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Botanical pesticide production, trade and regulatory mechanisms in sub-Saharan Africa: making a case for plant-based pesticidal products

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Abstract Pesticides are the major technology used in the management of field and postharvest losses due to pests. There is growing demand for effective alternatives that present low health risks and conserve ecosystems and biological diversity. Pesticidal plants are increasingly used as alternatives where synthetic products are unaffordable, have limited availability or are ineffective. Plant materials, however, are often used inefficiently and their effective use requires optimisation. In Africa wide-scale uptake of pesticidal plants remains limited despite the success of pyrethrum in some countries and other pesticidal plant products in China and India. This is mainly due to lack of data on efficacy and safety, inconsistent efficacy of plant products, the prohibitive cost of registration, and an inadequately developed conventional pesticides sector. Globally, the demand for botanicals is poised to grow due to an increasing shift in consumer demand for safe food, increasing organic farming, lobbying by environmentalists and the increasing pressure from new regulations on internationally traded foods in Europe. These demands can only be met by formalising production, marketing and use of pesticidal plants. This has to be supported by friendly registration procedures, sustainable forest management, propagation and cultivation of pesticidal plants. This paper presents a critical review of the enabling environment required for wide-scale adoption and commercialisation of botanical pesticides in sub-Saharan Africa. We conclude that regulations and protocols for production, marketing and trade need to be reviewed to facilitate the development of the botanicals sector in Africa.

Keywords Botanical insecticides · Pesticidal plants · Pesticide industry · Pesticide legislation

Introduction

Sustainable pest management is crucial for enhancing food security in sub-Saharan Africa (SSA) where most livelihoods are dependent on agriculture. It is estimated that more than

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20 % of the world's potential food supplies are lost to pre-harvest and postharvest pests (Phillips and Throne 2010). Losses begin in the field when crops are attacked by a number of insect pests. Some of the most important field pests include aphids (*Brevicoryne brassicae*); red spider mites (*Tetranychus urticae*); and diamond back moth (*Plutella xylostella*) which increase production costs by up to 30 % for smallholder horticulture farmers (Grzywacz et al. 2010). In grain storage, the larger grain borer (*Prostephanus truncates*); the lesser grain borer (*Rhyzopertha dominica*); weevils (*Sitophilus* spp.); bruchids (*Callosobruchus* spp. and *Acanthoscelides obtectus*); and flour beetles (*Tribolium* spp.) are the most prevalent pests causing the greatest damage and post-harvest losses (Mvumi et al. 2003; Phillips and Throne 2010).

Efforts to intensify agricultural productivity have resulted in the introduction of new crop varieties which, in turn, increase use of pesticides (Siziba and Mekuria 2003; Schreinemachers and Tipraqsa 2012). This approach has paid off and chemicals have contributed to a major increase in crop yields of up to four times the value of the applied pesticides (Cooper and Dobson 2007; Bennett et al. 2010). However, this has come at a cost in SSA with increased risks to the environment and human safety. In addition, the experience of smallholder farmers, who are typically resource-poor, is that synthetic products are unaffordable, sporadically available, poorly labelled and packaged, adulterated and/or sold beyond their expiry date (Stevenson et al. 2012a). Considering the well documented health risks associated with synthetic pesticides, the need for alternatives is even more crucial (Wesseling et al. 2001). Chemical pesticides are under increasing pressure to become more sustainable, especially under the European Union Thematic Strategy on the Sustainable Use of Pesticides (EC 2010).

The constraints of synthetic pesticides have led to increased interest in the application of botanical pesticides for crop protection. It has been well argued that pesticidal plant products or botanical pesticides are an appropriate technology for resource-poor smallholder farmers (Isman 2008). The active components in pesticidal plants are non-persistent with many being UV labile and others broken down through oxidation or by microorganisms, thus presenting lower risks to consumers (Devlin and Zettel 1999). Botanical pesticides maintain biological diversity of predators (Grange and Ahmed 1988; Amoabeng et al. 2013) which makes their use in agriculture a sustainable pest management alternative to synthetic pesticides. Furthermore, resource-poor smallholder farmers typically use botanicals as crude plant materials or extracts which exposes users to lower concentrations of active ingredients compared to synthetic chemical pesticides (Isman 2008). However, surprisingly few plants have led to major commercial pesticidal products akin to those produced by the synthetic pesticides industry. Pyrethrum products from *Tanacetum cinerariifolium*, Neem products from *Azadirachta indica* and rotenone from *Derris* and *Lonchocarpus* spp. are commercial examples of botanical pesticides that have been developed and are being traded globally.

Phytochemical variation in pesticidal plants is a serious hurdle to their exploitation (Sarasan et al. 2011) and it has been argued that they are generally not as effective as synthetic chemical pesticides, as they have relatively low, variable and sometimes unknown pesticidal activity. This leads to inconsistent efficacy, which is one of the many reasons why pesticidal plants have not been successfully commercialised. However, recent work indicates that pesticidal plants have lower impacts on beneficial insects compared to synthetic products and are cost beneficial when used as an alternative pesticide in vegetable production (Amoabeng et al. 2013, 2014), The high diversity of African plant species with pesticidal properties and existing indigenous use of such plants by resource-poor farmers suggests that there is scope for developing a strong market that meets local as well as international demand for more ecologically benign pest control.

This paper presents a critical review of the current state of the pesticidal plants industry in SSA, identifying existing challenges and opportunities with regards to the uptake of botanicals. We review and synthesize research and policy in order to understand existing and potential markets for pesticidal plants as well as compare and contrast the regulatory frameworks across SSA in order to establish the status of existing practices and legal systems. We assess the production, trade and adoption potential of pesticidal plant products and identify policy changes that could lead to greater promotion and development of effective pesticidal plant value chains. We also reflect on the biopesticides industries of the emerging economies, using India as an example, so as to draw lessons and recommendations for the SSA region. After evaluating the literature between 1994 and 2012, six countries were selected to represent SSA for further evaluation of differing levels of known use of and trade in pesticidal plants. The countries were selected based on the existence and location of members of the African Drylands Alliance for Pesticidal Plants Technologies (ADAPPT; www.nri.org/adappt). In addition, we use four case studies of pesticidal plant products to highlight issues associated with commercialisation and regulatory aspects of the pesticidal plant industry.

Subsistence production and use of natural pesticides

Pesticidal plants are widely distributed across many countries in SSA but their use tends to be restricted. In this study, an evaluation of literature describing work in six selected countries (Ghana, Kenya, Malawi, Tanzania, Zambia and Zimbabwe) between 1994 and 2012 has revealed that 59 species have been evaluated for pesticidal activity or pest control use and documented, yet only a few are being used in more than three countries (Table 1). This suggests that the substantial investment in research is not leading to marketable products. For instance, *Azadirachta indica* and *Tagetes minuta* were used in five countries while eleven other species were documented in three countries, including *Tephrosia vogelii*, *Securidaca longependunculata*, *Bobgunnia madagascariensis* and *Neorautanenia mitis* (Table 1). Research identifying new species with biological activity should be refocused on improving the use and adoption of plant materials already known to be effective.

A number of studies have indicated that use of plant pesticides is a long-standing tradition passed down generations in Africa and other developing countries (Berger 1994; Belmain and Stevenson 2001). However, their use may be less widespread than assumed as more recent studies in Malawi and Zambia indicated that over 70 % of farmers interviewed were aware of pesticidal plants but only about 20 % had actually used them (Kamanula et al. 2011; Nyirenda et al. 2011). In contrast, another study reported over 80 % of the interviewed farmers in Malawi, Tanzania, and Uganda exclusively employed traditional methods that included pesticidal plant use in storage pest management (Minja et al. 1999). In Ghana, studies across different regions showed that more than 90 % of farmers in the North-east routinely used botanicals, but less than 50 % of farmers in the North-central region did so (Cobbinah et al. 1999). These studies indicate that there is demand and preference for botanicals by some smallholder farmers in SSA but it cannot be assumed that they will be universally accepted.

Production, processing, preparation and standardisation pose major problems for resource-poor smallholder farmers across the continent. Traditional methods of preparation are often variable and lead to inconsistent efficacy. This is compounded by inherent differences in plant chemistries that may be genotypic, especially in obligate out-crossers, or spatio-temporal variations caused by abiotic factors such as altitude, rainfall and soil type or different chemistries expressed in different plant parts (Sarasan et al. 2011; Belmain et al. 2012; Stevenson et al. 2012b). *Lippia javanica* for example is a species well studied for its bioactivity against arthropods (Madzimure et al. 2011; Chikukura et al. 2011; Muzemu et al. 2012) but has recently been reported to show a level of chemical variability that suggests predicting efficacy based on the presence of specific bioactive compounds may not be possible (Ricciardi et al. 2009). These inherent and preparative differences mean that some farmers may experience very good pest control when using a certain plant species, whilst others do not. This inconsistency in efficacy remains one of the major difficulties that stands in the way of exploitation of pesticidal plants.

Commercial plant pesticide products

Plant-based biopesticides are still just a promising, and in many cases unproven, alternative to synthetic pesticides even though for some pests various crude or processed products have been commercialised (Khater 2012). By the beginning of the year 2013, 400 active ingredients and over 1,250 biopesticide products had been registered and commercialised in the United States of America (U.S. Environmental Agency 2013). However, there is still only a handful of successful commercial pesticidal plant products in use, and what is available comprises a very small percentage (<0.1 %) of pesticidal products that are largely used for domestic or specialist applications (Isman 2006). There is also limited information available on application, efficacy and safety of most of these products (Foerster et al. 2001). In order to be effective alternatives, plant products must be available in a wide range of formulations and provide broad spectrum protection of crops (O'Brien et al. 2009). Some successful existing and potential products are critically reviewed in the following sections in order to determine opportunities and lessons for replication.

Tanacetum cinerariifolium and pyrethrum

Pyrethrum is an insecticidal natural product extracted from flowers of *Tanacetum cinerariifolium* (Asteraceae) (Rhoda et al. 2006). *T. cinerariifolium* has been grown in Kenya as a crop for more than 70 years and is currently produced across East Africa including in Rwanda, Tanzania and Uganda. Kenya was formerly the world's leading producer of natural pyrethrum, supplying 80 % of the global demand (Wandahwa et al. 1996). Pyrethrum growing in Kenya can be traced back to 1928. By 1950, production was 5,710 MT and had reached a peak in 1993/94 when the country produced 17,450 MT against a world demand of 20,000 MT, earning approximately USD 70 million. In 2005 about 8,000 MT of dry flowers of pyrethrum were produced with 6,000 MT earmarked for export and 2,000 MT for domestic use. The major market for Kenya was the USA which accounted for 60 % of its produce, while Europe and Africa accounted for 35 and 5 %, respectively. In Africa, Egypt and South Africa absorbed 4 % and the remaining 1 % was used in Kenya (Rhoda et al. 2006). However, by 2011 less than 1000 MT was produced, illustrating the drastic fall in production, yet the country still has the potential to produce 30,000 MT of dried flowers with a yield of 1 MT of dried flowers/ha per annum (FAO 2012). Kenyan production has since declined due to poor supply chain management and ineffective management

Table 1 Level of documentation of pesticidal plants, research and use in selected countries in sub-Saharan Africa

Species name	Common name	Countries	References
Acanthiosicyos sp	African melon	Zm	Berger 1994
Agave sisaliana	Sisal	Mw Tz, Ke	Berger 1994; Foerster et al. 2001; Nyirenda et al. 2011
Alium cepa	Onion	Zm, Tz, Ke	Foerster et al. 2001; Nyirenda et al. 2011
Alium sativum	Garlic,	Zm, Mw	Berger 1994; Nyirenda et al. 2011
Aloe ferox	Cape aloe	Zw	Natural Resources Institute 2010; Stevenson et al. 2012a
Aloe vera L.	Aloe vera	Mw	Nyirenda et al. 2011
Anacaidium occidentalis	Cashew nut tree	Gh	Berger 1994
Annona stenophylla subsp. *cuneata*	Dwarf custard apple	Zw	Berger 1994
Azadirachta indica	Neem	Gh, Ke, Mw Tz, Zm	Berger 1994; Foerster et al. 2001; Nyirenda et al. 2011
Bobgunnia madagascarensis	Snake bean	Tz, Mw Zw	Berger 1994; Page 1997; Foerster et al. 2001; Natural Resources Institute 2010; Nyirenda et al. 2011; Stevenson et al. 2010; Nyahangare et al. 2012
Boscia sp	Shepard tree	Zm, Zw	Berger 1994
Buddleia sp.	Butterfly Bush	Tz	Foerster et al. 2001.
Capsicum annuum	Hot pepper, Chillies,	Ke, Mw Tz, Zm, Zw	Berger 1994; Foerster et al. 2001; Nyirenda et al. 2011; Amoabeng et al. 2013
Cassia abbreviata	Long tail cassia	Mw Zm	Berger 1994; Natural Resources Institute 2010; Nyirenda et al. 2011
Cassia sophera,	Senna sophera	Gh	Stevenson et al. 2012a; Belmain et al. 2001; Amoabeng et al. 2013
Chamaecrista nigricans,	Black grain	Gh	Stevenson et al. 2012a; Belmain et al. 2001
Cissus quandrangularis	Velvet grape	Zm, Zw	Natural Resources Institute 2010; Nyahangare et al. 2012
Combretum imberbe	Leadwood	Zw	Natural Resources Institute 2010; Chikukura et al. 2011
Courbonia virgata	Blue bush Cherry	Zm	Berger 1994
Crotolaria juncea	Sunhemp, Comfrey	Tz	Foerster et al. 2001
Cucumis myriocarpus	Prickly paddy melon	Zm	Cooper and Dobson 2007
Cussonia spp	Cabbage tree	Mw	Nyirenda et al. 2011
Datura stramonium	Thorn apple,	Zw	Page 1997
Derris elliptica	Poison vine	Zw	Moyo et al. 2006
Dolichos kilimandscharicus	Veld lupin	Mw	Nyirenda et al. 2011
Erythrophleum suaveolens	Missanda	Mw	Nyirenda et al. 2011
Eucalyptus spp	Gumtree	Zw, Tz	Berger 1994
Euphorbia ingens	Candelabra	Mw	Berger 1994; Nyirenda et al. 2011
Euphorbia tirucali	Milk bush, rubber hedge	Ke, Mw Tz, Zm	Berger 1994; Foerster et al. 2001; Nyirenda et al. 2011
Homolanthus populifolius	Bleeding heart tree	Zw, Gh	Berger 1994
Lantana camara	Wild sage	Ke, Mw Tz	Foerster et al. 2001; Nyirenda et al. 2011
Lippia javanica	Fever tea	Zw	Natural Resources Institute 2010; Katsvanga and Chigwaza 2004; Muzemu et al. 2012; Madzimure et al. 2011
Melia azedarach	Persian lilac	Gh, Zm, Zw	Berger 1994
Mitragyna inermis	False abura	Gh	Belmain et al. 2001
Mormordica	Bitter melon	Tz	Foerster et al. 2001
Mucuna pruriens	Velvet bean	Zm	Nyirenda et al. 2011
Nasturtium trapaeolum		Zw	Mwale et al. 2006
Neorautanenia mitis		Mw Tz, Zm	Berger 1994; Foerster et al. 2001;
Neorautanenia brachypus		Zw	Murungweni et al. 2012
Nicotiana tabacum	Tobacco,	Ke, Mw Tz, Zm	Berger 1994; Foerster et al. 2001; Nyirenda et al. 2011; Amoabeng et al. 2013
Ocimum americanum	Wild basil /Sweet basil	Gh	Stevenson et al. 2012; Belmain et al. 2001
Ocimum suave *O. basilicum*	American basil	Gh, Tz, Zm	Berger 1994; Foerster et al. 2001

Table 1 (continued)

Species name	Common name	Countries	References
Parinari spp	Mobola plum	Mw	Nyirenda et al. 2011
Pedilantcullatus spp.	Cyperus pedunculatus	Tz	Berger 1994
Securidaca longependuncculata	Violet tree	Gh, Mw Zm	Natural Resources Institute 2010; Stevenson et al. 2012; Belmain et al. 2001
Sesbania sesban	Sesban	Zm	Nyirenda et al. 2011
Solanum panduriforme *S. delagoense* *S. incanum*	Poison apple	Mw, Zm, Zw	Natural Resources Institute 2010; Nyirenda et al. 2011; Madzimure et al. 2011, 2013; Muzemu et al. 2012
Solanum villosum, *S. scabrum*, *S. tarderemotum and* *S. americanum* *S. sarrachoides*	African nightshade	Ke	Murungi et al. 2010
Spirostachys africana	Tambotie	Zw	Berger 1994; Chikukura et al. 2011
Strychnos spinosa	Spiny monkey orange	Zm, Zw	Natural Resources Institute 2010; Nyahangare et al. 2012; Madzimure et al. 2013,
Synedrella nodiflora	Cinderella tree	Gh	Belmain et al. 2001; Amoabeng et al. 2013
Tagetes minuta *T. erecta*	Mexican marigold African marigold	Ke, Mw Tz, Zm, Zw	Berger 1994; Foerster et al. 2001; Katsvanga and Chigwaza 2004; Moyo et al. 2006; Natural Resources Institute 2010; Nyirenda et al. 2011
Tanacetum cinerariifolium	Pyrethrum	Ke, Tz	Berger 1994; Foerster et al. 2001.
Tephrosia vogelii	Fish poison bean	Mw Tz, Zm, Zw	Berger 1994; Mwale et al. 2006; Cooper and Dobson 2007; Gadzirayi et al. 2009; Natural Resources Institute 2010; Nyirenda et al. 2011; Belmain et al. 2012
Terminalia sericea	Silver terminalia	Mw	Nyirenda et al. 2011
Tithonia diversifolia	Wild sunflower	Ke, Mw Zm	Nyirenda et al. 2011; Foerster et al. 2001
Toona ciliata	Australian cedar	Mw Zm	Nyirenda et al. 2011
Vernonia amygdalina	Bitter leaf	Mw, Zw	Nyirenda et al. 2011; Nyahangare et al. 2012
Vernonia subuligara		Tz	Foerster et al. 2001

Key: Country names

Gh Ghana, *Ke* Kenya, *Mw* Malawi, *Tz* Tanzania, *Zm* Zambia, *Zw* Zimbabwe

of the industry by government agencies (Omiti et al. 2007; World Bank 2005).

The rapid decline in pyrethrum production was mainly due to farmers shifting to horticultural enterprises after the state owned Pyrethrum Board of Kenya (PBK) failed to pay them for the flowers collected. The Pyrethrum Act 1963 (CAP 40) gave the PBK the sole monopoly of the industry; being responsible for registering and licensing growers, providing seedlings and technical support as well as buying dry flowers from growers for export. The failure by PBK was attributed to financial problems, fluctuating market conditions and bureaucratic inefficiency that paralysed the subsector (Omiti et al. 2007; World Bank 2005). However, the industry is expected to pick up again after the government enacted the Pyrethrum Act of 2013 which has replaced the PBK with the Pyrethrum Regulatory Authority and liberalised the industry, allowing investors and other private sector players into the industry (Government of Kenya 2013).

Other East African countries have increased their production of Pyrethrum to meet the growing global demand, especially Tanzania and Rwanda. Both countries privatised former government operated control boards in the late 1990s and since then production has expanded and farmer incomes have increased. Furthermore, a significant commercial investment by McLaughlin Gormley King (MGK) in the Pyrethrum Company of Tanzania Ltd has provided a reliable and expanding international market for the product (McLaughlin Gormley King Company 2010). A comparison of the failure of the pesticidal plant sector in Kenya and the success in Tanzania suggest that policy changes that enable private sector investments will be required to resuscitate the pyrethrum industry in Kenya.

Pyrethrum is a good example of how a pesticidal plant product can be commercialised. Farmers grow *T. cinerariaefolium* which then enters either of two separate value chains; one for crude pyrethrum powder, a lower quality product mostly for local markets; and the other for natural pyrethrin insecticides which contain up to 30 % active ingredient (Khater 2012). The latter requires more technology investment but delivers a product that is more valuable and for which there is increasing demand internationally (Fig. 1).

Azadirachta indica and azadirachtin

The neem tree, *Azadirachta indica*, is one of the most commercially successful pesticidal plants. Although it is native to India it has been naturalised globally including SSA and has been widely grown as a shade tree, a wind break, for timber and for pesticide products. The main active insecticidal component of neem is azadirachtin, and, along with several other bioactive limonoids present, has low mammalian toxicity (Koul et al. 2004). The seed has the highest content of azadirachtin of all plant parts, and most products are based on oil extractions from the seed kernel. Comparatively lower bioactivity occurs in leaves owing to lower concentrations of the bioactive compounds. However, many African farmers use the leaves in the preparation of crude pest control products, despite low efficacy as the leaves are easier to use: also, in some cooler climates neem trees do not flower so do not produce seed. Clearly practices need modifying and end users need information to ensure time and resources are not wasted using ineffective materials. Neem seed oil has been formulated into hundreds of different products such as soaps, medicines and pesticides. A number of Neem pesticidal products are being produced and traded internationally, especially from China and India, whereas in Africa neem has enjoyed far less success. There has, however, been some progress in the development of various products like Neemros, Neemroc, Neemroc-Combi and Neem Azal F, TS and ANKE and NLAE in Kenya and Tanzania (Rhoda et al. 2006).

Tephrosia vogelii and rotenoids

Rotenoids are natural insecticides found in a range of plant genera including species of *Derris*, *Lonchocarpus*, *Neorautanenia* and *Tephrosia*. Products based on these genera, particularly *Derris* which contains high concentrations of rotenone are some of the oldest pesticides used in agriculture and were formerly marketed globally before the advent of synthetic products. The use of rotenone as a botanical insecticide in Europe and North America has now largely ceased with the exception of a very few specific uses associated with clearing waterways of aquatic life. The European Commission [EC] Directives on pesticide registration and use, that has required re-registration of all agricultural chemical products, resulted in withdrawal of rotenone albeit for commercial reasons rather than its toxicity. WHO classifies the representative rotenoid rotenone as moderately toxic with equivalent acute mammalian toxicity to many currently accepted products including pyrethroids. Rotenone is thought to have an oral LD_{50} of between 300 and 500 mg/kg in humans (Ray 1991). Thus exposure to the plant material in which the concentration is <1.0 mg/g by weight in dry plant material is in reality unlikely to present acute dangers to users in SSA where its use is still widespread since an average adult man would need to consume 3–500 g of dry plant material/kg body weight equivalent to more than 20kg to be dangerously exposed (Belmain et al. 2012).

Tephrosia vogelii is widespread in Africa where it is one of the most popular pesticidal plants and one of the most well studied, frequently promoted and widely used (Gadzirayi et al. 2009; Kamanula et al. 2011; Nyirenda et al. 2011). It is a fast growing leguminous shrub that can easily be cultivated, but its promotion has largely been for its soil enriching qualities through nitrogen fixing and as a green mulch (Mafongoya

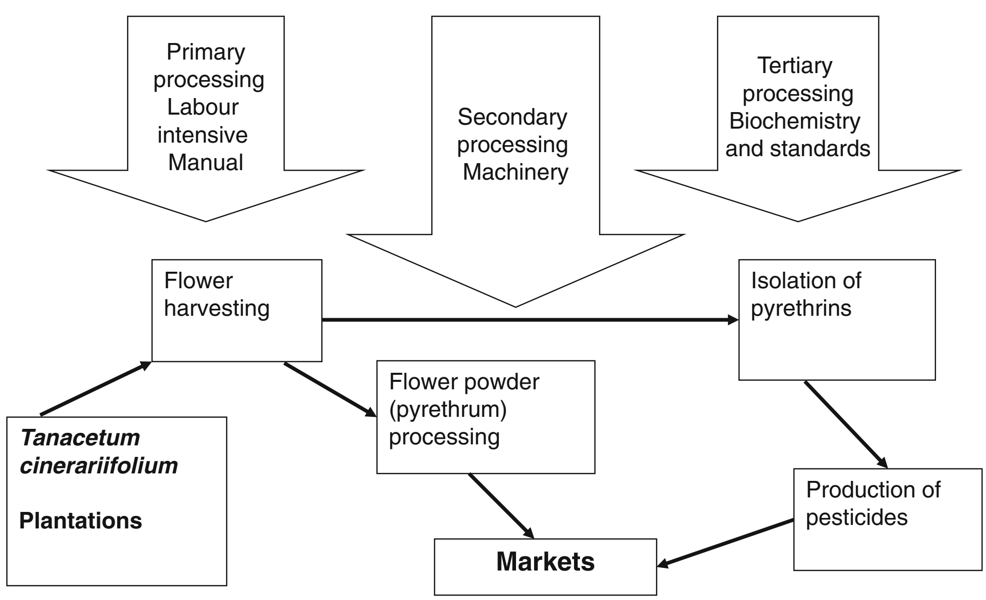

Fig. 1 Schematic representation of the pyrethrum value chain. The harvested flowers move through three possible stages of primary, secondary and tertiary processing before a final product is produced for various markets

and Kuntashula 2005). Pesticidal activity in *T. vogelii* has been attributed to the presence of the rotenoids, deguelin and tephrosin (Belmain et al. 2012). Unlike *Derris* and *Neorautanenia*, where the rotenoids are found in the roots and where rotenone is the main active component, in *Tephrosia* the bioactive compounds occur in the leaves presenting a more easily harvested and sustainable product. Recent research has shown that natural chemical variation exists within *Tephrosia vogelii*, confirming the presence of two distinct chemotypes (Stevenson et al. 2012b) with one being active and the other inactive. Surveys in Malawi indicate that at least 25 % of *Tephrosia* currently grown on farms is the inactive chemotype so is not effective as an insecticide. New crude formulations using liquid soaps have been proposed as a way to optimise use, based on recent data showing that soap increases the extraction efficiency of water (Belmain et al. 2012) and this is now being promoted in Kenya, Tanzania and Malawi. As this species is abundant and easily cultivated, it would be relatively easy to commercialise along the lines of the pyrethrum model.

Securidaca longepedunculata and saponins

Securidaca longepedunculata is a small tree found throughout SSA which has been widely used to control pests in storage. The main compounds are the volatile compound methyl salicylate and the high molecular weight saponins which are both found in the root bark of *S. longependunculata* (Stevenson et al. 2012b). Saponins and methylsalicylate are both responsible for the biological activity of *S. longepedunculata* (Jayasekera et al. 2005; Stevenson et al. 2009). Saponins are soap-like compounds that produce foam in water or when shaken in aqueous solutions. These detergent properties favour their extraction in water. No formulations have been developed and promoted but the root bark consistently provides efficacy in field trials against weevil pests of maize. This is one species that requires a propagation strategy (Zulu et al. 2011) as it does not occur in high populations in the wild and the harvesting and extraction method can be destructive as it is the root bark that is the harvested part of the plant. Therefore, investment in product development is required to optimize efficacy and reduce the amounts of raw material harvested from the wild. To date no commercial production has been undertaken in SSA despite its widespread use by subsistence farmers.

The above examples therefore are a clear indication that, besides Pyrethrum and Neem based products, the commercialisation of botanicals is still in its infancy in SSA. Research efforts and funding need to be targeted much more at the development, formulation and standardisation of the known pesticidal plant products rather than solely focusing on identifying new sources of biologically active plant materials. This would lead to greater uniformity of crude extract efficacy with a known quantity of active ingredients and sustainable production, forming a solid foundation for commercialisation.

African pesticides industry structure

To fully understand how a plant based pesticidal industry could be developed in Africa it is important to understand how the synthetic pesticide industry operates and is developing in the continent. The development and supply of pesticides is mostly limited to a few global players. This is a result of the high costs of research and registration which effectively excludes small companies (Foerster et al. 2001). Thus the pesticide sector is generally not well developed in Africa and is dominated by a few manufacturers and formulators of active ingredients based in Asia and Europe. Research and formulation is mostly done out of Africa in source countries. In SSA, most of the multinational companies have set up subsidiary companies which import active ingredients for formulation of various pesticides. This has seen the production of agricultural chemicals from Africa reaching 5 % of global production in 2002 a trend that suggests a continued increase also attributed to more multinational companies setting up in Africa (UNEP 2006). The prime African producer countries are Nigeria and South Africa from the SSA region as well as Algeria, Egypt, Morocco and Tunisia from North Africa. In East and Southern Africa countries, there is no production of synthetic active ingredients with the exception of South Africa (AGENDA 2006; Rhoda et al. 2006). South Africa is the greatest producer of synthetic pesticide in Africa, ranking 16th in the world (UNEP 2007).

Thus despite all the developments, companies in most countries engage largely in importing ready to use products in bulk for repackaging which provides an often exploited opportunity for adulteration of products in some facilities and also negates the need to develop the local industry. For instance, in Tanzania, there were as many as 14,211 companies importing and/or trading in pesticides in 2006 but none were manufacturing (AGENDA 2006). Major challenges to venturing into manufacturing were inadequate financial resources, unavailability of appropriate technology and inadequate skills. One other major characteristic of these companies is that they do not have a distribution structure and thus have to link with distributors which, in general, are locally owned, have storage facilities and are engaged in repackaging and distributing pesticides to smaller retailers and stockists (Mudimu et al. 1995). This offers an opportunity of a distribution channel for botanical pesticides beyond the geographic and ecological areas of the plants from which they are derived.

The emerging industry structure for the production of and trade in plant pesticides products is conversely related to that of synthetic products as it is mostly driven by researchers working with small scale farmers and small local companies (Fig. 2). This is because large companies are still very sceptical about the return on investment on a product with unknown markets and unreliable raw material supply, uncertain patent issues and often less than absolute efficacy. In fact, lessons from Europe and the United States have shown that the biopesticides industry has its foundations in, and is driven by, small to medium scale enterprises and this has been suggested as a suitable model for SSA (Eilenberg 2006). However, the model still needs to be backed up by policies at national and regional levels that facilitate production, registration and marketing as illustrated by the change in fortunes of the Pyrethrum sector in East Africa.

Reflecting on the Asian models, India provides a classic case. In Asia, development and use of biopesticides is more advanced than in Africa. For instance, the value of the Indian pesticide industry in 2012 was estimated to be USD 3.8 billion. This is strongly attributed to multinational companies that had set up operations in response to low production costs, turning India into a manufacturing hub (Tata Strategic Management Group 2013). The Indian pesticide industry is comprised of three main stages, i) production of active ingredients as technical grades (with about 85 % active ingredient), ii) formulation of the pesticides and iii) distribution to consumers. By the start of 2013 it was estimated that there were more than 150,000 players in the industry, the bulk being distributors (approximately 145,000) followed by formulators (approximately 800) and the least being the technical grade manufacturers (approximately 125). Some of the manufacturers also produce pesticides and supply wholesalers and retailers directly (Tata Strategic Management Group 2013).

The top ten companies controlled almost 80 % of the market share and included United Phosphorus Ltd, Bayer Crop Science Ltd, Syngenta Ltd, Rallis India Ltd, Gharda Chemicals Ltd and BASF India Ltd. Increasingly, multinational and large companies are forming strategic alliances by entering into co-marketing and co-distribution arrangements. For these large manufacturers to have a wider reach, they maintain an elaborate distribution network of 400 to 1,000 distributors who supply 25,000 to 30,000 wholesalers and retailers (Tata Strategic Management Group 2013). Having locally based multinational companies that develop and produce new products is a great strength for the Indian industry when compared to Africa, which largely lacks multinationals that make this kind of investment. However, India has a large presence of unorganized or informal players, some of whom produce counterfeit biopesticides as a result of poor monitoring and enforcement by state authorities (Tata Strategic Management Group 2013). Only about 10 % of the enterprises operate on a commercial basis, providing quality products for export, whilst the rest are part time, lack infrastructure and have limited access to the majority of local farmers as they cannot afford their products (Bambawale and Bhagat 2012). Therefore, advanced as Indian industry is, the biopesticides sector is still not well studied or documented.

Pesticide marketing and trade

The value of world pesticide market was about USD 32.8 billion in 2006 with the USA, Canada, Mexico, France,

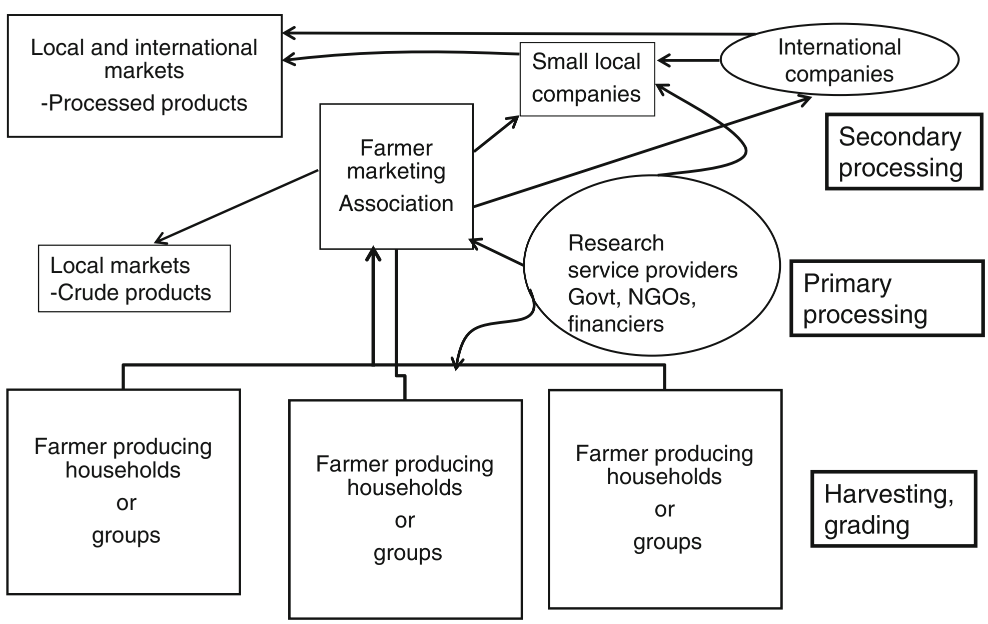

Fig. 2 Schematic representation of the structure of the emerging plant pesticides industry. Researchers, NGOs and governments are facilitating formation of farmer groups and their linkages with processing companies and local markets

Germany, Spain, UK, Japan, China, Thailand and South Korea as the major buyers worldwide (AGENDA 2006). The recent trends are that the production of synthetic pesticides is declining largely due to changing regulatory policies in the European Union and to some extent North America. At the same time the production of biopesticides has been increasing globally (Leng et al. 2011). However, Africa with all its potential is still accounting for only 3 % of the pesticides market share (Menzler-Hokkanen 2006). It is also important to note that there is significant informal trade and a number of products that are illegally imported and sold that bypass pesticide registration processes (Rhoda et al. 2006).

Pesticide use in Africa is largely targeted at high-value cash crops predestined for export. Therefore, it is those countries with a vibrant cash crop sector that use the highest volumes, especially Ghana, Kenya and South Africa (Rhoda et al. 2006; USAID 1994) but with legislation against synthetic products growing in Europe it is the larger producers in SSA who will need to lead the way in Africa and provide a major commercial market for new plant based and more environmentally acceptable products. While some previous potential markets such as Zimbabwe, formerly one of the largest importers of agrochemicals in Africa has declined severely in the past decade other countries have recorded exponential increases in demand attributed to the expansion of the horticultural industry (Fig. 3; Mehrdad 2004; Rhoda et al. 2006). Despite this growing demand, biopesticides remain a small and fragmented sub-sector of the pesticide industry. The sub-sector was estimated at 0.2 % of the total pesticide market in 2000, but reached 2.5 % in 2005 and 4.2 % in 2010 (Chandler et al. 2011; Kumar 2012; Leng et al. 2011; Parmar 2010). In 2012 the global market for biopesticides was valued at US $1.3 billion, and it is expected to reach US $3.2 billion by 2018. North America dominates the global biopesticides market and accounted for about 40 % of the global biopesticides demand in 2012 (Shukla and Shukla 2012). Of all the biopesticides on the market, the production and trade in biological control agents such as insect viruses and fungi is most advanced.

India is currently one of the top three manufacturers of pesticides in Asia and ranks fourth globally after the US, Japan and China (Tata Strategic Management Group 2013). The Indian industry in 2012 was estimated to be USD 3.8 billion with exports accounting for 50 % of the market. However, biopesticides represented only 4.2 % of the overall pesticide market, up from 2.89 % in 2005 (Gupta and Dikshit 2010; Mazid et al. 2011; Tata Strategic Management Group 2013). Neem products are the most widely researched, produced and marketed, making up 85 % of the biopesticides in the market (Rao et al. 2011; Sinha and Biswas 2008; Tata Strategic Management Group 2013). Neem based products exported by India in 2012 stood at USD 5.73 million, mainly to the USA and Italy (Gupta and Dikshit 2010). Otherwise pesticide use in India is still relatively low with a per capita consumption of crop protection products of 0.6 kg/ha compared to 13 kg/ha in China, 7 kg/ha in USA and the world average of 3 kg/ha. Insecticides account for 65 % of the total market, 50 % of which are used in cotton production. Some of the reasons for low consumption in India are: limited knowledge and awareness among farmers and state government personnel, limited availability and accessibility of products, and low purchasing power of farmers (Chandler et al. 2011; Parmar 2010; Tata Strategic Management Group 2013). However, crude preparations are in use at farm level as part of integrated pest

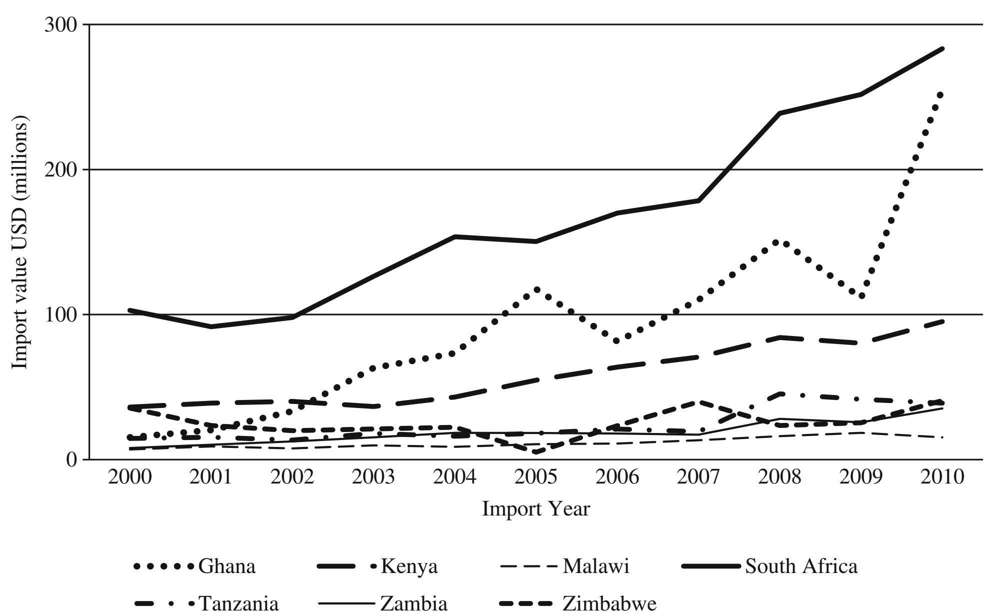

Fig. 3 Pesticide import levels in sub-Saharan Africa. Countries with thriving horticulture industries have steadily increased imports of pesticides (*Data source*: FAO 2012)

management, although a couple of studies have shown that this too is limited (Alam 2000; Parmar 2010).

In Africa, biopesticide markets remain small and undeveloped with limited production for local use. The few initiatives have remained as pilots and demonstration projects with the exception of pyrethrum in East Africa. However, commercial botanicals could become particularly attractive for crops produced for export to markets that have strict and enforced legislation covering maximum residue levels (MRLs) for synthetic pesticides. The organic production of fruits and vegetables for the local and European Union markets is, for example, of critical importance in this regard, especially for Kenya, South Africa, Tanzania and Uganda. Kenya is a good example where many smallholder flower producers have adopted biological control agents (Guillon 2004). However, the commercial production of botanical pesticides is still limited in scope and scale for most sub-Saharan African countries.

Policies and legislation governing pesticides

The aggressive promotion of synthetic pesticides as an absolute necessary condition for increasing agricultural production has indeed paid off but not without risk during manufacture, transportation, storage, distribution, use, and disposal. Developing and enforcing policies and legal frameworks for conflicting objectives of promoting agricultural productivity and avoiding environmental degradation in Africa has remained a challenge. Over the years the governments have responded by establishing guidelines and regulatory mechanisms to minimize risk and reduce impacts on the environment. Most sub-Saharan African countries have developed clear legal frameworks to govern the distribution and use of pesticides, but lack adequate resources to implement and enforce such legislation (Table 2; USAID 1994). The Rotterdam Convention is the main overall legislation for monitoring and controlling international trade in hazardous pesticides. Additionally all countries use the FAO International code of Conduct for the Distribution and Use of Pesticides (2002) as the basis for developing national legal frameworks (FAO 2005). The Code of Conduct:

- details the standards for testing pesticides and their packaging, advertising, labelling, storage and disposal
- provides a base for many of the national policies and also helps countries that have not yet established regulatory controls to promote the judicious and efficient use of pesticide products and the handling of potential risks associated with them
- seeks to encourage responsible and generally acceptable trade practices
- stipulates that governments should introduce necessary legislation, establish registration schemes, conduct risk assessments, collect data on the import and export of pesticides

Generally, pesticides legislation in most countries states that; no pesticides may be imported, exported, manufactured, distributed, advertised, sold or used unless they are registered according to the national pesticide regulations (AGENDA 2006; Mudimu et al. 1995; PCPB 2009; Government of Ghana 2004; Government of Tanzania 1997). Just as in the FAO (2002) Code of Conduct most countries define a pesticide as “any substance or mixture of substances intended for preventing, destroying or controlling pests, including vectors of human or animal disease, unwanted species of plants or animals causing harm during or otherwise interfering with production, processing, storage, transport or marketing of food, agricultural commodities, wood and wood products or animal feedstuffs, or substances which may be administered to animals for the control of insects, arachnids or other pests in or on their bodies” (FAO 2005).

As per the FAO Code of Conduct definition, any pesticide, synthetic or a plant extract is required to go through stringent registration procedures. Additionally, before they are registered, they cannot be promoted, traded or used. Conditions for registration are very similar in all countries, varying mostly in the level of specificity to groups of pesticides as detailed in the Kenya legislation. For instance, Kenya has specific application procedures for conventional, microbial and biochemical pesticides (PCPB 2009). This has facilitated registration, manufacturing, use and trade in botanicals more than in any other country in Africa. In 2003, over 620 pest control agents had been registered, most of which are based on pyrethrum and *Bacillus thuringensis* (Bt). Equally in Tanzania successes have been recorded with a number of botanicals being registered for experimental purposes including those with pyrethrum and azadirachtin as active ingredients (Rhoda et al. 2006).

However, in most cases costs of producing the pre-requisite information is the major constraint for wide-scale production and use and any changes to this status quo may require modification of such procedures. In the Southern Africa Development Countries the cost from product development to the shelf is estimated to be USD 250,000 whilst the cost of registration including field trials is about USD 20 million (personal communication, BASF Zambia). Field trial costs can be reduced by using data and information from previous studies conducted under similar climates. These trials are supposed to be conducted under at least two different microclimatic conditions and seasons.

Thus generally, in all countries the pesticide industry is subject to strict regulatory frameworks and procedures.

Table 2 Plant protection legislation in selected countries in sub-Saharan Africa

Country	Legislation	Legislative authority
Ghana	Pesticide control and Management Act 1996 (Act 528)	The Environmental Protection Authority
Kenya	Pest Control Products Act, Cap 346 (1984)	Pest Control Product Board
Tanzania	Plant Protection Act of 1997 and its regulations of 2001 Tropical Pesticides Research Institute (TPRI) Act No 18, 1979 Pesticide Control Regulations, 1984 Industrial and Consumer Chemicals (Management and Control) Act No. 3 of 2003	Tropical Pesticides Research Institute
Malawi	Fertilizers, Farm Feeds, and Remedies Regulations Act of 2002	Malawi Bureau of Standards
Zambia	Pesticides and Toxic Substances Regulations 1994	Environmental Protection and Pollution Control Act in 1990
Zimbabwe	Fertiliser, Farm Feeds and Remedies Act (Chapter 186, Section 24).	Plant Protection Research Institute
	Environment Management Act 2002	Environmental Management Agency

Globally, there were 400 registered biopesticide active-ingredients at the beginning of 2013 (U.S. Environmental Agency 2013) and 1,400 products available on the market in 2011 (Chandler et al. 2011). In India, there were about 25 biopesticides registered whilst more than 227 synthetics were registered as of 2008 (Chandler et al. 2011). In India, two pieces of legislation, the Insecticides Act, 1968 and the Insecticide Rules, 1971, regulate the registration, manufacture, trade and use of insecticides. As such, all insecticides including biopesticides are registered under the Insecticides Act, 1968 and will now be managed under the Pest Management Bill, 2008 once it is passed (CSE 2011; Parmar 2010). Like all pesticides, biopesticides have to satisfy the residue tolerance levels stipulated by the Food Safety and Standards Act, 2006 (Bhushan et al. 2013). However like Kenya, India has special provisions within the revised Insecticide Act 1968 that provide specific guidelines and procedures for various types of biopesticide registration (Bambawale and Bhagat 2012).

To support the above, the National Agriculture Policy 2000 and the National Farmer Policy 2007 are strongly in favour for the production and promotion of biopesticides, according them the same status, emphasis and support as given to synthetics (Gupta and Dikshit 2010; Shukla and Shukla 2012). Some critics have indicated that there are good regulatory frameworks and structures for pesticide regulation, but that enforcement is lacking. In an effort to improve the situation, the Indian government has initiated a process to repeal the Insecticide Act, 1968 and replace it with new legislation, the Pesticide Management Bill, 2008. This bill is meant to address some of these challenges by devolving authority and decentralising responsibilities to state governments, which will administer procedures for licensing manufacture of pesticides, increase transparency in laboratory accreditation and ensure companies recover R&D costs for registration (Tata Strategic Management Group 2013). However, it has met a great deal of criticism and has still to be passed by parliament (CSE 2011).

Conclusion and recommendations

Food production, access and availability are key to food security; thus, issues of pest management are crucial. This has become more so as the world is trying to produce more food to feed a growing global population. One way of sustainably increasing food production and food availability is to improve the control and management of pests in ways that do not lead to adverse environmental and human health impacts, phenomena associated with the use of synthetic pesticides. The role of pesticides in enhancing food security and reducing poverty in SSA is all too well known and documented. This paper has explored the status of production and distribution of biopesticides in SSA in order to advocate their wider use as an ecologically friendly technology, which could increase food production and food safety. However, there are still challenges to be overcome as outlined in the following paragraphs.

Without an enabling legal and policy framework, development of biopesticides will remain informal, illegal and of limited economic and political consequence. Most successes in commercialising biopesticides have been registered in countries where there are specific and dedicated procedures and guidelines for registration and trade. A few countries in SSA have adopted this approach and more should be encouraged to do so.

The future of botanicals in SSA lies in the willingness by public and private institutions to invest in rigorous research that will assure policy makers and the public about human and environmental safety and their efficacy. Such research could lead to adequate and commercially viable pest control. Already there are a number of pesticidal plant species that have been partly or adequately researched as detailed in this paper, thus presenting opportunities for testing and demonstrating the viability of the biopesticides industry in SSA. It is recommended, therefore, that novel products are developed and commercialised with regional/national investment in plant species that are locally abundant and/or domesticated agroforestry multipurpose species such as *Tephrosia*, using similar development models to those of pyrethrum and neem.

Although there is currently wide use of botanicals by farmers and a growing organic production sector, development of the biopesticides sector is limited because multinational companies are reluctant to invest in their local production and distribution. This is a major constraint to the formalisation of the production, promotion and use of botanical pesticides. At the moment India is the production hub for biopesticides simply because it has low production costs, raw material availability, low cost technologies and low labour costs. SSA countries have to learn from this and adapt to local conditions to enable the biopesticide and synthetic pesticide industries to develop and grow, capitalising on the visible presence of multinational companies that have set up operations in many countries, despite their current business focus on importation and distribution of synthetic pesticides.

Indeed, unless there is investment in value chain development that will spread the costs of research and increase the value of botanicals, their widespread promotion and adoption will remain a fantasy. Private companies and research organisations have the challenge of bringing botanicals from the forest to the shelves at a reasonably low cost. The investments might seem insurmountable but the potential role of botanicals in sustainable pest management cannot be over emphasised.

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References

AGENDA (2006). *Pesticide and poverty: a case study on trade and utilization of pesticides in Tanzania: Implication to Stockpiling; Final Report*, Dar es Salaam, http://www.pan-uk.org/archive/Projects/Obsolete/15.%20Trade_and_Utilization_of_Pesticides_in_Tanzania_Final.pdf. Accessed 18 Feb 2014.

Alam, G. (2000). *A Study of Biopesticides and Biofertilisers in Haryana, India*. Gatekeeper Series no. 93 IIED, London. http://pubs.iied.org/pdfs/6348IIED.pdf. Accessed 18 Feb 2014.

Amoabeng, B. W., Gurr, G. M., Gitau, C. W., Nicol, H. I., Munyakazi, L., & Stevenson, P. C. (2013). Tri-trophic insecticidal effects of African plants against cabbage pests. *PLoS One, 8*, e78651.

Amoabeng, B. W., Gurr, G. M., Gitau, C. W., Nicol, H. I., Munyakazi, L., & Stevenson, P. C. (2014). Cost: benefit analysis of botanical insecticide use in cabbage: implications for smallholder farmers in developing countries. *Crop Protection, 57*, 71–76.

Bambawale, O. M., & Bhagat, S. (2012). Registration related issues in effective use of biopesticides in pest management. In O. Koul, G. S. Dhaliwal, S. Khokhar, & R. Singh (Eds.), *Biopesticides in environment and food security: Issuers and strategies* (pp. 265–285). Jodhpur: Scientific Publishers.

Belmain, S. R., & Stevenson, P. C. (2001). Ethnobotanicals in Ghana: reviving and modernising an age-old practise. *Pesticide Outlook, 6*, 233–238.

Belmain, S. R., Neal, G. E., Ray, D. E., & Golob, P. (2001). Insecticidal and vertebrate toxicity associated with enthobotanicals used as post-harvest protectants in Ghana. *Food and Chemical Toxicology, 39*, 287–291.

Belmain, S. R., Amoah, B. A., Nyirenda, S. P., Kamanula, J. F., & Stevenson, P. C. (2012). Highly variable insect control efficacy of *Tephrosia vogelii* chemotypes. *Journal of Agricultural and Food Chemistry, 60*, 10055–10063.

Bennett, B., Cooper, J., & Dobson, H. (2010). We know where the shoe pinches: a case study based analysis of the social benefits of pesticides. *Outlook on Agriculture, 39*, 79–87.

Berger, A. (1994). *Using natural pesticides: Current and future perspectives: a report for the Plant Protection Improvement Programme in Botswana, Zambia and Tanzania*. Swedish University of Agricultural Sciences. http://www.blackherbals.com/using_natural_pesticides.htm. Accessed 6 March 2014.

Bhushan, C., Bhardwaj, A., & Misra, S. S. (2013). *State of Pesticide Regulations in India*, Centre for Science and Environment, New Delhi. http://www.cseindia.org/userfiles/paper_pesticide.pdf. 18 February 2014.

Centre for Science and Environment (2011). *Pesticide Management Bill 2008*. Centre of Science and Environment, New Delhi. http://www.cseindia.org/userfiles/Factsheet-Pesticides.pdf. Accessed 6 March 2014.

Chandler, D., Bailey, A. S., Tatchell, G. M., Davidson, G., Greaves, J., & Gran, W. P. (2011). The development, regulation and use of biopesticides for integrated pest management. *Philosophical Transactions of the Royal Society, B: Biological Sciences, 366*, 1987–1998.

Chikukura, L., Mvumi, B. M., Chikonzo, R., & Chenzara, C. (2011). Evaluation of selected indigenous pesticidal plant powders against stored maize and cowpeas insect pests. *African Crop Science Conference Proceedings, 10*, 169–171.

Cobbinah, J. R., Moss, C., Golob, P., & Belmain, S. R. (1999). Conducting ethnobotanical surveys: an example from Ghana on plants used for the protection of stored cereals and pulses. *NRI Bulletin no. 77*, Chatham, Natural Resources Institute.

Cooper, J., & Dobson, H. (2007). The benefits of pesticides to mankind and the environment. *Crop Protection, 26*, 1337–1348.

Devlin, J. F., & Zettel, T. (1999). *Ecoagriculture: Initiatives in Eastern and Southern Africa*. Harare: Weaver Press.

EC (2010). *Thematic Strategy on Sustainable Use of Pesticides*, European Union, Brussels http://ec.europa.eu/environment/ppps/home.htm. Accessed 11 Nov 2012.

Eilenberg, J. (2006). Concepts and visions of biological control. In J. Eilenberg, H. M. T. Hokkanen (Eds.), *An ecological and societal approach to biological control*, (pp. 1–13). Springer Series: Progress in Biological Control.

FAO (2005). *International Code of Conduct on the Distribution and Use of Pesticides*. Food Agriculture Organisation of the United Nations Rome. http://www.fao.org/docrep/018/a0220e/a0220e00.pdf. Accessed 18 Feb 2014.

FAO (2012). FAOSTAT *Database on Pesticides trade.* Food Agriculture Organisation of the United Nations, Rome. http://faostat.fao.org/site/423/default.aspx. Accessed 18 Feb 2014.

Foerster, P., Varela, A., & Roth, J. (2001). *Best practices for the Introduction of Non-Synthetic Pesticides in Selected Cropping Systems: Experiences gained from selected crops in Developing Countries*, GTZ, Eschborn, 152 pp. http://www2.gtz.de/dokumente/bib/02-0007.pdf. Accessed 18 Feb 2014.

Gadzirayi, C. T., Mutandwa, E., Mwale, M., & Chindundu, T. (2009). Utilization of *Tephrosia vogelii* in controlling ticks in dairy cows by small-scale commercial farmers in Zimbabwe. *African Journal of Biotechnology, 8*, 4134–4136.

Government of Ghana (2004). *Pesticides Control and Management Act, 1996, ACT 528*. Government of the Republic of Ghana. http://www.lexadin.nl/wlg/legis/nofr/oeur/arch/gha/528.pdf. Accessed 18 Feb 2014.

Government of Kenya (2013). *The Pyrethrum Act, 2013, Special Issue*. Government of the Republic of Kenya Government Printer, Nairobi http://kenyalaw.org/kl/fileadmin/pdfdownloads/Acts/PyrethrumActNo22of2013.PDF. Accessed 18 Feb 2014.

Government of Tanzania (1997). *The Plant Protection Act No. 27. Vol. 78*, Government of the United Republic of Tanzania, Government Printer, Dar es Salaam http://www.ippc.int/file_uploaded/1285751010_Plant_Protection_Act,_1997.pdf. Accessed 18 Feb 2014.

Grange, N., & Ahmed, S. (1988). *Handbook of plants with pest control properties*. New York: John Wileys & Sons. 470 pp.

Grzywacz, D., Rossbach, A., Rauf, A., Russell, D. A., Srinivasan, R., & Shelton, A. M. (2010). Current control methods for diamondback moth and other brassica insect pests and the prospects for improved management with lepidopteran-resistant Bt vegetable brassicas in Asia and Africa. *Crop Protection, 29*, 68–79.

Guillon, M. (2004). *Current world situation on acceptance and marketing of biological control agents (BCAS)* International Biocontrol Manufacturers' Association. http://www.ibma-global.org/IBMA_Public_Positions/20041028_Presentation_BCAs_Thailand_Indonesia_Cuba.pdf. Accessed 18 Feb 2014.

Gupta, S., & Dikshit, A. K. (2010). Biopesticides: an eco-friendly approach for pest control. *Journal of Biopesticides, 3*, 186–188.

Isman, M. B. (2006). Botanical insecticides, deterrents, and repellents in modern agriculture and an increasingly regulated world. *Annual Review of Entomology, 51*, 45–66.

Isman, M. B. (2008). Perspective botanical insecticides: for richer, for poorer. *Pest Management Science, 64*, 8–11.

Jayasekera, T., Stevenson, P. C., Hall, D. R., & Belmain, S. R. (2005). Effect of volatile constituents from *Securidaca longepedunculata* on stored grain insect pests. *Journal of Chemical Ecology, 31*, 303–313.

Kamanula, J. F., Sileshi, G. W., Belmain, S. R., Sola, P., Mvumi, B. M., Nyirenda, G. K. C., et al. (2011). Farmers' insect pest management practices and pesticidal plant use in the protection of stored maize and beans in Southern Africa. *International Journal of Pest Management, 57*, 41–49.

Katsvanga, C. A. T., & Chigwaza, S. (2004). Effectiveness of natural herbs, fever tea (*Lippia javanica*) and Mexican marigold (*Tagetes minuta*) as substitutes to synthetic pesticides in controlling aphid species (*Brevicoryne brassica*) on cabbage (*Brassica capitata*). *Tropical and Subtropical Agroecosystems, 4*, 101–106.

Khater, H. F. (2012). Prospects of botanical biopesticides in insect pest management. *Journal of Applied Pharmaceutical Science, 2*, 244–259.

Koul, O., Singh, G., Singh, R., Singh, J., Daniewski, W. M., & Berlozecki, S. (2004). Bioefficacy and mode-of-action of some limonoids of salannin group from *Azadirachta indica* A. Juss and their role in a multicomponent system against lepidopteran larvae. *Journal of Biosciences, 29*, 409–416.

Kumar, S. (2012). Biopesticides: a need for food and environmental safety. Journal *of Biofertilisers and Biopesticides*, *3*, 1000e107.

Leng, P., Zhang, Z., Pan, G., & Zhao, M. (2011). Applications and development trends in biopesticides. *African Journal of Biotechnology, 10*, 19864–19873.

Madzimure, J., Nyahangare, E. T., Hamudikuwanda, H., Hove, T., Stevenson, P. C., & Belmain, S. R. (2011). Acaricidal efficacy against cattle ticks and acute oral toxicity of *Lippia javanica* (Burm F.). *Tropical Animal Health and Production, 43*, 481–489.

Madzimure, J., Nyahangare, E. T., Hamudikuwanda, H., Hove, T., Belmain, S. R., Stevenson, P. C., et al. (2013). Efficacy of *Strychnos spinosa* (Lam.) and *Solanum incanum* L. aqueous fruit extracts against cattle ticks. *Tropical Animal Health and Production, 45*, 1341–1347.

Mafongoya, P. L., & Kuntashula, E. (2005). Participatory evaluation of *Tephrosia* species and provenances for soil fertility improvement and other uses using farmer criteria in Eastern Zambia. *Experimental Agriculture, 41*, 69–80.

Mazid, S., Kalita, J., & Rajkhowa, R. (2011). A review on the use of biopesticides in insect pest management paper subtitle: biopesticides—a safe alternative to chemical control of pests. *International Journal of Science and Advanced Technology, 1*, 169–178.

McLaughlin Gormley King Company (2010). About *Pyrethrum*. McLaughlin Gormley King Company http://www.pyrethrum.com/About_Pyrethrum/Growing_Regions.aspx. Accessed 18 Feb 2014.

Mehrdad, E. (2004). Problems facing the flower industry. In: M. N. Wabule, P. N. Ngaruiya, F. M. Kimmins, P. J. Silverside (Eds.), *Registration for biocontrol agents in Kenya: Proceedings of the PCPB/KARI/DFID CPP workshop* (pp. 7–8). Nakuru, Kenya, 14–16 May 2003.

Menzler-Hokkanen, I. (2006). Socioeconomic significance of biological control. In J. Eilenberg & H. M. T. Hokkanen (Eds.), *An ecological and societal approach to biological control* (pp. 13–15). New York: Springer.

Minja, E. M., Shanower, T. G., Songa, J. M., Ongaro, J. M., Kawonga, W. T., Mviha, P. J., et al. (1999). Studies of pigeon pea insect pests and their management in Kenya, Malawi, Tanzania and Uganda. *African Crop Science Journal, 7*, 59–69.

Moyo, M., Nyakudya, I. W., Katsvanga, C. A. T., & Tafirei, R. (2006). Efficacy of the botanical pesticides, *Derris elliptica*, *Capsicum frutescens* and *Tagetes minuta* for the control of *Brevicoryne brassicae* in vegetables. *Journal of Sustainable Development in Africa, 8*, 216–222.

Mudimu, G. D., Chigume, S., & Chikanda, M. (1995). *Pesticide Use and Policies in Zimbabwe: Current Perspectives and Emerging Issues for Research*. Publication Series No. 2 Pesticide Policy Project Hannover. http://www.ifgb.uni-hannover.de/fileadmin/EUE_files/PPP_Publicat/Series/PPP02.pdf. Accessed 6 Mar 2014.

Murungi, L. K., Nyende, A., Wesonga, J., Masinde, P., & Knapp, M. (2010). Effect of African nightshade species (Solanaceae) on developmental time and life table parameters of *Tetranychus evansi* (Acari: Tetranychidae). *Experimental and Applied Acarology, 52*, 19–27.

Murungweni, C., Andersson, J. A., van Wijk, M. T., Gwitira, I., & Giller, K. E. (2012). *Zhombwe* (Neorautanenia brachypus (Harms) C.A.Sm.)—a recent discovery for mitigating effects of drought on livestock in semi-arid areas of Southern Africa. *Ethnobotany Research & Applications, 10*, 199–212.

Muzemu, S., Mvumi, B. M., Nyirenda, S. P. M., Sileshi, G. W., Sola, P., Kamanula, J. F., et al. (2012). Pesticidal effects of indigenous plants extracts against rape aphids and tomato red spider mites. *African Crop Science Conference Proceedings, 10*, 169–171.

Mvumi, B. M., Golob, P., Stathers T. E., & Giga, D. P. (2003) Insect population dynamics and grain damage in small-farm stores in Zimbabwe with particular reference to *Sitotroga cerealella* (Olivier) (Lepidoptera: Gelechiidae). In: P. F. Credland, D. M. Armitage, C. H. Bell, P. M. Cogan, & E. Highley (Eds.), *Advances in stored product protection. Proceedings of the 8th International Working Conference on Stored Product Protection*, York, UK. 22–26 July 2002, (pp. 151–168). Wallingford: CABI Publishing.

Mwale, M., Tangwara, R., Mapiye, C., Mupangwa, J. F., Madzinga, E., Mapurisa, C., et al. (2006). Awareness and adoption of *Tephrosia vogelii* and *Nasturtium trapaeolum* for the control of cattle parasites by the smallholder farmers in Upper Muzarabani District of Zimbabwe. *Journal of Sustainable Development in Africa, 8*, 198–202.

Natural Resources Institute (2010). *Final technical report: Southern African Pesticidal Plants (SAPP) Project. Caesalpinioid woodlands of Southern Africa: optimising the use of pesticidal plants*. www.nri.org/projects/sapp/docs/sapp_ftr.pdf. Accessed 18 Feb 2014.

Nyahangare, E. T., Hove, T., Mvumi, B. M., Hamudikuwanda, H., Belmain, S. R., Madzimure, J., et al. (2012). Acute mammalian toxicity of four pesticidal. *Journal of Medicinal Plant Research, 6*, 2674–2680.

Nyirenda, S. P., Sileshi, G. W., Belmain, S. R., Kamanula, J. F., Mvumi, B. M., Sola, P., et al. (2011). Farmers' ethno-ecological knowledge of vegetable pests and pesticidal plant use in Malawi and Zambia. *African Journal of Agricultural Research, 6*, 1525–1537.

O'Brien, K. P., Franjevic, S., &Jones, J. (2009). *Green chemistry and sustainable agriculture: The role of biopesticides.* Advancing Green Chemistry. http://advancinggreenchemistry.org/wp-content/uploads/Green-Chem-and-Sus.-Ag.-the-Role-of-Biopesticides.pdf. Accessed 18 Feb 2014.

Omiti, J., Waiyaki, N., Otieno, D., & Chele, A. (2007). *Policy and Institutional Interventions to Revitalize Kenya's Pyrethrum Industry*. Discussion Paper No. 68. Kenya Institute for Public Policy Research and Analysis (KIPPRA). http://www.kippra.or.ke/Resources/kippra-downloads.html. Accessed 18 Feb 2014.

Page, S. L. J. (1997). Natural pest management in Zimbabwe. *LEISA Magazine, 13*(4), 12–13. www.metafro.be/leisa/1997/13-4-12.pdf/base_view. Accessed 18 Feb 2014.

Parmar, B. S. (2010). Biopesticides: an indian overview. *Pesticide Research Journal, 22*, 93–110.

PCPB (2009). Product registration: Application forms, requirements and guidelines. http://www.pcpb.or.ke/index.php?option=com_content&task=view&id=40&Itemid=31. Accessed 18 Feb 2014.

Phillips, T. W., & Throne, J. E. (2010). Biorational approaches to managing stored-product insects. *Annual Review of Entomology, 55*, 375–397.

Rao, G. V. R., Rupela, O. P., Rao, V. R., & Reddy, Y. V. R. (2011). Role of biopesticides in crop protection: present status and future prospects. *Indian Journal of Plant Protection, 35*, 1–9.

Ray, D. E. (1991). Pesticides derived from plants and other organisms. In W. J. Hayes & E. R. Laws (Eds.), *Handbook of pesticide toxicology* (pp. 2–3). New York: Academic.

Rhoda, B., Freyer, B., & Macharia, J. (2006). *Towards reducing synthetic pesticide imports in favour of locally available botanicals in Kenya*: Conference on International Agricultural Research for Development, October 11–13, 2006, Tropentag, Bonn. http://www.tropentag.de/2006/abstracts/full/158.pdf. Accessed 6 March 2014.

Ricciardi, G., Ciccio, J. F., Ocampo, R., Lorenzo, D., Bandoni, A., & Dellacassa, E. (2009). Chemical variability of essential oils of *Lippia alba* (Miller) N. E. Brown growing in Costa Rica and Argentina. *Natural Product Communications, 4*, 853–858.

Sarasan, V., Kite, G. C., Sileshi, G. W., & Stevenson, P. C. (2011). The application of phytochemistry and in vitro tools to the sustainable utilisation of medicinal and pesticidal plants for income generation and poverty alleviation. *Plant Cell Reports, 30*, 1163–1172.

Schreinemachers, P., & Tipraqsa, P. (2012). Agricultural pesticides and land use intensification in high, middle and low income countries. *Food Policy, 37*, 616–626.

Shukla, R., & Shukla, A. (2012). Market potential for biopesticides: a green product for agricultural applications. *International Journal of Management Research and Review, 2*, 91–99.

Sinha, B., & Biswas, L. (2008). *Potential of Biopesticide in Indian Agriculture vis-a-vis Rural Development.* India, Science and Technology: 2008. NISTADS / CSIR http://www.nistads.res.in/indiasnt2008/t6rural/t6rur17.htm. Accessed 18 Feb 2014.

Siziba, S., & Mekuria, M. (2003). Farm Level Evaluation of the Impact of IPM on Pesticide Use: A Comparative Analysis of IPM and Non-IPM trained farmers in Zimbabwe's Smallholder Sector, Department of Agricultural Economics and Extension University of Zimbabwe, *Working Paper AEE1/2003.*

Stevenson, P. C., Jayasekera, T. K., Belmain, S. R., & Veitch, N. C. (2009). Bisdesmosidic saponins from *Securidaca longepedunculata* (Polygalaceae) with deterrent and toxic properties to Coleapteran storage pests. *Journal of Agricultural and Food Chemistry, 57*, 8860–8867.

Stevenson, P. C., Nyirenda, S. P. & Veitch, N. C. (2010) Highly glycosylated flavonoid glycosides from Bobgunnia madagascariensis. *Tetrahedron Letters, 51*, 4727–4730.

Stevenson, P. C., Nyirenda, S. P., Mvumi, B. M., Sola, P., Kamanula, J. F., Sileshi, G. W., et al. (2012a). Pesticidal plants: A viable alternative insect pest management approach for resource-poor farming in Africa. In O. Koul, G. S. Dhaliwal, S. Khokhar, & R. Singh (Eds.), *Botanicals in environment and food security* (pp. 212–238). Jodhpur: Scientific Publishers.

Stevenson, P.C., Nyirenda, S.P. and Veitch, N.C. (2010) Highly glycosylated flavonoid glycosides from Bobgunnia madagascariensis. Tetrahedron Letters, 51, 4727–4730.

Stevenson, P. C., Kite, G. C., Lewis, G. P., Forest, F., Nyirenda, S. P., Belmain, S. R., et al. (2012b). Distinct chemotypes of *Tephrosia vogelii* and implications for their use in pest control and soil enrichment. *Phytochemistry, 78*, 135–146.

Tata Strategic Management Group (2013). *Indian Agrochemicals Industry Imperatives of Growth Knowledge and Strategy Paper*, 3rd National Agrochemicals Conclave, 2013, FICCI, New Delhi http://www.tsmg.com/download/reports/Indian_Agrochemicals_Industry_2013.pdf. Accessed 18 Feb 2014.

UNEP. (2006). *Africa environment outlook 2; Our environment, our wealth*. Nairobi: Division of Early Warning and Assessment (DEWA), UNEP.

UNEP (2007). Chemical use in Africa. *Encyclopedia of Earth* April 13, 2007. http://www.eoearth.org/article/Chemical_use_in_Africa?topic=49513. Accessed 18 Feb 2014.

USAID (1994). Pesticides *and the Agrichemical Industry in Sub-Saharan Africa*. Bureau for Africa, Division of Food, Agriculture, and Resource Analysis. Environmental and Natural Resources Policy and Training Project. Winrock International Environmental Alliance Arlington, VA, 117 pp.

U.S. Environmental Protection Agency (2013). *What are Bio pesticides*? http://www.epa.gov/oppbppd1/biopesticides/whatarebiopesticides.htm. Accessed 18 Feb 2014.

Wandahwa, F., van Ranst, E., & van Damme, I. (1996). Pyrethrum (*Chrysanthemum cinerariaefolium* Vis.) cultivation in West Kenya: origin, ecological conditions and management. *Industrial Crops and Products, 5*, 307–322.

Wesseling, C., Ruepert, C., León, C., Monge, P., Hermosillo, H., & Partanen, T. J. (2001). Paraquat in developing countries. *Journal of Occupational and Environmental Health, 7*, 275–286.

World Bank (2005). *Summary of Kenya Value Chain Analysis*. Note Number 8, September 2005. World Bank Group, Africa Region, Private Sector Unit. 15. http://siteresources.worldbank.org/EXTAFRSUMAFTPS/Resources/note_8_screen.pdf Accessed 18 Feb 2014.

Zulu, D., Thokozani, B. L. K., Sileshi, G. W., Teklehaimanot, Z., Gondwe, D. S. B., Sarasan, V., et al. (2011). Propagation of the African medicinal and pesticidal plant, *Securidaca longependunculata. African Journal of Biotechnology, 10*, 5988–5992.

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