedicine for treating a variety of diseases (Fan et al., 2019), its use by locals in the management of insect pests of agricultural and medical importance have not been documented.

Solanaceae Species With Insecticidal Properties

Three species in the family, Solanaceae were reported effective against a number of important field and stored product insect pests. Zapata et al. (2006) investigated the insecticidal efficacy of the leaf extract of *Cestrum parqui* against the Mediterranean fruit fly, *Ceratitis capitata* and recorded 55% mortality in the adults of this pest. Investigations on the insecticidal activity of *Solanum elaeagnifolium* showed that the leaf and seed extracts of this plant accounted for 88 and 84% mortality, respectively against the larvae of *T. castenum* in Tunisia (Ben Hamouda et al., 2015a). The leaf and seed extracts of *S. elaeagnifolium* offered effective control against the *Spodoptera littoralis* (Ben Hamouda et al., 2015b). The authors found that leaf and seed extracts, respectively caused 80 and 100% mortality in the larvae of *S. littoralis*. Ben Hamouda et al. (2015c) reported the mortality

TABLE 1C | Published reports on the impact of some invasive alien plants in sub-Saharan Africa.

Family/Species	Growth form	Native range	Distribution ranges in Africa	Impact of the weed	Reference (s)
Bignoniaceae					
Jacaranda mimosifolia	Tree	South America	AN, BO, CV, CA, CAR, EG, ET, GAB, GH, GU, KE, MA, MOR, MO, NG, RW, SA, SW, TZ, UG, ZA, ZM	The dense foliage it produces tends to shade out native plants and prevent their regeneration. Deep rooted and may thrive conditions/outcompete some species	Henderson, 2001
Chenopodiaceae					
Chenopodium ambrosioides	Herb	Mexico	BO, CA, EG, GAB, GH, KE, LE, MA, MO, NA, NG, SA, SE, TA, UG, ZA, ZM	Common weed of agricultural, pastural and natural ecosystems. Inter-seasonal host for *Erysiphe betae* (powdery mildew) of sugar beet. The plant can smother native plants and may outcompete them in the disturbed areas	Foxcroft et al., 2003
Euphorbiaceae					
Jatropha curcas	Shrub	Americas	AN, BE, BF, CV,CA, CAR, CH, CD, EG, ET, GA, GAB, GH, GU, KE, LI, MA, MALI, MO, NI, NG, RW, SA, SE, SL, SO, SU, TZ, TOGO, UG, ZA, ZM	The plant is poisonous to grazing stock of animals and may contribute to significant modifications of the ecosystems that they are invading. It cause significant shift of biodiversity.	Negussie et al., 2014
Fabaceae					
Prosopis juliflora	Tree or shrub	Caribbean	AL, BO, BF, CV, CH, EG, ER, ET, GA, GH, GU, KE, LIB, MALI, MOR, MO, NA, NG, NI, SE, SO, SA, SU, TZ, TUN, UG, ZM	Reduces grazing capacity, eliminates many species from invaded ecosystems and depletes groundwater resources. Despite some benefits in the form of firewood and edible pods, the overall net economic contribution is negative, and set to worsen as the species continues to spread	Henderson, 2007; Zachariades et al., 2011a,b; Abdulahi et al., 2017
Sesbania grandiflora	Tree	Asia	BE, CV, CH, ET, GAB, GH, MA, NG, SA, SE, SL, SO, SU, TZ	It has allelopathic effects on crop seed germination	Gillett, 1963

Algeria (AL); Angola (AN); Benin (BE); Burkina Faso (BF); Botswana (BO); Burundi (BU); Cameroon (CA); Central African Republic (CAR); Côte d'Ivoire (CD); Chad (CH); Congo (CO); Cabo Verde (CV); Egypt (EG); Equatorial Guinea (EQ); Eritrea (ER); Ethiopia (ET); Gambia (GA); Gabon (GAB); Ghana (GH); Guinea (GU); Kenya (KE); Lesotho (LE); Libya (LI); Malawi (MA); Mali (MALI); Mozambique (MO); Morocco (MOR); Namibia (NA); Nigeria (NG); Niger (NI); Rwanda (RW); South Africa (SA); Senegal (SE); Sierra Leone (SL); Somalia (SO); Sudan (SU); Swaziland (SW); Togo (TOGO); Tunisia (TUN); Tanzania (TZ); Uganda (UG); Zambia (ZA); Zimbabwe (ZM).

rate of up to 5 and 43% caused by the leaf and seed aqueous extract of *Solanum elaeagnifolium* against *M. persicae*. In an investigation into the insecticidal activity of *S. sisymbriifolium* leaf extract against *T. castenum*, Padín et al. (2013) reported 22% mortality in adult beetles. The traditional use of the leaf extract of *C. parqui, S. sisymbriifolium,* and *S. elaeagnifolium* for the control and management of insect pests in their invasive ranges in Africa have not been documented and therefore requires some ethnobotanical studies.

Apocynaceae, Euphorbiaceae, and Fabaceae Species With Insecticidal Properties

Two species each in the family, Apocynaceae, Euphorbiaceae, and Fabaceae were reported effective against some insect pests of medical, environmental and agricultural importance. Remia and Logaswamy (2010) studied the insecticidal activity of the leaf extract of *Catharanthus roseus* against *Ae. aegypti* and reported over 71% mortality in the larvae and pupae of this mosquito species. Khan and Qamar (2015a,b) investigated the efficacy of *Nerium oleander* against the larvae of a rice moth, *Corcyra cephalonica* and *P. americana* and found up to 83% mortality in the larvae of the rice moth and *P. americana*. Despite the usage of Apocynaceae species in ethnomedicine (CABI, 2020a), their use as pesticides by locals is yet to be reported.

The leaf, seed, stem bark and root extracts of *Jatropha curcas* have been found effective (i.e., with 40 to 100% mortality) against the nymphs and larvae of *P. xylostella, Helicoverpa armigera, Spodoptera frugiperda,* and *Schistocerca gregaria* (Ribeiro et al., 2012; Bashir and El Shafie, 2013; Ingle et al., 2017). Opuba et al. (2018) and Adetimehin et al. (2018) showed that 3.0 g of the leaf and stem bark powders of *J. curcas* caused 100 percent mortality in *C. maculatus* in a laboratory test. The leaf extract of *Ricinus communis* reportedly caused 100% mortality on the larvae of *P. xylostella* (Tounou et al., 2011). Investigations into the insecticidal efficacy of the leaf, seed and fruit extracts of *Prosopis juliflora* caused up to 73% mortality in adult cotton aphid, *A. gossypii* (Zerihun and Ele, 2018). Sangavi and Johnson Thangaraj Edward (2017) reported between 73 and 96% mortality in *P. xylostella* when the larvae were treated with the leaf extract of *P. juliflora* and *Sesbania grandiflora*. While the use of *R. communis* for the management of insect pests by locals is not known, *J. curcas* is used by farmers in Uganda for the control and management of both field and storage pests (Mugisha-Kamatenesi et al., 2008). The ethnopesticidal usage of *P. juliflora*

TABLE 1D | Published reports on the impact of some invasive alien plants in sub-Saharan Africa.

Family/Species	Growth form	Native range	Distribution ranges in Africa	Impact of the weed	Reference (s)
Euphorbiaceae					
Ricinus communis	Shrub		AL,AN, BE, BO, BF, BU, CV, CAR, CH, CO, EG, ET, GAB, GA, GH, GU, KE, LI, MA, MALI, MOR, MO, NA, RW, SE, SO, SA, TZ, TOGO, TUN, UG, ZA, ZM	Pollen causes respiratory allergies for animals. *R. communis* is extremely poisonous to animals and humans and pollen causes respiratory allergies in humans	Henderson, 2001; Kiran and Prasad, 2017
Meliaceae					
Melia azedarach	Tree	Asia	AN, BO, BF,CV CA, CH, CO, CD, EG, ER, ET, GH, KE, LE, MA, MALI, MO, MOR, NA, NI, NG, SE, SO, SA, SU, SW, TZ, TUN, UG, ZA, ZM	The dense monospecific stands suppress the regenerating native plants. It alters soil chemistry, and can act as respiratory irritants	Henderson, 2001, 2007
Mimosaceae					
Mimosa diplotricha	Shrub		BU, CA, CO, CD, ET, GH, GU, MA, MO, NG, RW, SA, TZ, TOGO, UG, ZM	Dry thickets are prone to fires and density of the plant restricts movement of mammals, including people. It suppresses the shaded species and thus prevents regression of other plants	Ekhator et al., 2013; Uyi, 2020
Myrtaceae					
Eucalyptus camaldulensis	Tree		AL, AN, BE, BF, BO, BU, CA, CD, CH, CO, CV, EG, EQ, ER, ET, GA, GH, KE, LE, LI, MA, MALI, MO, MOR, NA, NG, NI, RW, SA, SE, SL, SO, SU, SW, TUN, TZ, UG, ZA, ZM	The plant suppresses native plants, improves the fuel loads, depletes nutrients and excessive water use	Henderson, 2001

Algeria (AL); Angola (AN); Benin (BE); Burkina Faso (BF); Botswana (BO); Burundi (BU); Cameroon (CA); Central African Republic (CAR); Côte d'Ivoire (CD); Chad (CH); Congo (CO); Cabo Verde (CV); Egypt (EG); Equatorial Guinea (EQ); Eritrea (ER); Ethiopia (ET); Gambia (GA); Gabon (GAB); Ghana (GH); Guinea (GU); Kenya (KE); Lesotho (LE); Libya (LI); Malawi (MA); Mali (MALI); Mozambique (MO); Morocco (MOR); Namibia (NA); Nigeria (NG); Niger (NI); Rwanda (RW); South Africa (SA); Senegal (SE); Sierra Leone (SL); Somalia (SO); Sudan (SU); Swaziland (SW); Togo (TOGO); Tunisia (TUN); Tanzania (TZ); Uganda (UG); Zambia (ZA); Zimbabwe (ZM).

and *S. grandiflora* is yet to be documented and therefore warrant some ethnobotanical investigation.

Other Species With Insecticidal Properties

Insecticidal activity of at least one species from the following families: Araceae, Bignoniaceae, Chenopodiaceae, Meliaceae, Mimosaceae, Myrtaceae, Papaveraceae, and Verbenaceae was investigated. Ito et al. (2015) investigated the insecticidal activity of *Pistia stratiotes* and found that the leaf powder of this aquatic weed reduced the population of *Ae. aegypti* by 80%. Our survey also found that the leaf powder of *Jacaranda mimosifolia* caused 30% mortality in adults of *A. obtectus* (Waweru et al., 2017), while the leaf extract caused 49% mortality in adults of *T. castenum* (Padín et al., 2013). Guzzo et al. (2006) reported that the leaf and fruit extracts of *Dysphania ambrosioides* only caused low adult mortality (<5%) in *R. dominica*. The fruit extract of *Melia azedarach* has been reported to be effective in the control of several pests. For example. The fruit extract of this weed caused 44% larval mortality in *Liriomyza huidobrensis* and 100% larval mortality in *S. frugiperda* and *S. littoralis* (Hammad and McAuslane, 2010; Scapinello et al., 2014). Chiffelle et al. (2011) documented 86% mortality when the adults of the Elm leaf beetle, *Xanthogaleruca luteola* were treated with the fruit extract of *M. azedarach*. Similarly, Selvaraj and Mosses (2011) reported over 88% larval mortality in *An. stephensi*, *Cx. quinquefasciatus* and *Ae. aegypti* when larvae were treated with the fruit extracts. Although we found no traditional usage of the Araceae, Bignoniaceae, Chenopodiaceae species as pesticidal plants, we found that in Ghana, the leaves of *M. azedarach* were used as a bioinsecticide to minimize the impact of *Ephestia cautella* on cocoa beans (CABI, 2020b).

In a laboratory experiment on the efficacy of the root extract of *Mimosa diplotricha*, Uyi et al. (2018b) reported 100% mortality in worker termites, *Macrotermes* species when exposed to different concentrations for 12 h. In a different experiment on the efficacy of the leaf and root powders of *M. diplotricha* against *C. lectularius* and *C. maculatus*, Uyi et al. (2018a, 2020) reported more than 67% mortality for both insects. Nia et al. (2015) reported 53% mortality in the nymphs and adults of *M. persicae* when the leaf extract of *Eucalyptus camaldulensis* was used to treat infestations of this pest. Khan and Qamar (2015a,b) found significant mortalities (15–76%) in *C. cephalonica* and *P. americana* when the larvae of the moth and nymphs of the cockroach were exposed to the leaf extracts of *Argemone mexicana*. We found no reports on the ethnopesticidal usage of *M. diplotricha* and *E. camaldulensis*, but for *A. mexicana*,

TABLE 1E | Published reports on the impact of some invasive alien plants in sub-Saharan Africa.

Family/Species	Growth form	Native range	Distribution ranges in Africa	Impact of the weed	Reference (s)
Papaveraceae					
Argemone mexicana	Herb	Mexico	AN, BE, BO, BF, CV, CA, CD, EG, EQ, ER, ET, GA, GH, GU, KE, LIB, MA, MALI, MO, NA, NG, NI, SE, SL, SO, SA, SU, SW, TZ, TOGO, UG, ZA, ZM	It is a toxic plant, which is also toxic to feeding animals. The allelopathic effects result on suppression of plants in the ecosystem	Van der Westhuizen and Mpedi, 2011
Solanaceae					
Cestrum parqui	Shrub	Argentina, Brazil, Bolivia, Chile, Peru, Paraguay and Uruguay	KE, SA	The plant out-competes and disrupt regeneration of native plants. Thickets along waterways blocks access by to streams. Toxic to feeding herbivores, causes skin irritation (e.g., rashes)	Henderson, 2001; Witt and Luke, 2017
Solanum elaeagnifolium	Herb	Mexico	AL, EG, LE, LI, MOR, SA, TUN, ZM	The plant acts as a vector for the Lettuce chlorosis virus between cropping seasons. Competes for natural resources with cultivated crops and reduce production on agricultural lands. The berries are toxic to livestock	EPPO, 2007
Solanum sisymbriifolium	Tree	South America	CO, NA, SA, SW	Competes with native vegetation for space and natural resources. Acts as a trap crop for the potato and tobacco cyst nematodes, though it affects their reproduction	Dandurand et al., 2019
Verbenaceae					
Lantana camara	Tree or shrub	Mexico	AN, BU, CO, CD, CV, ET, GA, GAB, GH, GU, KE, LIB, MA, MO, NA, NG, RW, SA, SE, SU, SW, TZ, UG, ZA, ZM	Displaces natural vegetation and impacting negatively on plant and arthropod biodiversity. Toxic to livestock, causing animal deaths, reduced productivity, and allelopathic effects causes loss of pasture	Henderson, 2007; Taylor et al., 2012; Shackleton et al., 2017; Witt et al., 2018

Algeria (AL); Angola (AN); Benin (BE); Burkina Faso (BF); Botswana (BO); Burundi (BU); Cameroon (CA); Côte d'Ivoire (CD); Congo (CO); Cabo Verde (CV); Egypt (EG); Equatorial Guinea (EQ); Eritrea (ER); Ethiopia (ET); Gambia (GA); Gabon (GAB); Ghana (GH); Guinea (GU); Kenya (KE); Lesotho (LE); Libya (LI); Liberia (LIB); Malawi (MA); Mali (MALI); Mozambique (MO); Morocco (MOR); Namibia (NA); Nigeria (NG); Niger (NI); Rwanda (RW); South Africa (SA); Senegal (SE); Sierra Leone (SL); Somalia (SO); Sudan (SU); Swaziland (SW); Togo (TOGO); Tunisia (TUN); Tanzania (TZ); Uganda (UG); Zambia (ZA); Zimbabwe (ZM).

von Weizsäckerl (1995) reported that the leaf extract is used in parts of India to prepare antifeedant sprays for the management of insect pests.

From the Verbenaceae family, *Lantana camara* was reported active against some mosquito species and major pests of crops due to the insecticidal potential of the plant. Remia and Logaswamy (2010) investigated the efficacy of the leaf extract of *L. camara* against *Ae. aegypti* in the laboratory and found more than 65% larval and pupal mortality. The essential oils from the leaves of *L. camara* caused between 93 and 100% in *Ae. aegypti*, *Cx. quinquefasciatus*, *An. culicifacies, An. fluvialitis* and *An. Stephensi* when adults were exposed for 24 h (Dua et al., 2010). Leaf powders and extracts of *L. camara* were also reported effective against a number of stored product pests (*S. zeamais*, *S. oryzae*, *S. granaries*, *C. chinensis*, *T. castenum*) where it caused 9–100% mortality depending on the concentration (of the extract/powder) and period of exposure (Sexana et al., 1992; Zoubiri and Baaliouamer, 2012; Rajashekar et al., 2014; Taye et al., 2014). In a laboratory experiment in China, the leaf extract of *L. camara* caused 90% mortality in the subterranean termite, *Reticulitermes flavipes*, when the workers were exposed for 24 h. The leaf extract of *L. camara* was reported to possess some insecticidal activities against some field pests (e.g., *A. fabae*, *Ootheca mutabilis*, *O. bennigseni*, *Epicauta albovittata*, *E. limbatipennis*, *Clavigralla tomentosicollis*, *C. schadabi,* and *C. hystricodes*) of beans in Tanzania and Malawi (Mkindi et al., 2017). Despite the ethnomedicinal uses of *L. camara* in Africa and the numerous studies on its pesticidal properties, there is surprisingly only one report (Mugisha-Kamatenesi et al., 2008) on the use of the plant for the management of insect pest species in the invasive range of the plant in Africa.

Prospects, Challenges, and Safety of Using IAPs as Bio-Insecticides

Prospects for Exploiting IAPs for Insect Pest Control

Due to the associated non-target effects and cost of synthetic insecticides in Africa, many resource-poor small-holder farmers on the continent rely on the use of crude plant-based materials collected from the wild and locally prepared (using the available technology or crude methods) to control and manage insect pests problems in subsistence farming, which is wide spread on the continent (Cobbinah et al., 1999; Belmain and Stevenson, 2001; Isman, 2008; Nyirenda et al., 2011; Kamanula et al., 2017). Despite the demonstrated laboratory and field efficacy of botanicals from many invasive alien plants against

TABLE 2A | Published reports on the insecticidal activities of some plant species with invasive potentials in sub-Saharan Africa.

Family	Plant species	Plant parts	Formulation/application method	Insect target	Stage of insect	Importance of insect	Mortality (%)	Country	Reference (s)
Apocynaceae	*Catharanthus roseus*	Leaf	Acetone extract/spray	Mosquito (*Aedes aegypti*)	Larvae and pupae	Pest of medical importance	>71	India	Remia and Logaswamy, 2010
	Nerium oleander	Leaf	Methanol extract/spray	Rice moth (*Corcyra cephalonica*), Cockroach (*Periplaneta americana*)	Larvae	Rice and household pests	17.4–83	India	Khan and Qamar, 2015a,b
Araceae	*Pistia stratiotes*	Leaf	Aqueous extract/spray	*Aedes aegypti* (L.)	Larvae	Vector of some parasitic diseases	80.1	Nigeria	Ito et al., 2015
Asteraceae	*Ageratina adenophora*	Leaf	Acetone extract/spray	Cabbage aphid (*Brevicoryne brassiccae*)	Adults and nymphs	Pest of cabbage and other brassicae species	73	China	Xu et al., 2009
	Ageratum conyzoides	Leaf	Essential oils/fumigant	Storage grain beetle (*Tribolium castaneum*)	Adults	Stored grains	100	India	Jaya et al., 2014
		Leaf	Hexane extract/filter paper impregnation	Lesser grain borer *Rhyzopertha dominica*	Adults	Stored grains	76- 87	Brazil	Moreira et al., 2007a,b
		Leaf	Hexane extract/filter paper impregnation	Melonworm moth, *Diaphania hyalinata*, *Tuta absoluta*	Larvae	Pest of various plants in the cucumber family	100	Brazil	Moreira et al., 2004
		Leaf	Petroleum ether extract/filter paper impregnation	*Acanthoscelides obtectus*, *Musca domestica*	Larvae	Bean weevil	100	Colombia	Calle et al., 1990
		Leaf	Petroleum ether extract/ingestion	*Epilachna vigintioctopunctata*	Larvae	Agricultural pest (eggplant)	100	India	Saxena and Sharma, 2005

TABLE 2B | Published reports on the insecticidal activities of some plant species with invasive potentials in sub-Saharan Africa.

Family	Plant species	Plant parts	Formulation/application method	Insect target	Stage of insect	Importance of insect	Mortality (%)	Country	Reference (s)
Asteraceae	*Ageratum conyzoides*	Leaf	Essential oils/addition of extract to water	Asian tiger mosquito, *Aedes albopictus*.	Larvae		–	China	Liu and Liu, 2014
	Chromolaena odorata	Leaf and root	Powder/Dust	Bed bugs (*Cimex lectularius*)	Adults	Pest of humans and animals	>70	Nigeria	Uyi et al., 2018a
		Leaf and root	Aqueous extract/filter paper impregnation	Termites (*Macrotermes* species)	Adults	Pest of crops	100	Nigeria	Uyi et al. (2018b)
		Leaf, stem and root	Powder/Dust	Cowpea beetle (*Callosobruchus maculatus*)	Adults	Pest of cowpea	16–100	Nigeria	Uyi and Igbinoba, 2016; Uyi and Obi, 2017; Uyi and Adetimehin, 2018
		Leaf extracts	Methanol extract/filter paper impregnation	Maize weevil (*Sitophilus zeamais*)	Adults	Pest of maize, and cowpea	33–93	Nigeria	Lawal et al., 2015
		Leaf extract	Aqueous extract/spray	Cabbage aphid (*Brevicoryne brassicae*), cabbage webworm (*Hellula undalis*), Diamondback moth (*Plutella xylostella*)	Adults and nymphs of aphids and larvae of moths	Pest of cabbage and other brassicae species	36–74	Ghana	Ezena et al., 2016
		Leaf extract	Aqueous extract/filter paper impregnation	Cockroach (*Periplaneta americana*)	Adults	Household pest and vector of parasitic diseases	12–69	Nigeria	Udebuani et al., 2015
		Leaf extract	Methanol extract/addition of extract to water	*Anopheles stephensi, Culex quinquefasciatus* and *Aedes aegypti*	Larvae	Vector of parasitic diseases	20–100	India	Sukhthankar et al., 2014

TABLE 2C | Published reports on the insecticidal activities of some plant species with invasive potentials in sub-Saharan Africa.

Family	Plant species	Plant parts	Formulation/application method	Insect target	Stage of insect	Importance of insect	Mortality (%)	Country	Reference (s)
Asteraceae	*Parthenium hysterophorus*	Flowers, leaf and stem	Powder/dust	Bean weevil (*Callosobruchus chinensis*)	Adults	Cowpea and chickpea	>56.6	Ethiopia	Tesfu and Emana, 2013
		Leaf and stem	Aqueous extract/addition of extract to water	*Aedes aegypti*,	Larvae	Vector of some parasitic diseases	>80	Pakistan	Amir et al., 2017
		Leaf, stem and root	Acetone and hexane extract/addition to water	*Aedes aegypti*,	Larvae	Vector of some parasitic diseases	40–100	India	Kumar S. et al., 2012
		Leaf	Methanol extract/ingestion	Rice moth (*Corcyra cephalonica*)	Larvae	Pest of rice	81	India	Khan and Qamar, 2015a
		Leaf	Methanol extract/ingestion	American cockroach (*Periplaneta americana*)	Adults	Household pest	14.4	India	Khan and Qamar, 2015b
		Leaf	Methanol extract/ingestion	*Plutella xylostella*, *Aphis craccivora*	Larvae and adults	Agricultural pests	good toxicity	India	Reddy et al., 2018
	Tithonia diversifolia	Stem bark	Aqueous extract/spray	Cowpea beetle (*Callosobruchus maculatus*)	Adults	Pest of beans	100	Nigeria	Obembe and Kayode, 2013
		Leaf	Methanol extract/fumigant	Cowpea beetle (*Callosobruchus maculatus*)	Adults	Pest of beans	100	Tanzania	Green et al., 2017
		Leaf	Aqueous extract/spray	Maize weevil (*Sitophilus zeamais*)	Adults	Pest of maize, rice	43	Nigeria	Obembe and Kayode, 2013
		Leaf	Powder/dust	Maize weevil (*Sitophilus zeamais*)	Adults	Pest of maize, rice	90	Nigeria	Babarinde et al., 2008

TABLE 2D | Published reports on the insecticidal activities of some plant species with invasive potentials in sub-Saharan Africa.

Family	Plant species	Plant parts	Formulation/application method	Insect target	Stage of insect	Importance of insect	Mortality (%)	Country	Reference (s)
Asteraceae	*Tithonia diversifolia*	Leaf	Aqueous extract and powder/spray and dust	Cowpea beetle (*Callosobruchus maculatus*)	Adults	Pest of beans	98.3	Nigeria	Adedire and Akinneye, 2004
		Leaf	Aqueous extract/spray	Aphids (*Aphis fabae*), Bean foliage beetle (*Ootheca mutabilis* and *O. bennigseni*), and flower beetle (*Epicauta albovittata* and *E. limbatipennis*)	Nymphs, larvae and adults	Pest of beans		Tanzania	Mkenda et al., 2015
		Leaf	Aqueous extract/spray	Aphids (*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*)	Nymphs, larvae and adults	Pest of beans		Tanzania and Malawi	Mkindi et al., 2017
	Xanthium strumarium	Leaf	Ethanol extract/spray	Green peach aphid (*Myzus persicae*)	Adults	Pest of peach	>82	Turkey	Erdogan and Yildirim, 2016
Bignoniaceae	*Jacaranda mimosifolia*	Leaf	Powder/dust	*Acanthoscelides obtectus*	Adults	Pest of cowpea	>31%	Kenya	Waweru et al., 2017
		Leaf	Methanol extracts/topical	*Tribolium casteneum*	Adults	Pest of stored grains	49%	Argentina	Padín et al., 2013
Chenopodiaceae	*Dysphania ambrosioides*	Leaf and fruit	Aqueous extract/spray	Lesser grain borer (*Rhyzopertha dominica*)	Adults	Pest of stored grains	0.5–2.9	Brazil	Guzzo et al., 2006

TABLE 2E | Published reports on the insecticidal activities of some plant species with invasive potentials in sub-Saharan Africa.

Family	Plant species	Plant parts	Formulation/application method	Insect target	Stage of insect	Importance of insect	Mortality (%)	Country	Reference (s)
Euphorbiaceae	*Jatropha curcas*	Leaf, seed, bark, root	Methanol extract/leaf dip method	Diamondback moth (*Plutella xylostella*)	Larvae	Pest of cabbage and other brassicae species	40–100%	India	Ingle et al., 2017
		Leaf, root and seed coat	Methanol extract/leaf dip method	*Helicoverpa armigera*	Larvae		60%	India	Ingle et al., 2017
		Leaf		Fall army worm (*Spodoptera fragiperda*)	Larvae	Agricultural pest	3–60%	Brazil	Ribeiro et al., 2012
		Seed	Hexane extract/spray	Desert locust (*Schistocerca gregaria*)	Nymphs	Agricultural pest	20–59%	Sudan	Bashir and El Shafie, 2013
		Leaf and Stem	Powder/dust	*Callosobrucus maculatus*	Adults	Agricultural pest	100%	Nigeria	Adetimehin et al., 2018; Opuba et al., 2018
	Ricinus communis	Leaf	Aqueous extract/topical and ingestion	Diamondback moth (*Plutella xylostella*)	Larvae	Agricultural pest	100	Togo	Tounou et al., 2011
Fabaceae	*Prosopis juliflora*	Leaf	Methanol extract/spray	Cotton aphid (*Aphis Gossypii*)	Adults	Pest of cotton	73.3	Ethiopia	Zerihun and Ele, 2018
		Seed	Methanol extract/spray	Cotton aphid (*Aphis Gossypii*)	Adults	Pest of cotton	70	Ethiopia	Zerihun and Ele, 2018
		Leaf extract	Aqueous extract/spray	Diamondback moth (*Plutella xylostella*)	Larvae	Pest of cabbage and other brassicae species	96%	India	Sangavi and Johnson Thangaraj Edward, 2017

TABLE 2F | Published reports on the insecticidal activities of some species with invasive potentials in sub-Saharan Africa.

Family	Plant species	Plant parts	Formulation/application method	Insect target	Stage of insect	Importance of insect	Mortality (%)	Country	Reference (s)
Fabaceae	*Sesbania grandiflora*	Leaf	Aqueous extract/spray	Diamondback moth (*Plutella xylostella*)	Larvae	Pest of cabbage and other brassicae species	73	India	Sangavi and Johnson Thangaraj Edward, 2017
Meliaceae	*Melia azedarach*	Fruit	Aqueous extract/spray	Vegetable leaf miner (*Liriomyza huidobrensis*)	Larvae	Agricultural pest	44	USA	Hammad and McAuslane, 2010
		Fruit	Essential oil and methanol extract/ingestion	Fall armyworm (*Spodoptera frugiperda*)	Larvae	Pest of maize	100	Brazil	Scapinello et al., 2014
		Fruit	Acetone extract/leaf dipping technique	African Cotton Leafworm (*Spodoptera littoralis*)	Larvae	Pest of cotton	100	Egypt	Farag et al., 2011
		Fruit	Ethanol extract/filter paper impregnation	Elm leaf beetle (*Xanthogaleruca luteola*)	Adults	Environmental pest	86	Chile	Chiffelle et al., 2011
		Fruit	Methanol extract/addition to water	*Anopheles stephensi*, *Culex quinquefasciatus* and *Aedes aegypti*	Larvae	Vectors of some parasitic diseases	>88	India	Selvaraj and Mosses, 2011
Mimosaceae	*Mimosa diplotricha*	Leaf	Powder/dust	Bed bugs (*Cimex lectularius*)	Adults	Pest of medical importance	>70	Nigeria	Uyi et al., 2018a
		Leaf	Powder/dust	*Macrotermes species*	Adults	Pest of crops	100	Nigeria	Uyi et al., 2018b
		Root	Powder/dust	*Callosobruchus maculatus*	Adults	Agricultural pest	67	Nigeria	Uyi et al., 2020
Myrtaceae	*Eucalyptus camaldulensis*	Leaf	Ethanol extract/leaf dipping technique	Green peach aphid (*Myzus persicae*)	Nymphs and adults	Agricultural pest	53	Algeria	Nia et al., 2015; Erdogan and Yildirim, 2016

TABLE 2G | Published reports on the insecticidal activities of some plant species with invasive potentials in sub-Saharan Africa.

Family	Plant species	Plant parts	Formulation/application method	Insect target	Stage of insect	Importance of insect	Mortality (%)	Country	Reference (s)
Papaveraceae	*Argemone mexicana*	Leaf extract,	Methanol extract/ingestion	Rice moth, (*Corcyra cephalonica*) and Cockroach (*Periplaneta americana*)	Larvae, adults	Agricultural and household pests	15.4–76	India	Khan and Qamar, 2015a,b
Solanaceae	*Cestrum parqui*	Leaf extract	Aqueous extract/leaf dipping and ingestion	Mediterranean fruit fly (*Ceratitis capitata*)	Adults	Fruits	55	Chile	Zapata et al., 2006
	Solanum elaeagnifolium	Leaf extract	Methanol extract/seed treatment	Red flour beetle (*Tribolium castaneum*)	Larvae	Pest of stored grains	88	Tunisia	Ben Hamouda et al., 2015a
		Seed extract	Methanol extract/seed treatment	Red flour beetle (*Tribolium castaneum*)	Larvae	Pest of stored grains	84	Tunisia	Ben Hamouda et al., 2015a
		Leaf extract	Methanol extract/leaf treatment and ingestion	African cotton leafworm (*Spodoptera littoralis*)	Larvae	Agricultural pest	80	Tunisia	Ben Hamouda et al., 2015b
		Seed extract	Ethanol and methanol extract/leaf treatment and ingestion	African cotton leafworm (*Spodoptera littoralis*)	Larvae	Agricultural pest	100	Tunisia	Ben Hamouda et al., 2015b
		Leaf and seed extracts	Ethanol and methanol extract/leaf treatment and ingestion	Green peach aphid (*Myzus persicae*)	Adults	Agricultural pest	5–43	Tunisia	Ben Hamouda et al., 2015c

TABLE 2H | Published reports on the insecticidal activities of some plant species with invasive potentials in sub-Saharan Africa.

Family	Plant species	Plant parts	Formulation/application method	Insect target	Stage of insect	Importance of insect	Mortality (%)	Country	Reference (s)
Solanaceae	*Solanum sisymbriifolium*	Leaf	Methanol extract/filter paper impregnation	Red flour beetle (*Tribolium castaneum*)	Adults	Pest of stored grains	22%	Argentina	Padín et al., 2013
Verbenaceae	*Lantana camara*	Leaf	Acetone extract/addition to water	Mosquito (*Aedes aegypti*)	Larvae and pupae	Vector of some parasitic diseases	>65	India	Remia and Logaswamy, 2010
		Leaf and stem	Methanol extract/fumigant	Bean weevil (*Callosobruchus chinensis*)	Adults	Pest of pulse	9- 23%	India	Sexana et al., 1992
		Leaf	Chloroform extract/filter paper impregnation	subterranean termite, *Reticulitermes flavipes*	Adults	Agricultural pest	90	China	Yuan and Hu, 2012
		Leaf	Essential oil/spray	*Aedes aegypti*, *Culex quinquefasciatus*, *Anopheles culicifacies, Anopheles fluvialitis* and *Anopheles stephensi*	Adults	Vector of parasitic diseases	93–100	India	Dua et al., 2010
		Leaf and flower	Powder/dust	Maize weevil (*Sitophilus zeamais*)	Adults	Pest of maize and rice	>45	Nigeria	Taye et al., 2014
		Leaf extracts	Acetone and methanol/direct contact application	*Sitophilus oryzae* (L.) *Callosobruchus chinensis* (Fab.) and *Tribolium castaneum*	Adults	Pests of stored grains	>92	India	Rajashekar et al., 2014

TABLE 2I | Published reports on the insecticidal activities of some invasive alien plants in Africa.

Family	Plant species	Plant parts	Formulation/application method	Insect target	Stage of insect	Importance of insect	Mortality (%)	Country	Reference (s)
Verbenaceae	*Lantana camara*	Leaf and stem	Essential oil/fumigant	Grain weevil (*Sitophilus granaries*)	Adults	Pests of stored grains	100	Algeria	Zoubiri and Baaliouamer, 2012
		Leaf extract	Aqueous extract/spray	Diamondback moth (*Plutella xylostella*)	Larvae	Pest of cabbage and other brassicae species	3.3–6.7	India	Sangavi and Johnson Thangaraj Edward, 2017
		Leaf extract	Aqueous extract/spray	Aphids (*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*)	Nymphs, larvae and adults	Pest of beans	NA	Tanzania and Malawi	Mkindi et al., 2017

a myriad of agricultural, medical and environmental insect pests (**Tables 2A–I**), only a few studies have documented the indigenous use of these IAPs as botanical pesticides by the locals and small-holder farmers in Africa (e.g., Cobbinah et al., 1999; Mugisha-Kamatenesi et al., 2008). Therefore, there is an urgent need to conduct ethnobotanical surveys to identify and document the IAPs used for the control and management of insect pest by locals and small-holder farmers in Africa. Although, assessing efficacy under field condition remains a serious challenge in the use of botanicals to control insect pests of crops, recent field trials on bean and cabbage pests suggest that some plant extracts are as effective as synthetic pesticides; however, botanicals tend to be much less harmful to natural enemies (Amoabeng et al., 2013; Mkenda et al., 2015). Such findings are crucial in convincing the policy makers and other relevant stakeholders to support the use of botanicals to control pests. Therefore, field studies on the insecticidal efficacy of IAPs with botanical pesticides should be prioritized and such study may receive generous funding from stakeholders in the agricultural sector because of the direct impact of such research.

Despite their efficacy against pests, botanical pesticides are often less harmful to beneficial insects and are therefore more compatible with other pest management strategies (Stevensona et al., 2017). For example, Mkenda et al. (2015) showed that *Tithonia diversifolia* (an invasive alien plant species) and other three pesticidal plant species were able to control a several of agricultural pests attacking *Phaseolus vulgaris* (common beans), but were also less harmful to beneficial insects (i.e., lady beetle and spider mites) compared to a synthetic pesticide. In similar field study, Ezena et al. (2016) investigated the insecticidal potential of three concentrations (10, 20, and 30 g/L) of the invasive *C. odorata* in the management of the major pests of cabbage (*B. brassicae and P. xylostella*) and their natural enemies in southern Ghana. The authors found that the three concentrations of *C. odorata* significantly reduced (by more than 30%) the number of *B. brassicae and P. xylostella* than tap water and conventional insecticide, lambda-cyhalothrin. The authors also found that plots sprayed with 20 g/L of *C. odorata* extract supported the highest number of insect natural enemies (*Diaretiell rapae*, *Cotesia* plutellae (Hymentoptera: Braconidae) and hoverflies compared to plots treated with lambda-cyhalothrin. Research to demonstrating compatibility of botanical pesticides with other pest management strategies is needed. Such research should also focus on determination of the underlying mechanisms that reduce the impact of pesticidal IAPs on beneficial insects and understands if this is due to selective toxicity or lower persistence. Due to their high efficacy and low toxicity to beneficial insects (e.g., Mkenda et al., 2015), there is the prospect to inform locals, small-holder farmers, and other relevant stakeholders of the potential usage of the IAPs listed in **Tables 2A–I**. This will allow for the exploitation of IAPs by harvesting and using them to control insect pests and alternately minimizing the invasion intensities and impact of IAPs in ecosystems. This will give the small-holder farmers and locals who are typically resource poor access to technologies and information to control insect pests and

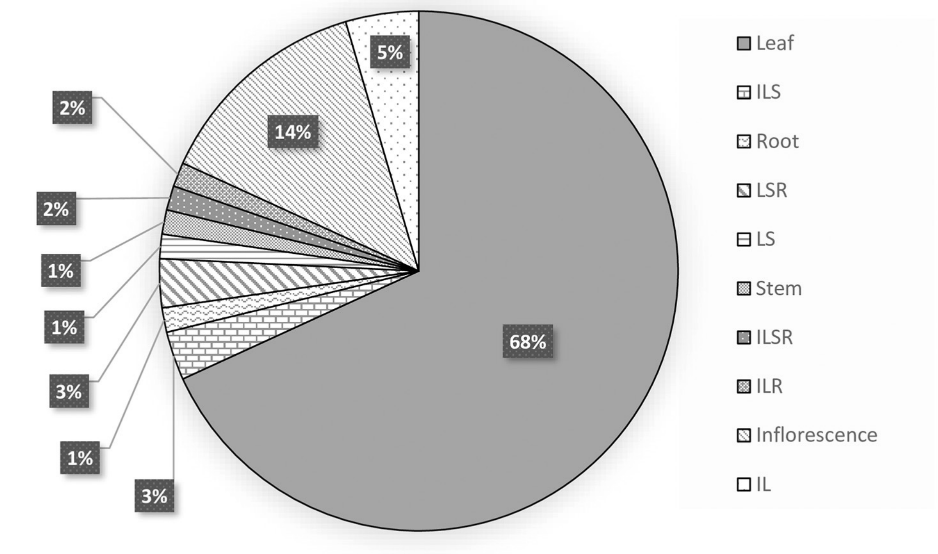

FIGURE 1 | Percentage prevalence of case studies on the parts of plant used to test for insecticidal activities of invasive alien plants. Data was obtained from 69 published case studies. IL, Inflorescence and leaf; ILS, Inflorescence; leaf and stem; ILR, Inflorescence; leaf and root; ILSR, Inflorescence; leaf, stem and root; LS, Leaf and stem; LSR, Leaf, stem, root.

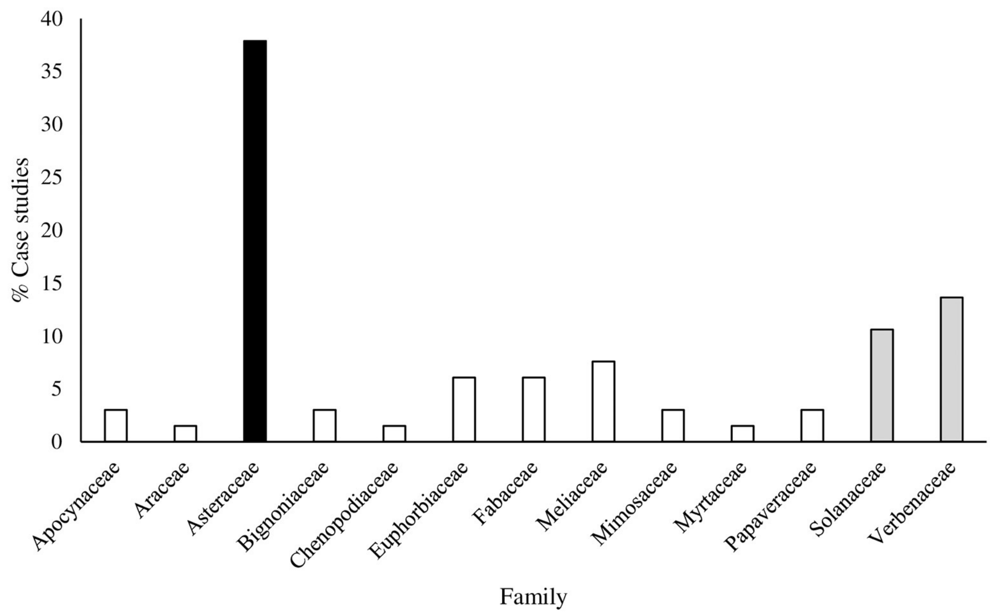

FIGURE 2 | Prevalence of case studies on different families of invasive alien plant species tested for insecticidal activities. Data was obtained from 69 published case studies.

diseases that limit crop production and successful storage of agricultural produce.

Safety and Exposure Concerns of Using Botanical Pesticides From IAPs

A key priority in the widely popular subsistence farming system in Africa is to prevent stored product insects from reducing the market and nutritional values of the harvested produce. Many small-holder farmers (peasants) in Africa use botanical pesticides, locally derived from either indigenous or IAPs to protect stored commodities (Cobbinah et al., 1999; Belmain and Stevenson, 2001; Isman, 2008; Nyirenda et al., 2011; Midega et al., 2016; Kamanula et al., 2017). The use of botanical pesticides to protect stored products may directly or indirectly expose

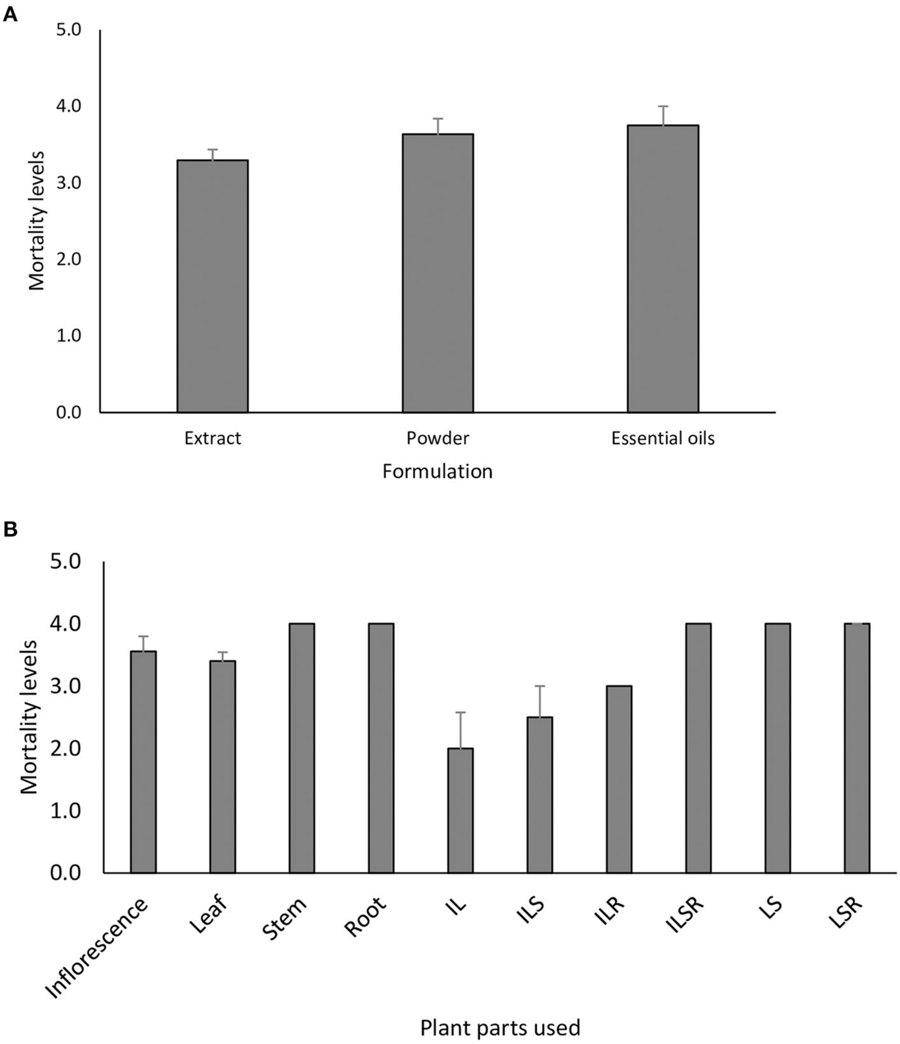

FIGURE 3 | Mean mortality rank (±se) of insect pests of agriculture and medical importance caused by **(A)** different formulations from, and **(B)** different plant parts or combinations plant parts of invasive alien plants. Data was obtained from 69 published case studies. IL, Inflorescence and leaf; ILS, Inflorescence, leaf and stem; ILR, Inflorescence, leaf and root; ILSR, Inflorescence, leaf, stem and root; LS, Leaf and stem; LSR, Leaf, stem, root.

farmers and/or consumers to potentially toxic chemicals from the plant materials used. It is important to note that naturally occurring plant chemicals are not necessarily safe. For example, some compounds (e.g., Aconitum, aconitine, nicotine, rotenone, and strychnine) of plant origin are known to be highly poisonous to mammals and fish (Kolev et al., 1996; Neuwinger, 2004).

Although the use of pesticidal plants to control pests in agro-ecosystems and other modified ecosystems is perceived to be safer than conventional pesticides, care must be exercised in the use of some of plants (especially invasive alien plants with novel biochemicals) for pest management. Invasive alien plants with potential toxicity to aquatic fauna or mammals should be restricted and discouraged. Plant scientists and entomologists should conduct special bioassays not only to show the efficacy of botanical pesticides from alien invasive plants but also to demonstrate the safety of these locally manufactured pesticides on mammals and aquatic fauna. The results of such safety and risk assessment studies should be communicated to various stakeholders including small-holder farmers who rely heavily on exploring new plant species for various purposes including to manage pests and for ethnomedicinal purpose. Although the likelihood of acute toxicity from handling plants is substantially lower than the risk from handling synthetic pesticides (Coats, 1994; Isman, 2006), the use of appropriate personal protective equipment should be encouraged when processing and handling powders and extracts from invasive alien plant materials.

Challenges of Using IAPs as Bio-Insecticides and Future Research Focus

Despite the acceptance and increasing usage of the biopesticides by the global communities, the lack of government published regulatory framework impedes the rigorous research processes and hampers the adoption of the compounds [Gahukar, 2011; AATF (African Agricultural Technology Foundation), 2013; Ivase et al., 2017; Damalas and Koutroubas, 2018]. Like synthetic insecticides, the international and national regulations should be developed to govern the development of bio-insecticides and alternately protect the consumers and the natural ecosystems from the hazardous compounds (Chandler et al., 2011). Although the natural resources extracted from nature are generally regarded as safe to humans and the environment, risk assessment protocols and registration portfolio of bio-insecticides follow conventional insecticides (Damalas and Koutroubas, 2018; Marrone, 2019). The procedures are somewhat time-consuming and expensive for the bio-insecticide development companies. Furthermore, the costs of production of these natural compounds decelerate the commercialization processes of the products and once commercialized, the prices are inflated (Marrone, 2014; Ivase et al., 2017; Damalas and Koutroubas, 2018). The prospects of developing biopesticides include the distinct development of legislations that govern the screening and commercialization of the products (AATF, 2013; Seiber et al., 2014; Kumar and Singh, 2015; Ivase et al., 2017; Damalas and Koutroubas, 2018). Government's ability to subsidize the research on the development of compounds that are safer to use may accelerate the bio-insecticide development and commercialization processes (Marrone, 2014). Furthermore, the efficiency of bioinsecticides with limited efficacy may be integrated with compatible pest management practices to optimize the efficiency of the pest management program (Chandler et al., 2011). Further investigations on the persistence and efficiency of biopesticides derived from IAPs need to be prioritized to measure the overall cost of the benefit of the pest management products. Public and private sectors should also be encouraged to participate (i.e., technically or financially) on the development and production of this economical and environmentally friendly alternative, especially in the developing countries.

CONCLUSIONS

The diversity of invasive alien plant species (in Africa) with numerous examples of their insecticidal efficacy against important pests listed in this paper suggest that opportunity exist for using invasive alien plants in Africa as pesticides in agro-ecosystems and other managed ecosystems. This will result in small-holders spending less on synthetic insecticides, substantially reduction in crop production or pest management costs and increase productivity and quality of life. Despite the rise of research interest in plant pesticides from native plants and IAPs over the last decade in Africa (Isman and Grieneisen, 2014; Isman, 2015), surprisingly little time is invested in assessing efficacy under field conditions. The lack of meaningful chemical data (i.e., elucidation of bioactive compounds) reported alongside efficacy trials remains a major concern. Some of the published works on the effects of pesticides from native plants or IAPs are not repeatable for various reasons and adds little to our knowledge about mechanisms, efficacy or scope to use plant materials in pest management. Although the efficacy of the botanical pesticides from 23 invasive alien plant species in this study have been documented, further investigations on; (1) their efficacy under field conditions, mode of action and chemical data, (2) their compatibility with other pest management strategies, (3) the economic benefits of using pesticidal plants over synthetic products and (4) how to effectively commercialize the production of botanical insecticides from IAPs. For the first time, our review elucidates the insecticidal efficacy of the invasive alien plants in Africa and highlights the prospects for the use of these IAPs as pesticidal plants in African countries especially among resource-limited small-holder farmers and locals. It remains to be seen whether stakeholders (governments, research institutions, scientists, agriculturists, farmers, locals, extension workers, etc.) can effectively explore the safe use of botanically based insecticides (extracts, powders or other formulations) from IAPs in their regions for the control and management of insect pests in agro-ecosystems and other modified environments. This paper serves as a veritable reference for researchers and stakeholders who are interested in advancing, the science, technology or our understanding of the use of invasive alien plant to control and manage insect pests of agricultural, environmental medical importance.

AUTHOR CONTRIBUTIONS

OU and LM conceptualized the study and wrote the manuscript. OU, LM, AE, and MT interpreted the results and critically reviewed and amended the manuscript. All authors contributed to the article and approved the submitted version.

ACKNOWLEDGMENTS

We thank our respective institutions for availing us the needed time to write this review. We also thank Glory Dickson for providing some of the literature used in this review.

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