Biopesticides in Environment and Food Security

Issues and Strategies

Edited by

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Pesticidal Plants: A Viable Alternative Insect Pest Management Approach for Resource-Poor Farming in Africa

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INTRODUCTION

The principal need for most African farmers is food security, so the production of sufficient food is paramount. Additional yields, however, provide a potential route out of poverty by generating income. While productivity is affected by numerous biotic and abiotic constraints, arthropods (including insects and mites) are perhaps the most important due to their widespread and severe damage and because even the poorest farmers can have some direct control over them. Synthetic pesticides are usually effective but may have limited distribution in rural areas, are frequently adulterated and inappropriately applied and are often ineffective because the pest insect has become resistant to the limited number of insecticides available in remote areas.

When they are available, insecticides are applied with little personal protection which puts farm workers at risk. Furthermore, there is no process for ensuring the safety of food for consumers or for assessing chronic outcomes from exposure despite guidance on correct use from manufacturers. In environmental terms, the impact on wildlife, natural enemies and pollinators is a serious problem, and finally, the cost of pesticides can be prohibitive for poor farmers and can cost a substantial percentage of the overall product value. Recent surveys highlight these problems but also indicate that they are well understood by farmers (Kamanula *et al.,* 2011; Nyirenda *et al.*, 2011) and have led to many avoiding commercial products altogether. Thus an alternative management strategy for controlling insect pests of crops and livestock is essential since severe losses in most field crops and storage are otherwise guaranteed and the impact on poor farmers can be catastrophic.

Pesticidal plants are an effective alternative and their promotion, particularly with optimised application protocols and effective extension services, would have enormous impact on the ability of farmers to manage insect pests. Here we refer to pesticidal plants as crude materials that have undergone limited processing that can be carried out by farmers as compared to botanical insecticides that are generally more sophisticated and commercialised products and thus may come a price that farmers can't or don't wish to afford.

Farmers are familiar with the concept of plant materials as pesticides and recognise that they are environmentally benign, less toxic and cost-effective compared to synthetic pesticides. They also overcome the problems of adulteration particularly if produced or harvested by the farmers themselves. Perhaps the most important factor is their cost to farmers is calculated in time rather than cash or credit.

Generations of farmers have used plants in this way, making the technology familiar, trusted and acceptable, but their priority in agricultural policy is low (Belmain and Stevenson, 2001) and consequently, despite the overall interest in plant materials as pesticides, few farmers actually use them (Kamanula *et al.*, 2011). This may also be due to knowledge gaps or because there is inadequate policy to drive commercialisation as is the case with commercial synthetic pesticides; yet the hurdles to register products appear to be the same for plants as they are for synthetics.

Nevertheless, some plant species are effective at controlling some pests and so help secure crop production, storage and livestock production. Optimising their full potential, however, especially for poor farmers, is constrained by inadequate evaluation and development of materials, which is required to increase the reliable options available to farmers. This paper aims to identify the hurdles to the successful deployment of plants as pesticides in Africa and ways to overcome them.

Farmer surveys carried out in Ghana have highlighted that many farmers do not use commercial synthetics (Belmain and Stevenson, 2001) and, instead, use plant-based products. More recently, surveys in Malawi and Zambia in 2007/2008 (Kamanula *et al.*, 2011; Nyirenda *et al.*, 2011) reported that farmers were knowledgeable about plant materials as environmentally benign, safer and cost effective alternatives to synthetic pesticides. Surveyed farmers recognize pesticidal plants as reliable and if collected or produced themselves, that their cost can be calculated in terms of time rather than in cash. However, despite a wide knowledge of which plants are effective and how to use them, surprisingly few farmers in these countries were doing so. The study concluded that there was a need for targeted research to optimize their use rather than simply evaluate yet another plant against yet another species of insect with little concern for how the material might ultimately be used.

The target beneficiaries of the information in this paper include researchers at universities, governmental research stations, NGOs, policy makers, community-based organisations and small and medium enterprises such as farmer cooperatives who may be able to generate revenue from the technologies developed through pesticidal plant research. The collective knowledge of the stakeholders about the use and optimisation of pesticidal plants is important for the establishment of multi-disciplinary and multi-country research partnerships who are needed in Africa to develop, optimise and promote pesticidal plant use widely. An analysis of published African-based science on pesticidal plants indicates that much research remains largely ill-informed of the critical knowledge gaps and is repeated work or delivers outputs that are unlikely to have any impact on agricultural development and poverty alleviation. It does not address the problems that limit the development, uptake and promotion of pesticidal plants. Furthermore, >80% of published work in this research area in Africa reports laboratory bioassays that simply evaluate pesticidal plants against insects with little consideration of the information needed to optimise use, facilitate up-scaling, enhance field efficacy or address health and safety issues (vertebrate toxicity), propagation, cultivation or conservation. This is particularly well illustrated by the example of biological activity reported in non-polar extracts of a plant against a pest species that farmers will attempt to control in the field using crude water extracts that will unlikely contain any of the active components reported in the scientific study.

PESTICIDAL PLANTS AS ALTERNATIVES TO SYNTHETIC PRODUCTS IN AFRICA

The use of plants and their crude extracts for the protection of crops and stored products from insect pests has been a part of African agriculture for generations (Thacker, 2002). Globally, plants were the major technology for insect pest control before the advent of synthetic pesticides (Isman, 2008). They have been reviewed countless times in the literature and this paper does not attempt to repeat this. For example, Prakash and Rao (1997) have published a comprehensive review of pesticidal plants in which they describe the biological activities and practical applications for 150 species with some agricultural potential. Koul and Dhaliwal (2000) and Koul (2005) describe in detail numerous examples of phytochemical biopesticides and their role in integrated pest management, while discussing the problems and prospects of biopesticides for commercial exploitation. One sobering thought, however, is that despite tens of thousands of research articles in the literature there are only a handful of successful commercial botanical products used for insect control including pyrethrum, rotenoids, neem, and essential oils. Plants as commercial products have arguably fallen short of their purported potential (Isman, 2006). However, in Africa their use still has a major importance for farmers despite its decline elsewhere in the world and it is perhaps for the rural poor that plants have the greatest value in agriculture (Isman, 2008). Stoll (2005) provides a comprehensive list – specifically of African species – and presents suggested practical applications for a wide variety of different tropical pests and crops that are low tech requiring the minimum facilities for their preparation. Similarly in this paper, we consider pesticidal plants that comprise crude plant materials including leaves, stem bark, roots, fruits and seeds that are effective but need only rudimentary preparation and are thus more suitable for the resource poor small holder farmers across Africa. This processing includes drying, crushing and mixing with stored products (Belmain and Stevenson, 2001) or producing crude extracts in water for application with a sprayer or applied using a brush (Stoll, 2005). The less processing required the more universally appropriate the plant material.

A survey in Malawi and Zambia showed that all farmers were aware of at least one plant that could be used as a pesticide but less than half in Malawi and less than 20% in Zambia actually used them (Kamanula *et al.*, 2011; Nyirenda *et al.*, 2011). It is not immediately clear why this is but relatively low efficacy or high variability in efficacy could explain this anomaly. For many farmers some efficacy even if only moderate is better than none, provided a reduction in damage can be perceived that is quantifiable and of economic benefit to them. There may also be scope to optimize efficacy by understanding the mechanisms of the effect and developing processes for their application that exploit this knowledge as discussed below.

Pesticidal plants are low cost compared to synthetic products and some have multiple uses which can help promote their use. For example, *Tephrosia vogelii* is a well studied pest control species (Ogendo *et al.*, 2005; Boeke *et al.*, 2004a,b; Koona *et al.*, 2005) and is particularly popular among farmers in south eastern Africa where 80% of farmers report its use (Kamanula *et al.*, 2011; Nyirenda *et al.*, 2011). *Tephrosia vogelii* is also cultivated for soil improvement (Mafongoya and Kuntashula, 2005), and this means that farmers can cultivate their own pesticidal material rather than spend time harvesting from the wild. This additionally reduces pressure on declining natural environments. Indeed, efforts to optimize the propagation of pesticidal plants that cannot be easily cultivated are required. Furthermore, propagation needs to be assisted through understanding the chemical mechanisms involved in their use for the selection of elite material (Sarasan *et al.*, 2011). Home grown plants may provide an opportunity for entrepreneurial farmers to acquire additional income from their preparation and sale of excess material to other farmers. Commercialization of this process would ultimately drive an effective promotion strategy, but this is likely to be complicated by the regulatory bodies that approve of use of pesticides. Materials that are collected from natural woodlands can cost extra time which can make such plant materials less attractive, so the scope to develop the most basic commercial processing may have potential to increase the extent of their use.

SAFETY OF PESTICIDAL PLANTS

While there are clear economic benefits for the use of pesticidal plants, the greatest benefit from their use may be in terms of human health. Most acute human poisonings from pesticides are recorded in developing countries, particularly Africa where in some regions they are a major cause of mortality (Ecobichon, 2001) – this is very rare event in western Europe or North America. Despite dramatic improvements in the safety of agrochemicals with dramatically reduced health and environmental impacts, the overall perception of the public remains largely negative with strong memories of damaging products from the past, such as DDT. Plant products, however, are relatively safe but this cannot be assumed. Some of the most toxic substances known to man e.g., aconitine and ricin are produced by plants. While *Aconitum* spp. and *Ricinus communis* have no place in pest control some popular and commonly used plant materials in Africa such as *Tephrosia vogelii* have well-known environmental impacts, particularly against fish (Neuwinger, 2004; Agbon *et al.*, 2004). Many highly toxic plants are particularly well-known for their activity and their use, while impossible to curb, should be promoted with caution and good advice. Some plant compounds that are important in pest control such as nicotine and rotenone have acute mammalian toxicity but in reality, the human health risks associated with the application of these compounds are largely mitigated owing to the concentrations of the active substances being typically very low in crude preparations (Isman, 2008).

In an ideal world, the production of extracts should be standardized to ensure safety and moderate efficacy, but in reality this is an unrealistic expectation in many of the poorer locations of Africa. Regulations are in place for at least some of the most common materials elsewhere in the world such as rotenone in the USA and these standards should be adopted. What is clear is that plant compounds, e.g., rotenone, azadirachtin and pyrethrum, break down, particularly in sunlight, into environmentally benign products, leaving no dangerous residues behind as often occurs with synthetics. Pesticidal plants certainly have the popular vote. Organic growers and regulators accept pesticidal plants as organic production, an increasingly important market share in agricultural produce. Certain materials should be promoted with caution, however, since some plant compounds previously considered acceptable and indeed popular in organic farming are now listed as hazardous under new European directives and thus may not be acceptable contaminants on food entering Europe, including rotenone. This could have consequences for African farmers whose produce may contribute to European exports.

From a resource poor farmers perspective, pesticidal plants are appealing because they cannot be adulterated (at least if they are collected by the farmer), and are cost effective. Although they do require time to collect and prepare on top of the input required to apply them. However, their efficacy can vary across seasons and locations and the application procedure is not always as efficient or effective as it could be. This highlights the importance of understanding the chemistry of their activity to optimize their application. Nowhere is this demonstrated more emphatically than with Neem, although other species are now benefitting from increased knowledge about their activity.

KEY RESEARCH PRIORITIES FOR OPTIMIZING THE USE OF PESTICIDAL PLANTS IN AFRICA

Understanding the Chemistry of Activity

The sustainable use of pesticidal plants could be improved substantially through a deeper understanding of the chemistry that governs their activities. This information could be used to enhance application methods, improve harvesting strategies and even identifying novel plant alternatives for threatened species (Koul and Dhaliwal, 2000). For example, an abundant plant with similar chemistry to a scarce but popular and over harvested species could be promoted as an environmentally benign alternative. Furthermore, plants in which active components are water soluble, such as saponins, might be more efficiently applied as water extracts than powdered plant material, as has been proposed for the securidacaside saponins present in *Securidaca longepedunculata* (Stevenson *et al.*, 2010). The chemistry of some plants varies according to the season, the plant age and location so chemical analysis is essential to determine the best time to harvest or for identifying elite material for propagation (Sarasan *et al.*, 2011). Of course, the need to use fresh plant material over dry might determine harvesting priorities but chemical knowledge of the active components would certainly optimise harvesting times. The ability of many African laboratories to carry out this analytical work is limited to a handful of institutes. Cooperation through research networks is essential to move this area of work forward, and expertise and equipment in natural product chemistry needs to be expanded.

Chemical analysis using tandem linked detection techniques such as mass spectrometry can maximise information acquisition of compounds in each plant and can identify many components quickly, particularly seasonal variations and genotypic differences between specimens of a single species to better understand the potential variation in efficacy. These techniques can also be used to authenticate specimens before promoting widely. While these facilities are beyond the reach of many research institutes, many materials could be authenticated by less costly techniques such as thin layer chromatography.

Safety of Key Pesticidal Plants

It is invariably assumed that natural is safe, and this received wisdom applies particularly to pesticidal plants. This is, however, not the case with some illustrative plant species having notoriously high toxicity such as *Taxus* spp., *Aconitum* spp. and perhaps most notorious of all *Ricinus communis* (Hernandez *et al.*, 2010; Bonnici *et al.*, 2010; Kuca and Pohanka, 2010). Several well-known pesticidal plants are also known to have toxic properties that could present a significant health risk to users when extracting, pounding or concentrating active ingredients, including rotenoid containing species of *Derris*, *Tephrosia* and *Lonchocarpus*. Yet little work has been published internationally on the vertebrate toxicity of African pesticidal plants. One study on West African plants used to protect stored grain from insect pests has shown that some of those most commonly found and used by farmers can adversely affect growth and development (when fed to rodents), with potentially long term effects (Belmain *et al.*, 2001). Ideally plants that have other users such as in foods can indicate relative safety and this approach is being used in North America to focus attention on essential oils from herbs (Isman, 2006). Despite this, even plant species that are traditionally consumed – such as *Lippia javanica* which is drunk as a green tea in Malawi – showed acute oral toxicity in mice when consumed at very high concentrations (Madzimure *et al.*, 2011).

In reality, plant materials are normally used for pest control at concentrations that are too low for them to pose any significant acute toxicity to users (Isman, 2008) even when this is intended (Chesneau *et al.*, 2009). Perhaps the greatest risks exist when pesticidal plants are used for post-harvest treatment particularly for the storage of produce that will be used for food. Current post-harvest pest management practices in Africa rely on pirimiphos-methyl, an anticholinesterase targeting organophosphate, and in cases where pest complexes include the larger grain borer, *Prostephanus truncatus*, pirimiphos-methyl is combined with permethrin (Sekyembe *et al.*, 1993). Syngenta who market Actellic EC50 (pirimphos-methyl) warn that this product is moderately toxic to mammals if consumed directly and is extremely toxic to aquatic invertebrates and highly toxic to algae and fish (http://www.syngenta-crop.co.uk/pdfs/products/ Actellic50EC_uk_environmental_information.pdf). Thus, fears over the toxicity of plant species like *Tephrosia vogelii* that are very popular alternatives to pesticides in southeastern Africa (Kamanula *et al.*, 2011; Nyirenda *et al.*, 2011), but have known toxicity to fish, are perhaps excessively cautious. Such plants present an effective no cost product for very poor farmers that cannot be adulterated if produced by the farmers themselves and is less toxic and hazardous. Unfortunately, appropriate cell based procedures for mammalian toxicity testing for plant materials are not currently available and would be very useful to understand the potential risks associated with pesticidal plant materials.

Farmer Participatory Rural Appraisals

Much research published in international journals on African pesticidal plants has been carried out in laboratories or on agricultural research stations. While relevant, these trials fail to assess the use of plant materials under farm conditions which may differ from the uniform environment of a research station. Consequently, they do not assess many of the other factors, besides efficacy, which are important to farmers when they choose to use plant materials for insect pest control (e.g. labour, availability, ease of use, marketability of treated produce). For example, Stevenson *et al.* (2010) showed that saponins were active components in the root bark of *Securidaca longepedunculata* against stored product pests and postulated that the unsustainable use of the root bark could be made more sustainable by making a water extract of the bark and using this to treat grain prior to storage. The thinking behind this is that current practice involves pounding bark to a powder and mixing this with the grain, a technique that is inefficient for several reasons and which could be made more efficient since the application of an extract would optimise the use of the active compounds. Anecdotal reports from current field trials, however, indicate that this application method is unpopular with farmers since the process of making the extract and then dipping the grain and drying before storage is too labour intensive despite the fact that it is as effective as using the whole root but only requires half as much to material treat the same amount of commodity (P. Stevenson, unpublished).

The small and irregular sized plots that are common among resource poor farmers in Africa may require specialised knowledge about how best to apply materials and some farmers may apply using a watering can rather than a specialised device like a knapsack sprayer. Farm trials will also engage farmers with a promotion strategy and help to better understand how applications can be optimised based on the available technology. For example, most farmers make cold water extracts of pesticidal plant materials yet the components may be non-polar and, therefore, inefficiently extracted by this process. Field trials with farmers will enable the evaluation of appropriate novel approaches such as the use of hot water or soaps that might enhance extraction and further optimise the application by acting as a surfactant.

Ultimately, the goal of pesticidal plant research in Africa should be simple, safe and environmentally conscientious protocols that can be easily understood and distributed widely by extension services and NGOs.

Sustainable Harvesting and Local Production of Pesticidal Plants

The use of pesticidal plants collected from the wild is only sustainable if small numbers of people use the plant or if the plant is abundant and ubiquitous or propagated easily. However, demand for some plants is outstripping supply (Shackleton *et al.*, 2005; Harnischfeger, 2000), particularly as overgrazing or bush fires also reduce supply not withstanding the fact that overgrazing can actually be a benefit when it comes to tree recruitment (Chidumayo, 1997). There is little knowledge about growing and propagating some pesticidal plant species making attempts to cultivate them difficult while a lack of phytochemical knowledge makes it difficult to know which the optimal methods for collecting plants are (Sarasan *et al.*, 2011).

Propagation. The conditions for germination vary considerably and plant seeds often need to be stimulated. Recent work has shown that some species can be propagated from seeds which could be important to establish large scale cultivation of some species particularly tree species such as *Securidaca longepedunculata* and *Bobgunnia madagascariensis* (Zulu *et al.*, 2011; Thokozani *et al.*, 2011) Timing of seed collections, seed drying, storage, and germination are also required.

Sustainable harvesting and processing. In some cases, roots, bark, seeds or entire plants of pesticidal species are used, and the collection of these parts is not sustainable (Belmain and Stevenson, 2001; Stoll, 2005). For example, where roots are harvested, often killing the plant, active compounds may also occur in leaves which would be more sustainable. Modified and limited root harvesting methods could also reduce the impact on species abundance. The compounds in pesticidal plants can vary according to geographic location and season and, since their efficacy as pest control agents depends on these compounds, harvesting times can be crucial in optimising their efficacy. Once harvested, plant materials are usually dried, ground or extracted to give a product which is used immediately, stored or sold. Exposure to sunlight and oxidation can change chemistry and thus affect efficacy, so trials are required that evaluate differences in the way in which farmers process pesticidal plant species.

Maximising availability of plant pesticides to small-scale farmers. If techniques to propagate pesticidal plants can be established, then this may open up the possibility of marketing pesticidal plants as a cash crop for small-scale farmers. This could provide very important additional income for poor farmers (Sarasan *et al.*, 2011) while developing a way to upscale and promote a technology. Up-scaling technologies are limited by funding programmes, particularly when such activities are paid through short-term extension initiatives with little follow-up. However, sustainable promotion can be more assured if the practice can be handed over to farmers with the incentive of income generation. This is an essential step towards the formalisation of pesticidal plant use for agricultural pest management in Africa, particularly if government and non-governmental organisations continue to promote the use of wild plants. Demand for pesticidal plants will continue to grow, which can only realistically be met through their cultivation and marketing. One problem that must be overcome, however, is the leniency with which governments are willing to allow plant based products to be registered as approved pest control products.

Currently in most African countries any pesticidal product whether a synthetic mass produced chemical or a plant material that is packaged for the specific purpose of controlling insects are required to satisfy the same level of interrogation regarding their efficacy, toxicity and environmental hazard. The costs of producing most of the information are prohibitive and will continue to be an insurmountable hurdle to their wide-scale use and production until the registration procedure is modified for natural products. Interestingly the laws governing the sale of herbal remedies in South Africa, products that are intentionally sold to consume internally, are very relaxed owing the perceived importance of this trade as a traditional practise. In the same country, however, if a plant product is sold as a pest control product it is quite simply considered as a pesticide and needs to be registered as such. Consequently, while the production and sale of pesticidal plants does occur, it all happens under the radar of the formal pesticide sector. Market surveys are required to establish which plants are already sold in markets, prices, demand, and the marketing chains involved. Perceptions of the target users is also required and could be obtained through surveying local and regional markets using questionnaires and structured discussion with individuals and groups of market traders, purchasers, suppliers and producers.

PESTICIDAL PLANTS IN MIOMBO WOODLANDS OF AFRICA: CURRENT RESEARCH AND DEVELOPMENTS

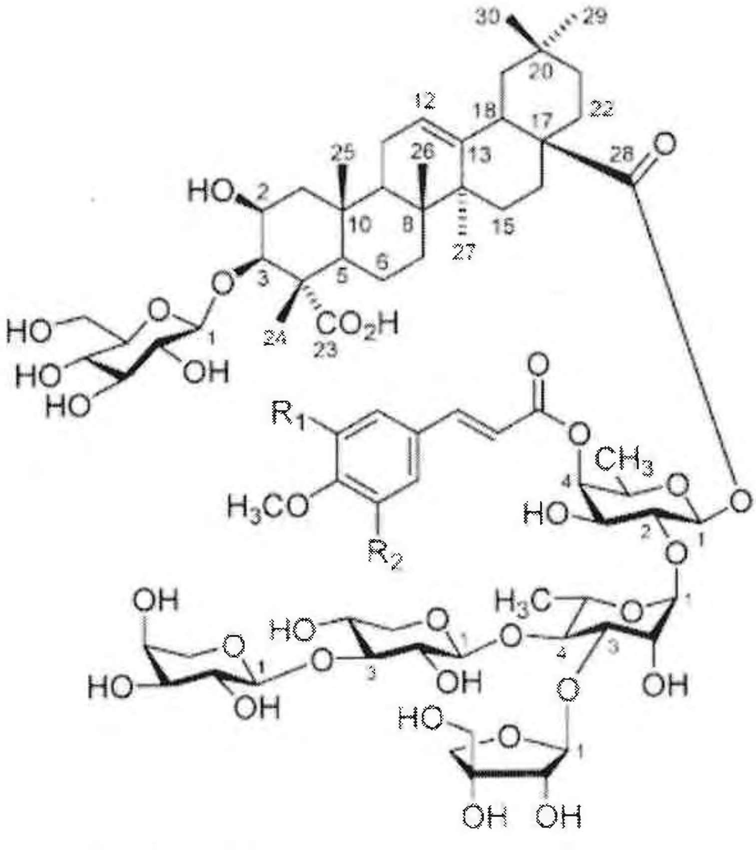
Numerous species, many with only local use and knowledge, are found across Africa. But through our recent work combining surveys (Kamanula *et al.*, 2011; Nyirenda *et al.*, 2011), databases (e.g., http://epic.kew.org) and scouring the literature, we identified key pesticidal plant species found in Miombo woodland. Miombo woodland is dominated by trees in the genus *Brachystegia* along with *Colophospermum mopane* (Mopane) and *Baikiaea plurijuga* which is misleadingly referred to as Rhodesian teak. Miombo derives from the Bemba pleural for *Brachystegia longifolia*. The below list is just a snapshot of plants of interest in the Miombo woodlands and is by no means exhaustive. However, it provides an opportunity to update the research on a select few species and raises questions and issues that are generally relevant to all pesticidal plant species. Interestingly, several of the species we encountered as of value in pest control are virtually unknown in the literature for the reported applications and present interesting new research and development opportunities. These include, *Aloe ferox* which is reportedly burned and the dust used to treat stored grain in Zimbabwe and Zambia and *Euphorbia tirucalli* which has been shown to have activity against larvae of two species of mosquitoes (Rahuman *et al.*, 2008; Yadav *et al.*, 2002) but has potent skin irritant properties associated with the latex (Kinghorn, 1979) which may in practice dissuade use.

Another species commonly reported is the poison apple *Solanum panduriforme* (now included in *S. incanum* although sufficiently different to warrant distinction) but apart from some work on its antimicrobial activity (e.g. Pesewu *et al.*, 2008) there is no evidence to support insect activity. Some exotic species have widespread uses such as *Cymbopogon nardus* and *C. citratus* and Neem, but the latter highlights the importance of good extension and training in use. Most farmers who report using Neem use the leaves which are notoriously low in their bioactive components. And in some parts of southern Africa, the climate is not conducive to flowering in *Azadirachta indica*, thus the trees do not produce seeds where the greatest quantities and diversity of pesticidal and deterrent compounds can be found. Other species such as *Lantana camara* that are popular in other parts of Africa do not appear to be used in southern Miombo regions where they are considered highly invasive and receive high priority for local eradication programmes.

Securidaca longepedunculata

Securidaca longepedunculata (Polygalaceae) is a small tree often referred to as the African Violet tree and is found throughout sub-Saharan Africa. Several studies have corroborated the effect of the plant. For example, Belmain *et al.* (2001) showed that *S. longepedunculata* was the most toxic to *Rhyzopertha dominica*, *Callosobruchus maculatus*, *Sitophilus zeamais*, and *Prostephanus truncatus* when compared to *Cassia sophera*, *Chamaecrista nigricans*, *Mitragyna inermis*, *Ocimum americanum* and *Synedrella nodiflora* which are other species reported in the Northern Region of Ghana to be used traditionally for pest control in stores. When evaluating 33 West African species for toxicity to *C. maculatus*, Boeke *et al.* (2004a,b) showed *S. longepedunculata* along with *Nicotinia tabacum* and *T. vogelii* to reduce F1 progeny, indicating a level of toxicity to the beetles or oviposition deterrence. In the same study, *Clausena anisata*, *Dracaena arborea*, *T. vogelii*, *Momordica charantia* and *Blumea aurita* were shown in a linear olfactometer to be repellent to the beetle. Surprisingly, *Chamaecrista nigricans*, *Azadirachta indica* and *Hyptis suaveolens* were attractive to the beetles. Root bark was also shown to reduce the FI progeny of *R. dominica*, *C. maculatus*, *S. zeamais*, and *P. truncatus* (Jayasekera *et al.*, 2003).

Methyl salicylate is the principal volatile component in the root of *S. longepedunculata* (Jayasekera *et al.*, 2002) and it is this compound that causes at least some of the toxic effects (Jayasekera *et al.*, 2005). However, toxicity is also attributable to the saponins (Fig. 11.1) that are found in abundance in the root extract (Stevenson *et al.*, 2009). These compounds might then explain the toxicity of *S. longpepedunculata* non-polar extracts to the mosquito *Ochlerotatus triseriatus* and to a lesser extent the whitefly, *Bemisia tabaci* reported by Georges *et al.* (2008). This activity was also shown to be high against the mosquito in other species in the same study including, *Datura inoxia*, *C. nigricans*, *Jatropha curcas* (skin and seeds) *Strophanthus hispidus*, and *Sapium grahamii*. If the active components against whitelfy and mosquitoes in *S. longepedunculata* are the saponins then they would be conducive to use as a spray by making a water extract since saponins are water soluble.



1 $R_1 = R_2 = H$; Securidacaside A
2 $R_1 = R_2 = OCH_3$; Securidacaside B

Fig. 11.1. Saponins isolated from *Securidaca longepedunculata*.

Bobgunnia madagascariensis

Bobgunnia madagascariensis (syn. *Swartzia madagascariensis*; Kirkrbide and Wiersema, 1997) (Leguminosae) is reportedly used for protection of stored products from beetles in Zambia and other parts of southern Africa. However, there is surprisingly little scientific evidence to substantiate activity for this reported application but considerably more reports of medicinal and molluscicidal activity (Kone *et al.*, 2004; Borel and Hostetmann, 1984; Marston *et al.*, 1993). There are some reports of activity against mosquitoes and whitefly. For example, ethyl acetate extract of *B. madagascariensis* caused 80% mortality in one report with other plants (Georges *et al.*, 2008) whereas other plants in the same bioassays exhibited only 30-50% mortality. In the report, antifeedant assays against *Helicoverpa zea* and *Heliothis virescens*, showed that the methanol extracts of *B. madagascariensis*, *C nigricans*, and *S. hispidus* were effective against *H. zea* causing a reduced weight gain of test insects. Earlier, the extracts of *B. madagascariensis* were shown to be active against mosquito larvae (Minjas *et al.*, 1986) and repellent to termites (Crombie *et al.*, 1971). The active components are likely to be saponins (Fig. 11.2) which occur in the pods and bark.

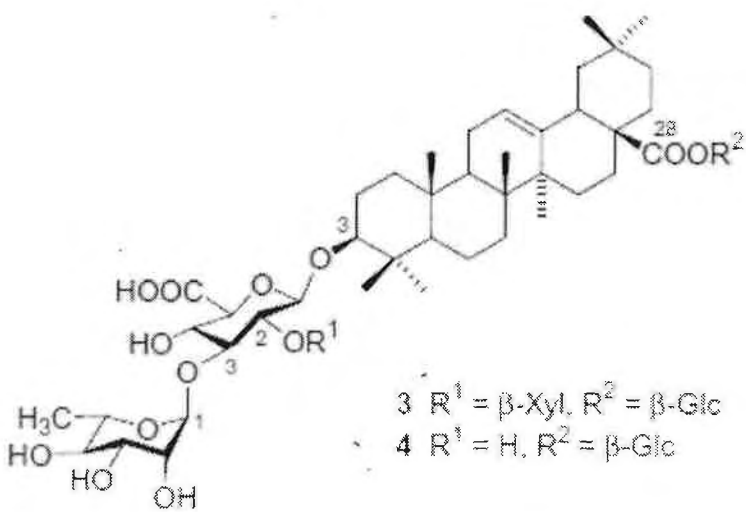


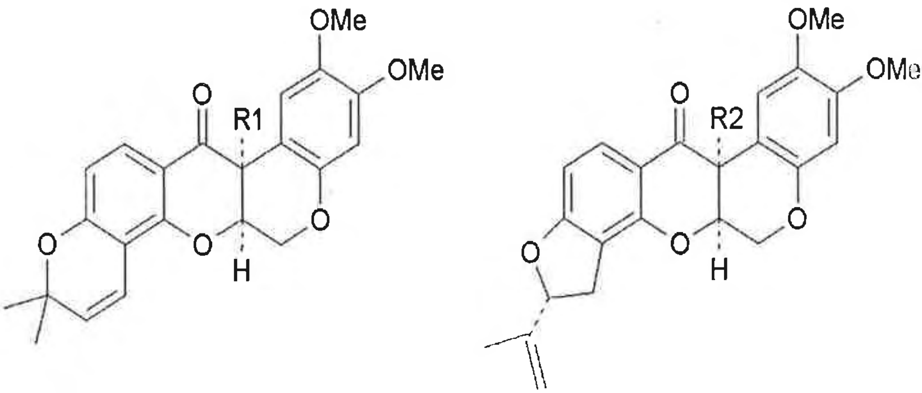
Fig. 11.2. Saponins from the pods of *Bobgunnia madagascariensis.*

Stevenson *et al.*, 2010; Marston *et al.*, 1993 since the only other components found in the pods are highly glycosylated flavonoids which are not biologically active to insects (Stevenson *et al.*, 2010). The presence of these saponins, however, does vary between locations, thus the selection of appropriate progeny for propagation or simply as a source of bioactive material is critical and should be based on chemical analysis (Sarasan *et al.*, 2011).

Tephrosia vogelii

T. vogelii (Leguminosae) is possibly the best known and widely used pesticidal plant in Africa, particularly in southern and eastern Africa (Nyirenda *et al.*, 2011; Kamanula *et al.*, 2011) but is widespread across the continent. The species is cultivated widely for soil improvement (Mafongoyo *et al.*, 2005) as well as for its pesticidal use and fish poisoning properties (Neuwinger, 2004) although the latter application is now prohibited in virtually all regions of the continent. It is clearly introduced in many locations so the extent of its natural coverage is unclear. A related species, *T. candida* is widespread in parts of Asia where it is also used as a mulch and cover crop (Fagerstrom *et al.*, 2001) and this is being increasingly used in Africa since it is considered to be more effective at soil improvement than *T. vogelii* (Mafongoyo and Kuntashula, 2005). This immediately presents a possible problem in that farmers, who know about the insecticidal properties of *T. vogelii* leaves now might assume the same of *T. candida*, which while not well studied, is not well-known for its use as a plant pesticide. While some chromene rotenoids are reported from the roots (Andrei *et al.*, 1997) and the stems and leaves (Kole *et al.*, 1992); our recent studies of *T. candida sensu stricto* herbarium vouchers indicate rotenoids to be absent from this species indicating poor scope for use as a pesticide (Stevenson, 2010) and any biological activity towards insects that they express is not associated with rotenoids (Lapointe *et al.*, 2003). Leaves of *T. vogelii, however,* contain at least four rotenoids (Fig. 11.3) with deguelin and tephrosin the major isoflavonoid components and rotenone and dehydrorotenone as minor components (Lambert *et al.*, 1993). The highest concentration of the active compounds is found in the leaf which makes it ideal for use since the foliage is the most abundant and sustainably harvested plant part. Besides this, it is relatively easily cultivated so is the species for which its use is least likely to have any environmental impact.

There is a need to determine the biological activity of the two main rotenoids tephrosin and deguelin to fully understand the potential activity of the species. Since much of the flag waving about the value of *Tephrosia* rests on its content of active rotenoids, and that rotenone is the only one that has been evaluated in laboratories much work still needs to be done in evaluating the other components to determine optimised applications. While much 'grey' literature cites rotenoids in the leaves of *Tephrosia* to be insecticidal, surprisingly there is no published work to corroborate this. Indeed the bioactivity of *T. vogelii* against bruchids and weevils was even reportedly not associated with rotenoids (Koona and Dorn, 2005) although this was largely based on the expectation that rotenoids would not occur in methanol extracts. Our recent research can confirm that rotenoids are found in methanol extracts and that rotenoids are the active principles, at least against bruchids.



Deguelin R1 = H
Tephrosin R1 = OH

Rotenone R2 = H
Rotenonlone R2 = OH

Fig. 11.3. Rotenoids from *Tephrosia vogelii*

The active components are generally reported to be in the leaves and roots and the reported effects are antifeedant, insecticidal, acaricidal, ovicidal, icthyotoxic and as a contact and stomach poison to insects (Gaskins *et al.*, 1972). Unpublished work indicates that the addition of liquid soaps can greatly optimise the efficiency of extraction (Stevenson unpublished) of rotenoids. For example, 5% teepol extracts 8 times more rotenoids from dried leaves than water alone, which is almost as efficient as using 100% methanol. If concentrated extracts are made using 5% liquid soap, these can then be diluted prior to spraying so that soap concentrations are more appropriate for field applications e.g., < 0.1%. The incorporation of soaps early on in the process may help to ensure that surfactants are ultimately used when sprayed to help disperse the active chemicals on the plants – an inclusion that is all too often overlooked by farmers using pesticidal plant extracts or commercial products.

Neorautanenia mitis

N. mitis (Leguminosae) is related chemically to *Tephrosia* spp. and other rotenoid producing plants. It produces a very large dense tuber that is high in flavonoids including rotenoids, isoflavones and pterocarpans. The size of the tuber can weigh tens of kilos and is relatively easy to propagate from tuber cuttings, thus like Tephrosia is conducive to cultivation by farmers. The principal rotenoid component of the root tuber in East and southern African specimens is rotenone (Stevenson, 2010) although earlier studies have identified a variety of pterocarpans with potential antifungal activity (Sakurai *et al.*, 2006) and earlier still reporting neotenone as the principal isoflavonoid component (Vanpuyvelde *et al.*, 1987). Indeed extracts of *N. mitis* root are biologically active against larvae of *Anopheles gambiae* and *Culex quinquefaciatus* mosquitoes, as well as against the adults of *An. gambiae* with the isoflavonoids neotenone and neorautanone and the pterocarpans neoduline, nepseudin and 4-methoxyneoduline reported to be responsible for these effects with activities comparable to deltamethrin and cypermethrin (Joseph *et al.*, 2004). With reports of this efficacy, it is surprising that more research on this species with respect to its possible role in pest control has not been conducted. Chimbe and Galley (1996) reported activity of the petroleum extract of the plant material against *Sitophilus oryzae* and *Prostephanus truncatus* but it was less effective than *Dicoma sessiliflora*.

Tithonia diversifolia

Tithonia diversifolia (Asteraceae) (Mexican marigold or Tree marigold) is a noxious exotic weed of southern and eastern Africa growing from South Africa to Uganda and from sea level to at least 1500m. It occurs in abundance in many places and is now listed in South Africa as an invasive plant that is illegal to grow and subject to national eradication programmes. On the brighter side, there may be scope to control its weed status by using it as a pesticidal plant. Indeed it is reported by farmers to be one of the pesticidal plant options available and used by them in southeastern Africa (Nyirenda *et al.*, 2011). Adedire and Akinneye (2004) showed that the leaf powder and the leaf extract reduced oviposition, adult emergence and increased mortality of *C. maculatus* although this effect was greatest for the leaf extracts. One hundred percent mortality was reported for adults after 48 h at all concentrations tested indicating a potent effect of compounds in the leaves. This effect could be associated with the sesquiterpene lactones that are reported to exude from the leaf hairs, particularly on the abaxial leaf face and are considered to be responsible for the deterrent effect of the leaves against bordered patch larvae, *Chlosyne lacinia*. *T. diversifolia* along with *Montanoa hibiscifolia* was also known to be a deterrent to *Bemisia tabaci* (Bagnarello *et al.*, 2009). Additionally there is evidence that *T. diversifolia* is deterrent to the leaf cutting ants, *Atta cephalotes*, although the greatest impact on colonies is associated with the effects of the plant on the fungus colony which they feed the leaves to (Rodriguez *et al.*, 2008; Valderrama-Eslava *et al.*, 2009).

Lippia javanica

The genus *Lippia* (Lamiaceae) has received a lot of attention in the last few years with respect to its potential uses in medicine and as an insect repellent owing to its broad spectrum activity and wide distribution in Africa and South America. It is also perhaps motivated by its use as a medicinal tea against the symptoms of fever, flu and cold (Viljoen *et al.*, 2005). This use suggests a low acute toxicity to mammals and favours promotion. Examples of its biological activity against various arthropods occur in the literature. Madzimure *et al.*, (2011) recently reported its biological activity against cattle ticks while mosquito repellency has also been reported in Zimbabwe (Lukwa *et al.*, 2009) and Kenya (Omolo *et al.*, 2004). In the case of mosquito repellency, the active components were reported to be essential oils including perillyl alcohol, cis-verbenol, *cis*-carveol, geraniol, citronellal, perillaldehyde and caryophyllene oxide whereas the compounds responsible for tick activity are not known but were present in a water extract thus unlikely to be essential oils. The work of Madzimure *et al.* (2011), however, reported acute toxicity of *Lippia javanica* when fed at high concentrations to mice so any promotion of this material needs to be done with caution.

Several related species are also known to be effective. For example, *Lippia alba* has been reported to be a potent deterrent to *Tribolium castaneum* with benzyl benzoate, β-myrcene, and carvone reported to be responsible for the effects (Caballero-Gallardo *et al.*, 2011). *Cymbopogon citrates*, *Lippia sidoides*, *Ocimum americanum* and *O. gratissimum* were reported along to have potent deterrent effects against *Aedes egypti* (Cavalcanti *et al.*, 2004) with similar effects reported for two other species of *Lippia*; *L. integrifolia* and *L. junelliana* (Gleiser *et al.*, 2011). Another species, *L. multiflora*, which is reportedly important in West Africa (Belmain and Stevenson, 2001) has recently been shown to be toxic against *C. maculatus* at around

5ul/l, although in these trials, *O. americanum* was ten times more effective and more persistent (Ilboudo *et al.*, 2010).

If there is one thing that is consistent about *L. javanica*; its chemistry is highly inconsistent. Numerous chemical studies report a variety of chemical compositions, and this identifies a critical area of work required before the material can be promoted widely. Even within Malawi, our recent work indicates that samples from 3 sites are chemically diverse. If there is a role for *L. javanica* in pest control, it needs to be based on a progeny of wild material that is validated by biological studies and chemical analysis. Since most of the compounds that are reported are likely to occur in foods its registration as a pest control material may be straight forward.

Vernonia amygdalina

V. amygdalina (Asteraceae) is well known for its healthy properties as a food supplement and perhaps best known as a choice supplement of chimpanzees who use it to deparasitise themselves (Yeap *et al.*, 2010). However, the species is reported to be a pesticidal plant by some farmers and appears to have some evidence supporting this potential use. Adeniyi *et al.* (2010) reported that organic extracts of *V. amygdalina* were more toxic to the bean weevil *Acanthoscelides obtectus* than *Sida acuta*, *Ocimmum gratissimum* and *Telfaria occidentalis*, while the combined essential oil of *V. amygdalina* was toxic against *S. oryzae* (Asawalam *et al.*, 2008).

CONCLUSIONS

Historically, pesticidal plant use in Africa has been an important part of traditional pest management practices by farmers. We believe that pesticidal plants should remain an important part of the future pest management options available for the many small-scale farmers in Africa who continue to face major impacts on their livelihoods caused by arthropod pests and who have been ill served by commercial synthetics for the reasons of cost, safety and availability as discussed earlier in this article. To ensure the future for pesticidal plants, many bottlenecks need to be addressed by the scientific community, policy makers and institutions involved in knowledge dissemination. Scientists need to provide better information that explains how pesticidal plants work, which arthropod species are affected, how the bioactive chemicals may vary according to season, locality or variety and how best plants should be harvested and processed to conserve and deliver bioactivity. Such information will increase the reliability of pest control and the expectations that farmers can make when they choose to use a pesticidal plant. Furthermore, scientists need to engage with policy makers to tackle issues such as conservation of wild habitats and the implications of "professionalising" pesticidal plant use as has occurred in many countries concerning Traditional Healers and medicinal plant use.

If African governments wish to encourage their farmers to use pesticidal plants, they need to recognise that useful plants need to be encouraged through conservation and propagation, and ultimately allow farmers to generate income by selling pesticidal plants (as individuals or through collectives) to their neighbours or urban farmers with limited access to pesticidal plants. In our opinion, it makes no sense to permit Africans to legally buy, sell and drink concoctions of medicinal plants, whereas to buy, sell and use the same plant species to control agricultural pests is prevented through regulatory burdens designed for synthetic pesticides. A strong future for indigenous knowledge and use of pesticidal plants in Africa will need policy changes to be made to current regulatory frameworks. Scientists and policy makers must work together to establish basic safety information data that are sensible and relatively easy to regulate, particularly for pesticidal plant species that are already being widely used by African farmers. Improving our knowledge on variability of efficacy, conservation and regulation remain the big challenges for the future of pesticidal plants in Africa. We remain confident that such a strategy will increase farmer usage of pesticidal plants and ultimately help pull farmers out of poverty, increase family incomes and health.

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Biopesticides in Environment and Food Security
Issues and Strategies

Opender Koul, G.S. Dhaliwal, Sucheta Khokhar and Ram Singh

Drivers behind food security and crop protection issues vis-à-vis the food losses caused by pests include rapid human population increase, climate change, loss of beneficial on-farm biodiversity, reduction in per capita cropped land, water shortages, and pesticide withdrawals. Integrated pest management, therefore, becomes a compulsory strategy in agriculture, which offers a 'toolbox' of complementary crop- and region-specific crop protection solutions to address these rising pressures. IPM aims at more sustainable solutions by using complementary technologies and one of them is the use of biopesticides including genetically modified cropping systems. The aim is to reduce pests below economic thresholds utilizing key 'ecological services', particularly biocontrol systems via semiochemicals, biopesticides, precision pest monitoring tools, and rapid diagnostics. In fact, we are facing twin problems of environment and food security for the expanding population and it is necessary to ensure adequate pesticide-free food. The ecofriendly nature of biopesticide products suggests environment safety and safety for natural enemies and non-target organisms. However, their adoption and use have lagged behind due to certain constraints like variable performance under field situations, lack of quality standards and interest by big industrial houses, and cumbersome regulatory procedures. The present book is an attempt to critically debate over all these issues and suggest a road map for future.

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