World Agroforestry Centre

UNIVERSITY of GREENWICH
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Handbook on pesticidal plants

Optimization of Pesticidal plants: Technology Innovation, Outreach & Networks (OPTIONs)

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ABBREVIATIONS

A.D.	Anno Domini – Year of the lord
ACP	African Caribbean, and Pacific Group of States
ADAPPT	African Dryland Alliance for Pesticidal Plant Technologies
B.C.	Before Christ
EC	European Commission
eRH	equilibrium Relative Humidity
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross Domestic Product
GRAS	Generally Regarded As Safe
ICIPE	International Centre of Insect Physiology and Ecology
ICRAF	World Agroforestry Centre
IFAD	International Fund for Agricultural Development
IUCN	International Union for Conservation of Nature and Natural Resources
L	Litre
mc	moisture content
NRI	National Research Institute
OPTIONs	Optimizing Pesticidal Plants: Technology, Innovation, Outreach and Networks
SE	Southeast
SOFA	State of Food and Agriculture
Spp.	Species
UN	United Nations
UNEP	United Nations Environment Programme
US$	United States Dollar
USA	United States of America
WFP	World Food Programme
WHO	World Health Organization
% w/w	percentage weight per weight
w/v	weight per volume
w/w	weight per weight

Language codes

Code	Language (Country)
Gus	Kisii
Kam	Kamba (Kenya)
Kik	Kikuyu (Kenya)
Kip	Kipsigis (Kenya)
Kis	Kisii
Luh	Luhya (Kenya)
Luo	Luo (Kenya)
Maa	Maasai (Kenya, Tanzania)
Ndebele	Ndebele (South Africa, Zimbabwe)
Shona	Shona (South Africa, Zimbabwe, Mozambique, Zambia)
Swa	Kiswahili (Kenya, Tanzania)

CHAPTER 1

Introduction

Food security and increased income are the primary goals of most poor farmers throughout sub-Saharan Africa where the majority of agriculture is carried out on smallholdings, often of less than 1 hectare. Farm size limits what farmers can produce, and this can be a great burden when most families' livelihoods depend on the amount of food they can produce. It has been estimated that for every 10% increase in farm yields, poverty was reduced by 7% in Africa (Irz *et al.,* 2001). According to the International Fund for Agricultural Development (IFAD) an increase of just 1% in agricultural per-capita Gross Domestic Product (GDP) would reduce the poverty gap five times more than a similar increase in GDP in any other sector, and would particularly target the poorest people. So helping smallholders to produce more food can alleviate poverty.

Among the many factors that affect food production in Africa are pests and diseases that can lead to total crop failure. Accessibility of synthetic pesticides for pest and disease control is limited for many farmers due to their cost, and restricted distribution networks. Products are frequently adulterated by unscrupulous traders, and inappropriate application can exacerbate pests and lead to pesticide resistance. Pesticidal plants are widely available at minimal or no cost to farmers, and have been used for centuries so are culturally relevant. Pesticidal plants are broadly safer to use and handle than synthetic pesticides (Rother, 2010), are environmentally benign, typically less harmful to beneficial insects (Amoabeng *et al*., 2013; Mkenda *et al*., 2015) and are difficult to adulterate.

However, many plants that are known to have pesticidal activity are not broadly utilized. While some pesticidal plants are abundant and include indigenous and weedy exotic species, others are less widely available, and their use can put species at risk of over-harvesting and have a negative impact on ecosystem biodiversity. Their use can be sustainable through concerted efforts to improve their propagation, harvesting and conservation; whilst increased use of pesticidal plants could contribute to increased agricultural productivity and sustainable livelihoods, as well as reduced environmental pressure. At present their priority in agricultural policy is minor since their commercial incentives are low and knowledge about their optimal use is limited. By building the capacities of farmers and local institutions on on-farm management strategies of pesticidal plant use, agricultural production could be increased resulting in improved food security and nutrition.

Farmers' knowledge and scientific evidence on pesticidal plants were transcribed during two workshops in 2013 and 2014 held at ICRAF's headquarters in Nairobi, Kenya. Farmers, technicians and scientists from southern and eastern Africa attended, sharing their knowledge and learning about best practices with regards to conservation, propagation and optimal use of pesticidal plants. (Anjarwalla *et al*., 2013, http://projects.nri.org/options).

This booklet summarizes the outcomes from these workshops, bringing together current understanding and knowledge on the use of pesticidal plants for post-harvest storage of grains and legumes, as well as their use in crop production, particularly for smallholder farmers in southern and eastern Africa, with detailed information on 18 pesticidal plant species common in the region (http://projects.nri.org/options/background/plants-database).

This publication can serve as a technical reference but can also be used to produce more targeted information briefs for farmers, nursery growers and to develop agricultural and conservation strategies.

What are pesticidal plants?

Pesticides are substances or mixtures of substances used to prevent, destroy, kill, control or mitigate pests. Pesticidal plants, sometimes referred to as botanical pesticides, are naturally occurring pesticides derived from plants. Pesticidal plants are our oldest form of pest control and take advantage of a plant's natural defences against herbivory developed over millions of years of evolution. Most plants produce chemicals that deter pests, often producing a mixture of compounds that repel and stop herbivores from feeding. In large enough quantities these compounds can even be toxic to the herbivore. Pesticidal plants have been used for millennia and were widely used in commercial agriculture up to the 1940s, when synthetic pesticides were developed. Overuse of synthetic pesticides led to problems such as environmental contamination, resistance development and health concerns that were not anticipated at the time of their introduction. Cancer, adverse effects on immune systems, neurodevelopment dysfunction, metabolic diseases such as diabetes, endocrine system disruption and infertility are some of the health risks associated with continuous exposure to synthetic pesticides (Gilden *et al*., 2010; Rahimi and Abdollahi, 2007).

WHO estimates that 200,000 people are killed worldwide every year as a direct result of pesticide poisoning (CAPE, 2009; Belmain *et al.*, 2013). Although in Africa synthetic pesticide consumption accounts for 2-4% of the global pesticide market of US$31 billion (Sola *et al*., 2014; Agrow, 2006), Africa continues to have the highest reported

human mortality risks related to misuse of pesticides (Williamson *et al*., 2008). According to UNEP, in sub-Saharan Africa, the potential cost of pesticide-related illnesses between 2005 and 2020 could reach US$90 billion (UNEP, 2011).

These problems with synthetic pesticides have led to more focused research and development of pesticidal plants. The use of pesticidal plants has been reported to be more environmentally benign and effective in the control of pests (Stevenson *et al.*, 2014; Mkenda *et al*., 2015). While the commercial success of pesticidal plants has fallen short of expectations, their scope for use in smallholder farming systems has considerable potential but remains under-exploited (Isman, 2006, 2008).

Economic importance of pesticidal plants

Farmers wishing to export their agricultural produce to Europe have to comply with the European Union's pesticide maximum residue limits, which is the amount that may legally remain on food sold in the EU. Meeting these residue limits while providing the quality products required has become a major challenge for African exporters, and pesticidal plants could assist as they are certified for organic production methods. At the smallholder farmer level, synthetic pesticides are costly and have limited distribution in rural areas. Synthetics are often adulterated by dilution, mixed incorrectly and sold beyond their expiry date (Stevenson *et al.*, 2012a).

Synthetics can also kill insects which may be predators of some pests, thus causing environmental imbalances in natural regulation that inadvertently lead to economic loss by exacerbating pest problems (Khater, 2012). Over time, and through misuse, pests can build resistance to synthetic pesticides (Belmain *et al*., 2013). This has resulted in the development of pesticide resistance among over 500 insect and mite species. It is also evident that repetitive use of synthetic pesticides has resulted in pesticide residue hazards, and this has had a negative impact on ecosystem service delivery of natural enemies, pollinators and other wildlife, as well as extensive persistent groundwater contamination (Khater, 2012).

Pesticidal plants can potentially surmount the problems resulting from use of synthetic pesticides. Pesticidal plants break down rapidly with negligible persistent ecological impacts and can thus provide environmentally-benign pest control. Their impacts on beneficial organisms and other non-target species is negligible compared to synthetic pesticides (Mkenda et al., 2015; Amoabeng et al., 2013; Charleston et al., 2006) and they are equally cost-effective when compared to the use of synthetic pesticides (Mkenda et al., 2015; Amoabeng et al., 2014). Additional benefits include soil-enhancing properties for some pesticidal plants such as *Tephrosia vogelii* (Mafongoyo and Kuntashula, 2005), and more species-specific pest control observed

with some other pesticidal plants such as *Tithonia diversifolia* (Rodriguez et al., 2015). When incorporated into integrated pest management programmes, pesticidal plants could decrease the need for synthetic pesticides while also being more easily used in combination with other pest management approaches such as biological control.

By cultivating and selling pesticidal plants, farmers could provide sustainable and environmentally-benign pest management control and boost their income. Most African countries rely on imported synthetic pesticides and generally are only involved in re-packaging, marketing and distribution of synthetic pesticides (Sola *et al*., 2014). This over-reliance on importation of pest management products could be corrected by developing local value chains to sell locally produced pest control derived from pesticidal plants, thus creating jobs, innovative new pest control products for farmers and independence from imported synthetic pesticide products. Considering that many African governments actually subsidize the use of imported synthetic pesticides, these subsidies could perhaps be redirected towards the development of local enterprise that improves pest management through use of pesticidal plants.

Using pesticidal plants could, therefore, increase business opportunities and food security and nutrition, reduce problems with health and safety and open up African exports of organic produce to the EU.

Pesticidal plants: An overview of traditional knowledge, examples and use

History and indigenous knowledge of pesticidal plants

When stored grains from Oriental (3000-30 B.C.), Greek (2000-200 B.C.) and Roman antiquity (500 B.C.-76 A.D.) were analysed, they showed that many plants, for example, *Cymbopogon* spp., were commonly used to protect stored food against insect damage in ancient times. Indeed, the same plant species are still used today in traditional farming systems. The most widely used botanical insecticide in the world is pyrethrum, extracted from the chrysanthemum flower, *Tanacetum cinerariaefolium*. Pyrethrum production has become increasingly globalized; however, East Africa continues to be an important region where many farmers grow it as a cash crop (Khater, 2012). Pesticidal plant compounds such as rotenoids from *Derris* spp., *Tephrosia* spp. and *Lonchocarpus* spp. have been produced as organic pesticides and used in agriculture and horticulture worldwide, with some products still registered in some countries, for example ‘Biocawach’ in India (Isman, 2014). The neem tree, *Azadirachta indica* is a popular pesticidal plant used in South Asia and parts of Africa. Other trees species related to neem such as the chinaberry tree, *Melia*

azedarach, have been developed into commercial products in China and Southeast Asia. Essential oils, which are complex mixtures of volatile organic compounds often found in many herbs and spices, also have pesticidal potential and have been commercialized in North America (Isman, 2000).

During a survey conducted among 168 vegetable farmers in northern Malawi and 91 farmers in eastern Zambia, 70% of these farmers were aware of pesticidal plants, with *Tephrosia vogelii, Tithonia diversifolia, Azadirachta indica, Vernonia amygdalina* and *Euphorbia tirucalli* being the most frequently used for control of pests in vegetable crops (Kamanula *et al*., 2011; Nyirenda *et al*., 2011). During workshops conducted by the World Agroforestry Centre in 2013 and 2014, participants from across southeastern Africa (farmers, extension agents and scientists) reported a more diverse group of botanical pesticides species as indicated in table 1. This information consists of species, parts used, preparation and application, effectiveness and availability.

Since many plant species are only found in certain kinds of habitats or are possibly rare in south and east Africa, other recognized pesticidal plant species were discussed. These include *Aloe ferox, Bobgunnia madagascarensis, Dilichos kilimandscharicus, Lippia javanica, Neorautanenia mitis, Solanum incanum, Securidaca longepedunculata, Strychnos spinosa, Cymbopogon citratus, Zanha africana, Zanthozylum holzianum and Dysphania* (syn*. Chenopodium*) *ambrosioides.* Not all participants were familiar with these species.

Table 1: Indigenous knowledge on pesticidal plants reported by participants from southern and eastern Africa at ICRAF workshops held in 2013 and 2014.

Scientific name of pesticidal plant	Common names of pesticidal plant	Target Pests	Plant part used	Preparation	Effectiveness – as reported by workshop participants	Source	Limitation
Aloe secundiflora	(English): Aloe, (Kichagga): Isale la njofu, (Kamba): kiluma, (Samburu): sukuroi	Newcastle in chicken	Sap	Cold infusion	Very effective	Wild/farm	Limited availability
Azadirachta indica	(English): Neem, (Swa): Mwarubaini	Cockroaches, weevils, aphids, termites	Seeds, leaves and bark	Seeds dried and crushed, crushed leaves extract	Good	Wild	Poor knowledge, limited availability
Bidens pilosa	(English): Black jack	Aphids	Leaves	Dry, grind and burn. Ash used or mixed in solution to spray on crops	Very effective	Wild/farm	Invasive, affects skin
Capsicum annuum L.	(English): Hot pepper	Thrips, aphids and white flies	Fruit	Dry and grind fruits. Use as a powder or mix with water and soap and apply to crops	Moderate	Cultivated on farm	Efficacy not long lasting, limited knowledge
Carica papaya	(English): Pawpaw	Several	Leaves, seeds	Pound leaves, mix with water overnight. Sieve. Spray on crops.	Effective	Farm	
Commiphora holtiziana	(English): commiphora (Somali): Haggar	Ticks, skin diseases	Bark resin	Mixed with milk, boiled and smeared	Effective	Wild	Limited availability
Cordia latifolia	(English): Latifolia, (Pakistan): Sebestan plum or fruit,	Maize weevil, butterfly	Leaves	Dry plant leaves placed on grains	Very effective	Wild	Toxic

Scientific name of pesticidal plant	Common names of pesticidal plant	Target Pests	Plant part used	Preparation	Effectiveness – as reported by workshop participants	Source	Limitation
Desmodium spp	(English): tick-trefoil, tick clover, hitch hikers or beggar lice., (Kikuyu): Desmodia	Stalk borer	Whole plant	Intercropping	Effective	Wild	Limited knowledge
Lantana camara	(English): Sleeper weed, lantana, wild sage, West Indian Lantana or LAVA, (Kiembu): Musimoro	Weevil, tuber moth	Leaves	Dry plant leaves placed on grains	Very effective	Wild/farm	Toxic
Melia volkensii	(English): Melia, (Somali): baba, boba, (Kamba, Embu): Mukau, (Boran): Bamba, (Taita): Mukowe	Termites	Fruit pulp	Mixed with water	Medium	Wild	Limited availability
Mondia whitei	(English): White's ginger, tonic root, mundondo, mudondo, (Malawi:) Gondolosi, (Luyha): Mkombela	Cut worms	Leaves	Warm water concoction used	Medium	Cultivated	Other uses
Ocimum kilimandscharicum	(English): Sacred Basil, Holy Basi, (Malayalam): Trittavu, (Marathi): Tulshi	Mosquito, fleas	Leaves, flower	Smashing, sweeping with twigs, planted near the house, burning	Medium	Wild	Limited availability, limited knowledge
Psidia punctulata	(North Zanzibar): Mpepe, Kipepe, (Maasai): Olaboi,	Lice, fleas, mites	Leaves	Infusion	Effective	Wild	
Tanacetum cinerariifolium	(English): Pyrethrum	Many pests	Flowers, seeds	Dry flowers and seeds and grind to a powder. Mix with water	Effective	Farm	
Senna didymobotrya	(English): Popcorn Senna, (Kikuyu): Mwino, (Kamba): Inyumganai, (Kipsigis): Senetwet	Nematodes	Leaves	Crushed and soaked in water	Medium	Wild	Limited availability

Scientific name of pesticidal plant	Common names of pesticidal plant	Target Pests	Plant part used	Preparation	Effectiveness – as reported by workshop participants	Source	Limitation
Symplytum spp.	Consoude	Aphids	Leaves, roots	Grind leaves, mix with water and spray. Whole plant intercropped with crops.	Leaves effective. Roots moderately effective	Wild	Limited availability
Tagetes minuta	(English): Mexican marigold, stinkweed, Khaki weed, (Maa): Ol' bangi, (Kikuyu): Mubangi, (Kamba): Muvangi/ kivangi, (Luo): Nyanjaga, (Luhya): Etakanyie, (Embu): Muvangi	Aphids, lice, fleas, ants, white flies	Whole plant, leaves, stem	Planted along the plot as repellent, ground and mixed with water, dry plant placed on grains	Very effective	Wild/farm	Seasonal, limited knowledge
Teclea nobilis	(English): small fruited Teclea, (Amharic): atesa, (Luganda): mubio, (Shona): Mumbanziti, Ruwanziri, (Kikuyu): Munderendu, (Meru): Muteratu	Vegetable and fruit insects	Leaves	Leaves mixed with ash and water	Very effective	Wild	Limited availability
Tithonia diversifolia	(English): Mexican sunflower, Tithonia, tree marigold, (Kisii): Amaua maroro, (Kikuyu): Maruru, (Kamba): Ilaa, (Luo): Maua makech, akech, maua madungo, (Luhya): Maua, (Embu): Kirurite	Aphids, weevils, white flies	Leaves, seeds	Cold infusion	Effective	Wild/farm	Seasonal, poor knowledge

Other pesticidal plant species are known to be present and used in South and East Africa (see Chapter 3)

Table 2: Some examples of common pesticidal plants used worldwide

Pesticidal plants used globally	Source	Action
Citrus oil (limonene, linalool)	This is extracted from citrus peel and used mostly as flea dips.	When combined with soaps, they are used as contact poisons against aphids and mites.
Neem	This is derived from the neem tree.	It is effective against several insects, mites and nematodes, including cutworms, armyworms, sodworms.
Nicotine	This is derived from tobacco and is commonly sold as a 40% nicotine sulphate concentrate.	It is very poisonous if inhaled and should not be sprayed within seven days of harvest. It is a fast acting contact killer for soft bodied insects and acts on aphids, thrips and caterpillars.
Pyrethrins (Pyrethrum)	This is a fast acting contact poison extracted from the pyrethrum daisy and is very toxic to cold blooded animals.	It is effective on most insects, including pickleworms, aphids, leafhoppers, spider mites, harlequin bugs, cabbage worms.
Rotenone	This is derived from over 68 plant species, including *Tephrosia spp*. and is very toxic to fish and other animals if inhaled (Ott, 2006). Several related and similarly active compounds also co-occur with it in some species e.g., Tephrosin and Deguelin (Stevenson *et al*., 2012).	It is a broad spectrum poison, mainly used to control leaf-eating caterpillars and beetles, spittlebugs, aphids, harlequin bugs, chinch bugs, spider mite and carpenter ants. It is toxic when inhaled and may cause skin and mucous membrane irritation.
Ryania	This is derived from *Ryania speciosa*, a native plant of tropical America.	It is a slow acting stomach poison which is used to control codling moths, Japanese beetles, squash bugs, potato aphids, onion thrips, corn earworms and silkworms. This is no longer commonly used.
Sabadilla	This is extracted from seeds of South American lilies.	It is a broad spectrum contact poison and also has some activity as a stomach poison. It is effective against grasshoppers, codling moths, moths, armyworms, aphids, cabbage loopers, blister beetles, squash bugs and harlequin bugs. It is very toxic to honey bees but least toxic to humans. This is not commonly used anymore.

Extracted from (Isman, 2006 and 2008)

Harvesting, processing and use of pesticidal plants

Farmers use pesticidal plants in various ways and in various amounts for different crops, pre- and post-harvest. For example, for any given pesticidal plant species farmers may report they use whole or different parts of fresh plants; whole or parts of dried powdered plant; cold/hot water extracts poured over, sprinkled or used as dip or placing pesticidal plant material and crops in layers. The amounts used of fresh or dry material can vary, and sometimes, one or more pesticidal plant species are extracted and used together. Although there may be good reasons why farmers do things in different ways, there are also good reasons to try to standardize and optimize the way pesticidal plant species are processed and applied.

Standard methods can increase reliability and predictability of pest control, as well as help disseminate knowledge on pesticidal plant use more widely. For example, understanding the chemistry of pesticidal plants and identifying the active ingredients can reveal if the compounds will be easily extracted in water. Some compounds will not easily dissolve in water, and the addition of soap during extraction can help get these more 'fatty' compounds to extract, leading to increased efficacy in pest control. Soap also acts as a surfactant, spreading the extract on the target surface with more coverage (Belmain *et al,* 2012). Detailed methods of pesticidal plant processing are discussed in Chapter 4.

Safety, toxicity and application

Although the toxicity level of pesticidal plants is not as high as synthetic pesticides, pesticidal plants still contain toxic compounds. Thus, care and safety measures should be applied by both users and consumers. For several plants, the active ingredients are well known, with strong evidence of relatively low toxicity of plant compounds such as rotenoids, azadirachtin and pyrethrum (El-Wakeil, 2013; Raguraman and Kannan, 2014; Gaskins, 1972; Walker *et al*., 2005; Ott 2006). Risks of toxicity are further mitigated in that the amount of active ingredients naturally found in parts of plants is often very low and certainly not present in the artificially concentrated amounts found in synthetic pesticides. Many of the compounds in pesticidal plants are found in food and medicines, notably herbs and spices from which essential oil pesticides are made, where the USA has categorized them as GRAS (generally regarded as safe) and not subject to toxicity testing requirements. It is nevertheless essential to remember that plants contain toxins and to use appropriate safety measures such as gloves, face masks, protective clothing and exercise caution particularly when processing plants, e.g. grinding, sieving plant powders and applying them to crops, e.g. spraying, admixing. Users should avoid inhaling powders or contact with skin and eyes. In case of accidental contact, the

affected area should be washed with clean running water.

Sustainable conservation and cultivation through propagation and cultivation

Many plant species have been recognized by farmers as having pesticidal properties, using leaves, fruits, seeds, bark, roots and flowers. Most pesticidal plants are collected from the wild and over-harvesting can lead to biodiversity loss. Weedy and invasive species are perhaps at no risk of over-collection. However, collecting some plant parts such as roots or bark from slow growing indigenous trees and shrubs can be particularly detrimental, thus weakening or killing the plant. In many cases unsustainable collection methods have already made some plant species difficult to find in the wild. Often, the same plant species are collected to make traditional medicines, therefore, training guidelines have been produced on how to sustainably collect wild plants, and we recommend that users of pesticidal plants follow these guidelines (Khumalo *et al*., 2006). Furthermore, the sustained availability of pesticidal plants may be maintained if they are managed, domesticated, conserved and used efficiently, thus helping to meet the needs of the present and future generations. Some species such as *Tephrosia vogelii* and *Tagetes minuta* are already cultivated and intercropped to take advantage of soil improvement properties or repellent properties. Many others can be easily grown, and even more difficult species can usually be propagated with the right knowledge provided. Chapter 3 provides a guide on distribution, uses, parts used and propagation of some selected pesticidal plants.

Herbarium specimen collection

It is important to correctly identify the plants to be used. Often, many species look similar, and there may be varietal differences that are not easy to tell apart. This can lead to recommending the wrong species, which does not have the pesticidal chemicals found in a closely related species. It is, therefore, important that plant specimens are collected and verified by experts. This is done by collecting herbarium voucher specimens and depositing these in a verified herbarium. Errors in identification can lead to serious problems of misuse of plant materials (Stevenson *et al.,* 2012).

Invasive species

Care should be taken about the spread of invasive species. Many weedy pesticidal plant species are found along roadsides and degraded land. In these cases, it is not usually necessary to propagate and cultivate them because they are already

abundantly available in nearby habitats. Collecting them for use as pesticides may actually be beneficial in helping to control their spread. However, care should be taken not to actively propagate invasive species and extensionists should check whether the species they promote are potentially dangerous to biodiversity (http://keys.lucidcentral.org/keys/v3/eafrinet/plants.htm).

Potential for marketing and up scaling

Demand for botanicals is set to grow due to increases in organic farming, consumers demanding safe food and environmentalists lobbying for eco-friendly pesticides. Unfortunately pesticidal plant products are not always readily available in the right forms for small scale farmers nor are there any ready-to-use products (Anjarwalla, 2015). This challenge in itself is an opportunity for small scale farmers to increase access and raise the profile of plant pesticides by engaging in low cost processing and marketing of such products. Thus, as the demand for organic products grow the potential for marketing and trading in plant pesticide products will also grow.

However, selling most pesticidal plant products is currently beset with some challenges which include: lack of data on efficacy, safety, toxicity, persistence, shelf life and safety, inconsistent performance of crude extracts and inherent differences in plant chemistries, unreliable and or unknown raw material supply, as well as lack of standardization and documented application protocols (Sola *et al*., 2014; Anjarwalla, 2015). Legislation in all countries requires that all pesticides including botanicals have to be registered, a process that requires detailed data. This remains a major constraint to promotion and marketing. However, successes in some countries like India, Kenya and Tanzania where specific procedures have been developed for biopesticide registration has led to remarkable successes in this regard (Sola *et al*., 2014).

Nevertheless, there are already a number of pesticidal plants that have been adequately researched (neem, pyrethrum, tephrosia) presenting opportunities for marketing and up scaling. For this to happen there is need to invest in local production and distribution; development of low cost technologies and value chain development where small scale farmers can play a critical role (Sola *et al*., 2014; Anjarwalla, 2015).

CHAPTER 2

Distribution of pesticidal plant species

Table 3: Distribution of pesticidal plant species, with particular reference to southern and eastern Africa

Species	Distribution and habitat
Aloe ferox	*A. ferox* is indigenous to South Africa and Lesotho, growing in the semi-arid open plains to rocky mountain slopes. In Kenya it is commonly cultivated in Nairobi gardens and its environs. It is distributed throughout the tropics and sub-tropics where it grows as an ornamental or medicinal plant. It grows in a wide range of climatic conditions, and is especially abundant on arid, rocky hillsides up to 1000m altitude, where mean temperature ranges from 27-31°C and annual rainfall is 50-300mm.
Azadirachta indica	Native to the Indian subcontinent, it is found in southeast Asia, sub-Saharan Africa, Fiji, Mauritius and parts of Central America. It grows in semi-arid to semi-humid climates and in regions with less than 500mm of annual rain, with modest soil requirements. In Kenya, it is found along the coastal regions.
Bobgunnia madagascariensis	It is found in semi-arid tropical Africa, from Senegal and Zambia to Central African Republic and below the rainforest belt from Democratic Republic of Congo to Tanzania, Namibia, Botswana and Mozambique. It is not found in Madagascar. It grows at altitudes of 150-1750m, in sandy or clay-loam soils in valleys and humid plains, and in open deciduous woodlands and grasslands.
Cissus quadrangularis	It is found in a variety of lowland rainfall habitats, throughout tropical Africa from sea level up to 2000m altitude. It is common in Arabia, India, Sri Lanka, Thailand, Vietnam, Indonesia and Philippines.
Dysphania (syn. Chenopodium) ambrosioides	It is found throughout the tropical and sub-tropical regions of the world, but mostly polymorphic in South America. It is found in a variety of disturbed habitats, gardens, cultivated fields, waste ground but most often on sand by rivers. Preferred altitude ranges between 550-1620m. It is exotic in Africa, and in Kenya it can be found in Tsavo East National Park, in Nyeri, Limuru, Thika, Machakos and Laikipia.

Euphorbia tirucalli	*E. tirucalli,* indigenous to tropical Africa, is the most widespread of all the *Euphorbia* species. It is found in Angola, Eritrea, Ethiopia, Kenya, Malawi, Mauritius, Rwanda, Senegal, Sudan, Tanzania, Uganda, Zambia, Mozambique, Zimbabwe, South Africa and Zanzibar, and can survive in a wide range of habitats. It can grow in tropical arid areas with low rainfall, on poor eroded soils, saline soils and high altitudes of up to 2000m, but cannot survive frost. It grows wild, often in abandoned sites of homesteads. In Kenya for instance, it is found in Ruaka on the northern bypass to Thika and in Jilore Forest Station in Kilifi, in Baringo, Sigor, Makueni and Kitui.
Lantana camara	*L. camara* is naturalized in many countries in the Asia-Pacific region, Australia, New Zealand, Central and South America, West Indies and Africa.
Lippia javanica	*Lippia javanica* is a woody shrub found throughout eastern and southern Africa, usually along forest fringes, grasslands on hillsides and banks of streams. In Tanzania, it can be found in Musoma district, Serengeti, Seronera-Soit Ayai, Arusha district, little Meru, Mt. Kisimiri, Ngurudoto area, Arusha National Park, Momela, Lushoto district, and Kwai Valley. In Kenya, it can be found in Cherangani Hills, Kiambu district, Narok district and along the Naivasha-Narok highway. In southern Africa, *Lippia javanica* is found from Eastern Cape through to Botswana, Swaziland, Mozambique and Malawi. The species is drought resistant and can grow in a variety of soil types.
Melia volkensii	*M. volkensii* can be found in altitudes of 350-1680m and where rainfall is 300-800mm. It is common in association with acacia-commiphora vegetation, in bushlands, sometimes along watercourses and on rock outcrops.
Securidaca longepedunculata	*Securidaca longepedunculata* grows in varying climatic conditions, from hot arid to humid climates and in a broad vegetation range, from semi-arid to dense forest. It is common in sub-Saharan Africa in savanna and Sahel environments. In Kenya, it can be found in Makueni and Kwale.
Solanum incanum	*Solanum incanum* is indigenous to Kenya and is normally abundant, around houses, in overgrazed grassland and along roadsides. It is also found along forest edges and in bushland and grassland, from sea-level to an altitude of 2500m. It is considered an indicator for low-fertility soils.

Strychnos spinosa	*S. spinosa* occurs in savanna forests all over tropical Africa and grows in open woodland and riverine fringes. It is native to Ethiopia, Kenya, Madagascar, Mali, Mauritius, Seychelles, Sudan, Tanzania, Uganda, Zambia, and exotic to South Africa and the United States of America. The tree can be found growing singly in well-drained soils. The tree can be found in bushveld, riverine fringes, sand forest and coastal bush from the Eastern Cape, to Kwazulu-Natal, Mozambique and inland to Swaziland, Zimbabwe, northern Botswana and northern Namibia, and north to tropical Africa. This tree prefers sandy soils and grows fast in rocky areas. It also prefers full sun and requires a moderate amount of water.
Tagetes minuta	It is an invasive weed on farms and grows well in disturbed areas and cultivated beds. Originally from South America, it is now an exotic, widespread weed in Africa, southern Europe, south Asia and Australia. In Kenya it can be found in Nairobi, Taita Hills, Voi-Nairobi road, Kaimosi, Maasai Mara, Kiambu, Nyeri, Embu and Machakos.
Tanacetum cinerariifolium	Pyrethrum was cultivated in Croatia from the end of the 19th century to the 1930s when it started decreasing. It was introduced to Kenya in 1928, near Nakuru (Chandler, 1948). It also grows in north western Australia, Tanzania, Rwanda, Ecuador, France and Chile.
Tephrosia vogelii	Tephrosia vogelii is indigenous to tropical Africa. It is found in widely varying habitats, including savanna-like vegetation, grasslands, forest margins, on farms and shrub lands, waste lands and fallow fields. It occurs in climates with annual rainfall of 850-2650mm and annual mean temperature of 12.5-26.2°C, and is found up to altitudes of 2100m. It is encountered most abundantly where cultivated.
Tithonia diversifolia	It is a common shrub on field boundaries, grasslands and disturbed lands in East Africa. Initially introduced into Kenya, where it is exotic, from Central America as an ornamental plant, it is now found in Western and Central provinces, in the coastal region and parts of the Rift Valley. It grows in regions of 550-1950m altitude, with mean annual temperatures of 15-31°C and mean annual rainfall of 100-2000mm.

Vernonia amygdalina	*V. amygdalina* occurs naturally along rivers and lakes, in forest margins, woodlands and grasslands up to 2800m altitude, with a mean annual rainfall of 750-2000mm. It requires full sunlight and prefers humid environments. It grows on all soil types but prefers humus-rich soils. Indigenous to Kenya, it is found in western Kenya around Lake Victoria. It is also found at Kona National Reserve in Tana River district (420m), in the eastern side of Mbololo forest in Taita (1400m), in Narok (2100m), in the Nguruman escarpment (900m) and Ol Donyo Orok (1400m).
Zanha africana	*Z. Africana* is found in open woodlands, on granite ridges and sometimes in riverine forests, at 600-1550m altitude, in Kenya, Angola, Mozambique, South Africa, Zimbabwe, Tanzania and the Democratic Republic of Congo. In Kenya it occurs in open woodlands and farms, and in wooded grasslands in Kiangombe, Makueni and Katumani.

Photos of these species can be found in Chapter 3

CHAPTER 3

Botanical description of species

Table 4: Botanical description of species: flowering and fruiting habits/growth and development

Species	Flowering and fruiting habits
Aloe ferox	Single-stemmed plant, up to 2-5m tall with dense crown of green to red-brown succulent leaves up to 1m long, with brown spines. Stem is covered with persistent dried leaves. Flowers are bisexual, about 10 cylindrical racemes on a branched panicle, long with dark orange stamens protruding from the mouth. Some forms can have red, yellow or white flowers. Fruit is an ovoid capsule up to 3cm long, many seeded. Seeds are 9mm long and broadly winged. In South Africa, flowers are seen in winter. Pollination is by birds and bees. It is self-incompatible.
Azadirachta indica	Small to medium tree, usually evergreen, up to 30m tall, with a round large crown up to 20m in diameter, with branches spreading; bole branches up to 7.5m x 90cm. Bark is moderately thick with scattered tubercles, deeply fissured and flaking in old trees. Leaves alternate, crowded near branch end, simply pinnate, 20-40cm long, exstipulate, light green with two pairs of glands at the base. Leaflets 8-19, short petioled, alternate proximally, ovate to lanceolate, glossy, up to 10 x 4cm. Inflorescence an axillary, many flowered, up to 30cm long, flowers bisexual, five petals, white or yellowish, sweet scented. Fruit, 1-2 seeded drupe, 1-2cm long, greenish to purple when ripe. Seed ovoid, with shell and kernel(s). Flowering and fruiting seasons dependent on habitats. Fruits ripen in 12 weeks from anthesis. Seed eaten by bats and birds which distribute seeds. The tree can live for up to 200 years.

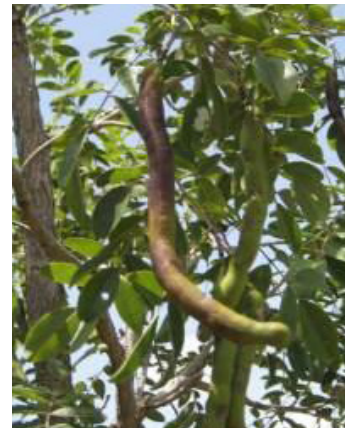
Bobgunnia madagascariensis	Semi-deciduous small tree, with height of up to 15m, multi-stemmed, with one bole up to 60cm in diameter. The grey bark surface is ridged, flaking off, with a yellowish white inner bark, with crimson black mucilage. The crown is dense and rounded. Leaves alternate, rounded at both ends, compound with (3-)5-9(-13) leaflets, petiole 2-4cm long. Terminal or axillary inflorescence, raceme up to 8cm long, with 2-14 flowers which are bisexual, zygomorphic, sweet scented, white with grey margin and yellow at base, numerous yellow stamens, and ovary superior. The fruit is a brown woody long pod up to 30cm, with 10-15 seeds which are flat oblong. Epigeal germination of seedling. Flowering occurs with new leaves in South Africa in September-November, in Ghana around April-May and in Cameroon in February-April. Seeds are released from fruits and fall to the ground.
Cissus quadrangularis	Succulent climbing herb with tendrils. Stems 4-angled with wings at the angles. Leaves fleshy, very broadly ovate, variously 3-lobed; margin dentate. Inflorescences axillary, few-flowered. Fruit, a rounded fleshy berry, red when ripe. It flowers during the rainy season and sheds leaves during the dry season.
Dysphania (syn. Chenopodium) ambrosioides	It is a hermaphrodic herb, up to 180cm tall, upright, green and branched, usually annual. The leaves are mostly lanceolate, up to 4 x 1cm and toothed. Flowers are small, green, in an elongate, dense, terminal structure. Fruits are green or brown with a strong odour and a pungent and bitter taste. Seed coat is reddish brown to black.
Euphorbia tirucalli	It is a deciduous shrub or small tree up to 12m tall with brittle, succulent branches up to 7mm thick, green with a whitish latex. Leaves are few, fleshy and linear-lanceolate, present at tip of branchlets. Cymes 2-6, congested at apices of branchlets, forking 2-4 times producing cluster of cyathia which develop into male and sometimes female flowers.
Lantana camara	It is a short vigorous shrub growing up to 2-4m in height. Leaves are ovate, 2-10cm long, 2-6cm wide, alternate, bright green, rough, hairy. The stem in cultivated species is non-thorny and in weedy varieties, with prickles. Lantana can climb to 15m with support. Flower heads contain 20-40 flowers, usually 2.5 cm across, colours vary between white, orange, pink purple and red. Fruit is greenish blue-black, 5-7mm in diameter, shiny with 2 nutlets.

Lippia javanica	*Lippia javanica* is a 1-2m high woody shrub that stands erect and is multi-stemmed. The stems are heavily branched and appear square when observed in a cross section. The leaves are elliptical, 3-4cm in length with sunken veins. When crushed they give off a lemon-like odour. The leaf margins are dentate, lightly toothed and hairy on both sides. The flowers are creamy white, clustered together in a dense round spike at the apex of the stem. Flowers are creamy white, densely clustered together, in round spikes. Flowers are inflorescence 1-3 per axils, globose to hemispherical or oblong to ovoid, 0.5-2cm. Bracts 3 x 2mm, broadly ovate; calyx 2-lobed, 2mm long; tube 3-4mm long, puberulous and glandular above corolla tube 4mm long.
Melia volkensii	It is a deciduous tree that grows up to 20m tall and 25cm wide, open crowned and laxly branched. Its bark is grey, fairly smooth and furrowing as it ages. Leaves are light green, bipinnate, 3-7 per pinna, up to 35cm long, and hairy when young. Leaflets are oval to lanceolate, tapering to apex with entire or serrated margins, up to 7.5cm long. Flowers are small, white fragrant and in loose sprays, andromonoecious, with 4-5 petals and stamens are united into a tube. Inflorescence congested up to 12cm long, axillary. Fruit is oval green to grey, usually 4cm long with a thick, bony endocarp.
Securidaca longepedunculata	It is a small tree measuring up to 6m in height, sometimes spiny and pale grey, smooth bark. Stems are initially pubescent, then glaborous. Leaves vary in size and shape, alternate, commonly in clusters. Flowers are sweetly scented, purple pink, about 1cm in length and in bunches, borne on a long slim stalk. Fruit is a round nut bearing a membranous wing about 4cm long, purple when young, and beige when mature. Flowers are produced in March-April in Kenya. When in flower, it attracts birds, butterflies and other insects. Fruits appear in May in Kenya and hang on trees for many months.
Solanum incanum	It is a soft shrub up to 1.8m tall. Leaves are alternate, ovate with wavy margins with green grey upper surface and green white lower surface. Flowers are pale to deep blue to purple. Fruits are mottled green and yellow when ripe. In Kenya, flowering occurs from November to March.
Strychnos spinosa	It is a small to medium-sized, spiny deciduous tree with green leaves turning yellow in autumn, with a flat, irregular, heavily branched canopy. Leaves are simple, opposite, elliptic-ovate up to 9 x 7.5cm, margin entire, petiole 2-10mm long. Flowers are creamy-green, up to 6mm long, in compact heads, and terminal on short lateral twigs. Fruits are round, woody-shelled, 5-12cm wide, yellow to brown when mature; containing many tightly packed flat seeds with fleshy, edible covering.

Tagetes minuta	It is a strongly scented annual herb with stiff erect stems up to 2m tall. Leaves stalked, opposite, light green, up to 15cm long, pinnately dissected into 4-6 pairs of pinnae. Leaflets lanceolate, margins finely serrated. Oil glands under leaves and on stems and involucres bracts. Inflorescences terminal with several tube-like capitula of dull yellow florets. Fruits, black achenes, narrowly ellipsoid and hard seeds, 6-7mm long.
Tanacetum cinerariifolium	Pyrethrum is a perennial herb, 30-100cm high, with branched shoots terminating into white, daisy-like flower heads, densely arranged. Fruits are pale brown, round with 5-7 ridges, glabrous, with pyrethrum active ingredient born in the tiny oil glands of the achenes.
Tephrosia vogelii	It is a soft, woody branching small tree or shrub with a dense foliage, up to 4m tall. Stems and branches tomentose, hairy. Leaves are arranged spirally, imparipinnate, stupules up to 22 x 3.5mm, rachis up to 25cm long. Leaflets in 5-14 pairs, narrowly elliptical, up to 7 x 2cm. Base acute to obtuse, apex rounded to emarginated. Inflorescence a terminal or axillary pseudo-raceme, 8-26cm long. Basal bract leaf-like. Flower 18-26mm long, white-purple-blue, fragrant, pedicel up to 23mm long. The pods are linear, slightly turgid, up to 14 x 1.8cm, brown or green, woolly to sericeous and 6-18 seeded. Seeds are dark brown to black, ellipsoid to kidney-shaped, and up to 7 x 5mm.
Tithonia diversifolia	It is a woody herb to succulent shrub up to 3m tall. Opposite leaves, attenuate base, acute apex, crenate margin, up to 17 x 12cm, densely pubescent beneath, palmate venetion. Flowers are yellow. Flower heads solitary on a peduncle 6-13cm long. Each mature stem may bear several flowers. The plant flowers and produces seeds all year round.
Vernonia amygdalina	It is a small tree up to 10m tall. Bark light grey or brown, fissured, brittle branches. Leaves lanceolate, oblong, 10-15 x 4-5cm, green, red-veining, apex and base tapering, petiole short. Flower heads thistle-like, small, creamy white, 10mm long, grouped in dense heads, axillary and terminal, forming large clusters, 15cm wide, sweetly scented. Fruit, a 10 ribbed achene, 1.5-3.5mm long, pubescent, glandular, brown to black, crowned by the longer pappus bristles.
Zanha africana	It is a tall shrub or small tree 12-17m tall, bole branchless up to 6m with reddish to brown bark, scaling off in large flakes. Crown open with erect branches; twigs hairy when young. Leaves are alternate, compound with 3-6(-8) pairs of leaflets, stipules absent, petiole 1-5cm long. Inflorescence is terminal or axillary panicle with flowers in dense clusters. Flowers are unisexual, regular, small, greenish, sweet scented, 2.5mm long. Fruit is ellipsoid fleshy drupe reaching 2cm x 2cm, velvety, hairy, yellow to bright orange with one seed which is ellipsoid up to 1.5cm x 1cm.

Aloe ferox

Azadirachta indica



Bobgunnia madagascariensis

Cissus quadrangularis

Chenopodium ambrosioides
Euphorbia tirucalli (syn. Dysphania)

Euphorbia tirucalli

Lantana camara

Lippia javanica

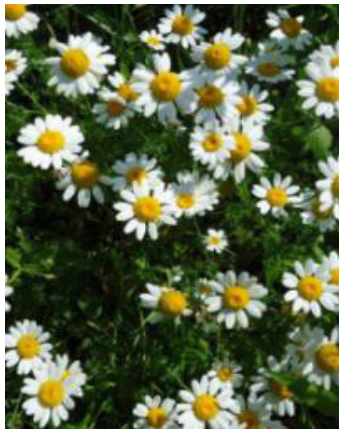
Melia volkensii

Securidaca longepedunculata

Solanum incanum

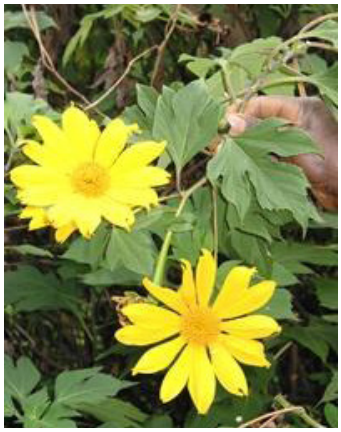
Strychnos spinosa

Tagetes minuta



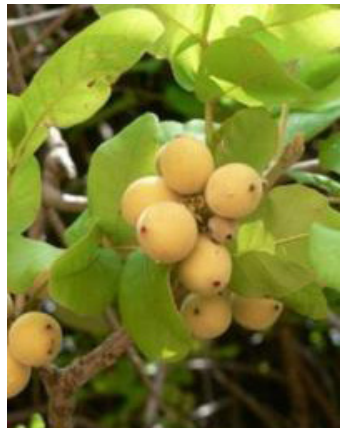
Tanacetum cinerariifolium

Tephrosia vogelii



Tithonia diversifolia

Vernonia amygdalina



Zanha africana

Figure 1: Pesticidal plants

CHAPTER 4

How to apply pesticidal plants on field crops and during post-harvest storage

Throughout this manual we have highlighted that there are many reasons why pesticidal plants can be difficult to use. Correct plant species identification, collection time, collection place, processing and application methods can all make a difference in how well a pesticidal plant works. For some plant species these issues are relatively simple, whereas with others, it can be more variable and important to make sure the right plant variety has been identified, the right plant part is used, harvested at the right time and extracted in the right way.

Despite all these difficulties, there are some basic standard methods and ideas that can be generally applied when it comes to using pesticidal plants. By providing knowledge on the basic concepts and procedures of using pesticidal plants, farmers can go on to do their own experimentation to optimize their time inputs and level of pest control desired.

Farmers first need to understand that pesticidal plants usually do not kill insects immediately. Exposed insects may take a few days to die, or the insects simply leave. Pesticidal plants can be directly toxic but often act through repellency, anti-feedancy, growth regulation or stop insects from laying eggs. Farmers who are used to the fast effects of synthetic pesticides killing insects may be disappointed when using pesticidal plants unless they learn how to more carefully observe crop damage. Farmers need to observe the effects of pesticidal plant application over longer time periods. Results may not be as dramatic as experienced with synthetic pesticide use.

It is also important for farmers to understand that we do not have all the answers, but we do have some answers. Farmers should be encouraged to experiment, e.g. establish efficacy before widely using, and try different plants, concentrations, or mixing different plant species together to achieve optimal results.

How to extract and apply pesticidal plants for field crops

Regardless of what plant part is collected, e.g. flowers, roots, leaves, all materials should be dried in the shade. This is because exposure to sunlight often reduces efficacy. Once dry, materials should be stored in dry, dark conditions until ready for use. Shortly before use, grind or pound and sieve the material to a fine powder.

(Figures 2a-e) A small particle size increases extraction in water. Care should be taken not to inhale fine powders during this processing by wearing a mask.

Farmers may want to store the material as already ground up powder. However, grinding the material will speed up oxidation and can reduce the amount of active ingredient if stored for a long time. Plant materials can be stored as powder, but the time stored as a powder should be limited to, say, no more than one field cropping season.

Farmers may also ask whether it is acceptable to use freshly collected leaves or other plant parts. Fresh materials contain a lot of water already, and this can reduce the total amount of compounds that can be extracted. It is also difficult to grind fresh leaves; these are often pounded into a mush. This reduces the amount of exposed surface area and the amount of compound that can be extracted. So generally using fresh material is more difficult to achieve a consistent product and efficiently extract the compounds.

However, with some plant species, particularly those which are aromatic and contain volatile compounds, there may be good reasons for using fresh material. Some volatile compounds will naturally leave the plant as it dries and it may also be that some compounds are easier to get out of fresh leaves than with dry leaves. The general recommendation should be to use dry materials, particularly as for many plants, they need to be collected well before the cropping season when the plants are available and when farmers have more time. Using fresh material is certainly allowed, particularly if it is more convenient for the farmer; however, the level of efficacy may differ between using fresh and dry material.

Adding soap during extraction should be a general rule no matter which plant species or plant part is used. Soap will help extract any compounds that are not easily water soluble; 0.1% soap is made by adding 1ml soap per litre. For example, a 10-litre bucket would require 10 ml soap. The soap also helps spread the extract on the plant leaves more effectively. This is because plant leaves are slightly waxy and the soap helps the extract to stick to the leaves evenly. If liquid soap is not available, farmers should be encouraged to use other kinds of soap such as bar soap. In this case, a small piece of bar soap, e.g. 10g, could be dissolved in a 10-litre bucket. Waste water from cleaning clothes with laundry soap can also be used.

To make up an extract for spraying on a crop, add the powdered plant in water overnight to be used the next day, i.e., let the extract sit for approximately 24 hours in the shade. For a 1% extract, add 10 grams of plant powder per 1 litre water, and for a 10% solution, add 100 grams per litre. Remember to add soap and the plant powder

at the same time. Do not try to make extracts higher than 10%. This is because the amount of powder will be too much for the amount of water, thus forming a sludgy mess that reduces the efficiency of the extraction.

Although making extracts at less than 1% may still give some good pest control for some pesticidal plant species, it is recommended that farmers try to use a concentration somewhere between 1% and 10%. Making a standard solution does not need precise balances and measures. Farmers could use a standard cup of powder per standard bucket of water, once the volumes of the containers have been worked out with extension agents to understand what the approximate concentration will be using locally available containers. Shortly before spraying, filter the extract through a fine cloth to remove particles that could clog the sprayer. Particularly if using a sprayer, filter higher concentrations of 10% solutions twice, once through a rough cloth and again through a finer mesh. Extracts can also be applied with watering cans or brushes, but sprayers are more effective in spreading the extract evenly.

Many pesticidal plant compounds break down quickly in sunlight. Thus always spray extracts during late afternoon or evening to maximize contact time with insects. This rapid breakdown of the compounds by sunlight means that pesticidal plants need to be sprayed more frequently than commercial synthetics. Frequent spraying is necessary because of their quicker breakdown and because they often don't kill all insects in one application. Weekly spraying of pesticidal plants has been shown to be as effective as commonly used synthetics (Mkenda *et al*., 2015). Although even synthetic pesticides are washed off by rain, plant extracts will be even more susceptible to wash off, so farmers should reapply the next day if it rained during the night after application. Farmers should be encouraged to monitor damage and insect numbers so as to spray as necessary.

2a: Plant specimen collection

2b: Pounding of dried plants to make powder

2c: Sieving of plant powder

2d: Preparation of plant solution for spraying

2e: Sprayers ready for spraying on field crops

2f: Pesticidal plants powder to protect stored grains

Figures 2a-f: Collection and preparation of pesticidal plants for use on field crops and stored grains

Using plant powders or MARC residues after extraction for field crops

Generally, using powders or solid residues obtained after extraction are not easy to use on field crops as they do not easily stick to the plant. However, they can be used in some circumstances such as with maize (or millet and sorghum) to prevent stem borers. This is done by sprinkling the powder on the plant so it gets trapped between leaves and stem. The pyrethrum extraction industry in East Africa produces a residue known as PyMarc, which is often sold locally. This product can be used by sprinkling on maize plants. Similarly, farmers who are making their own pesticidal plant extracts for spraying will have a residue left over after filtering which could be used in a similar way. Some farmers put this extract residue on the soil around their plants as a kind of treatment to control nematodes or other soil pathogens (Prakash and Rao 1997; Prasad *et al*., 2002).

Using pesticidal plants for post-harvest pest management

Using pesticidal plants for the protection of stored grain and legumes is widely recognized across sub-Saharan Africa. Smallholder farmers storing commodities at the household level continue to suffer from many insect pest species that infest their cowpeas, beans, maize, millet, sorghum, groundnuts and other dry grains and legumes. Controlling insect infestation during storage can involve several basic practices that could dramatically reduce the need for pesticides (synthetic or plant-based). Before considering the use of pesticidal plants in post-harvest storage protection, farmers should first ensure that they are following good storage practices. Some of these practices are summarised in Appendix 1 of this manual and include basic ideas of how to determine that grain is properly dried before being stored, and using non-chemical technologies such as solarisation to dry and dis-infest grain. More information on good storage practice can be found in the WFP's Training Manual for Improving Grain Postharvest Handling and Storage (Hodges and Stathers, 2012).

Unfortunately many problems with insects on stored commodities begin in the field at the time of harvest where some seeds become infested. Since many farmers find it difficult to properly dry their grain to low moisture content, the insect problem rapidly grows from the initial field infestation. However, even if grain is clean, dry and free of infestation when stored, it could still become infested later on through insect invasion, particularly as most on-farm storage structures are not insect-proof. For these reasons pesticidal plants can be an effective way of reducing or preventing infestation of stored commodities (Figure 2f).

Storage methods and structures vary, and thus this publication covers some of the different ways in which pesticidal plants can be used in post-harvest protection. In all

the different methodologies, and depending on storage duration, it may be necessary to re-apply pesticidal plants. The frequency of application will partly depend on the plant species as well as the severity of any existing infestation in the grain. Finally, in all cases where pesticidal plants have been used, the grain should be washed and/or winnowed to remove any plant materials before further processing and cooking for consumption.

How to admix powdered pesticidal plants with dry legumes or grain for on-farm storage

Pesticidal plants are collected and shade-dried. Note that many compounds in plants are light sensitive. The dry materials should be stored in the dark until ready for use. Shortly before use, grind or pound and sieve the material to a fine powder. Although some farmers often mix in whole leaves or other plant parts, admixed powder with grain has been shown to be more effective. A small particle size increases activity by increasing the surface area and small particles are more likely to stick to the grain and insects. Please note that care should be taken not to inhale fine powders during this processing by wearing a mask.

With some plant species, particularly those containing volatile compounds, it is recommended that one use whole leaves or layer whole plants to more slowly release volatiles or reduce grain tainting with powder. This varies depending on the plant species. Details are provided in Table 5.

To admix the plant powder with the grain, make a heap of grain on a clean concrete floor, tough plastic sheet, tarpaulin or metal sheet (but not on bare earth). Apply 1-2 cups of powdered pesticidal plant material to 100 cups of grain (1-2%) by sprinkling powder all over the heap of grain, then gently mixing with a shovel, followed by shovelling to another part of the clean surface and shovelling it back again. Repeat the process three times to ensure thorough mixing (Figure 3).

Image reproduced courtesy of Golob, P. (1977). Natural Resources Institute

Figure 3: Mixing pesticidal plant material with grains

How to admix powdered pesticidal plants with unthreshed grain (maize cobs, millet & sorghum panicles)

For unthreshed grain, e.g., maize, millet or sorghum, a tin sprinkler can be made using a clean tin with a tight fitting lid. About ten holes should be made in the lid using a 5cm nail or similar pointed tool (Figure 4). Pesticidal plant powder can be sprinkled on the cobs in layers using the tin (Figure 5).

Image reproduced courtesy of Golob, P. (1977). Natural Resources Institute

Figure 4: Tin sprinkler

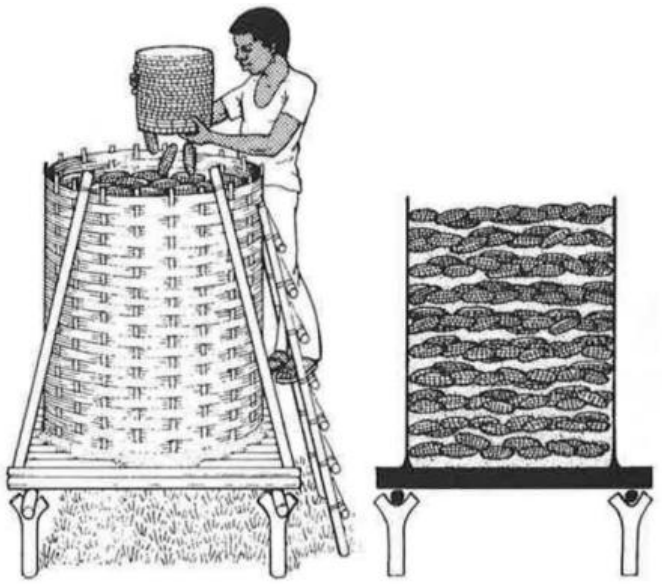


Image reproduced courtesy of Golob, P. (1977). Natural Resources Institute

Figure 5: Layering pesticide with cobs

Soaking absorbent sacks with pesticidal plant extracts

Storage sacks – particularly those made from jute which are absorbent – could be soaked in plant extracts, then dried and used to store grains. In this method, higher concentrations of 10% solutions should be used. This is more effective in preventing invasion of insects during the storage period. However, it would have less effect in controlling an ongoing infestation already in the grain. The method does mean that the grain is less in contact with any plant materials so should have lower residues of toxic compounds.

Double bagging with plant material between sacks

Grains can be stored in a sack which is then put in another sack which has been treated with pesticidal plant extracts by spraying or on which the inner surface is spread with plant paste. This is similar to soaking sacks described above, but works when using woven poly bags that most farmers have access to. Again, the method is effective in prevention of infestation, but not as effective as admixing when trying to dealing with existing infestation.

Dipping or spraying commodity with an extract

Coating commodities in an extract can sometimes be more effective than using an admixed pesticidal plant powder. Some farmers make a cold or hot water extract (10%). This can then be sprayed over the commodity spread out over a hard surface such as a clean concrete floor, tough plastic sheet, tarpaulin or mat. The commodity is shifted around when spraying in order to evenly coat the seeds. The seeds must then be thoroughly dried before storage. Alternatively, the commodity can be put in a basket, which is then dipped into the extract. The commodity is later spread out on a hard surface to dry. Using plant extracts combined with solarisation can be highly effective as it helps dis-infest and clean the grain before storage. The process does require more labour and time, and a sunny day for good drying conditions.

Table 5: Table of pesticidal plant species, the parts of the plants used, the preparation of the pesticide and it mode of use on target organisms

Species	Parts used	Preparation	Uses	Target organisms
Aloe ferox	Live plant	Dried and ground to powder	Repelling action	Against broad range of insects
	Leaves	Leaf ash	Repelling action	Against broad range of insects
			Dusted on stored maize and cowpea at a concentration of 5%w/w	Against weevils and beetles

Species	Parts used	Preparation	Uses	Target organisms
Azadirachta indica	Seed	Extract the oil or grind the harvested seed to a powder. Dilute the oil/ powder in soapy water for spraying on crops	Strong anti-feedant, repellent and affects insect growth, causing deformities	Very good for caterpillars, but generally effective against a broad range of insects
	Leaves	Leaves are not as effective as the seed, but are easier to collect and process. Dry the leaves and grind to a fine powder	Can be used both pre- and post-harvest. Compounds are very sensitive to light so important to spray in evening.	
Bobgunnia madagascariensis	Seed pods	Grind seed pods to powder	Toxic Can be used both pre- and post-harvest	Against broad range of insects; termites, weevils, rodents
Cissus quadrangularis	Fleshy stems and leaves	Dry and grind to powder	Mainly post-harvest uses	Post-harvest beetles

Species	Parts used	Preparation	Uses	Target organisms
Dysphania ambrosioides	Leaves, whole plants	Boiling leaves to produce a decoction Essential oil Grind dried leaves to produce powder Often layered whole plants in storage, occasional stirring to release volatile compounds	As a fumigant A fungicide in post-harvest grain Added to fertilizer Added to stored beans at 0.5% w/w Added to stored maize at 5% w/w	Mosquitoes, flies and snails Fungi Against insect larvae Against bruchids in beans Against storage pests, e.g., *Sitophilus zeamais*
Euphorbia tirucalli	Plant's latex	Extraction of latex, dry and grind to powder. Note highly irritant and gloves and masks must be worn when processing	Surface application	Against aphids, mosquitoes, some bacteria and molluscs

Species	Parts used	Preparation	Uses	Target organisms
Lantana camara	Leaves, flowers	Dry and grind Often layered whole plants in storage, occasional stirring to release volatile compounds	Can be used both pre- and post-harvest	Against broad range of insects Mosquito and fly repellent Post-harvest beetles
Lippia javanica	Leaves	Dry and grind Essential oil Often layered whole plants in storage, occasional stirring to release volatile compounds	Can be used both pre- and post-harvest	Against broad range of insects
Melia volkensii	Leaves	Dry and grind	Can be used both pre- and post-harvest	Against broad range of insects
Securidaca longepedunculata	Root bark	Dry and grind	Can be used both pre- and post-harvest	Against broad range of insects
Solanum incanum	Ripe fruits	Whole dry, ripe fruits are crushed and extracted in water at 5% w/v for 24 h and sprayed at 5L/ animal	Surface application	Against cattle ticks
Strychnos spinosa	Fruits	Aqueous fruit extracts made at 5% w/v	Surface application	Against cattle ticks

Species	Parts used	Preparation	Uses	Target organisms
Tagetes minuta	Whole plant	Grind dried plants to produce powder	Added to stored beans and maize	Maize and bean weevils
		Plant extract	As a fumigant	Against aphid *Brevicoryne brassicae* and red spider mites in vegetables
		Essential oil	Application	Against ticks
		Boil leaves to produce a decoction	Ingested by livestock	Against intestinal parasites in domestic livestock
	Live roots	Secretions from live roots		Against nematodes, worms, insects, fungi and perennial weeds
Tanacetum cinerariifolium	Flowers	Dry and grind Chemicals are not easy to extract in water and is often extracted in kerosene	Can be used both pre- and post-harvest	Against broad range of insects

Species	Parts used	Preparation	Uses	Target organisms
Tephrosia vogelii	Leaves	Crude extract by mixing 20 grams of fresh leaves with 100ml water. Soak for two hours away from direct sun, filter and spray. More effective extract made by adding 5ml liquid soap to the above solution Dried leaves	Surface application. Use immediately for optimum effectiveness. 24 hours later, effectiveness is reduced to 60-70% Mixed with stored grains	Against ticks and worms in livestock Against larval stages of mosquitoes, soft bodied insects and mites Against bruchids
Tithonia diversifolia	Leaves	Petroleum, methanol or chloroform extracts of dried, ground leaves	Surface application	Against plant pathogenic fungi
Vernonia amygdalina	Leaves	Essential oil	Can be used both pre- and post-harvest	Against maize weevil, *Sitophilus zeamais*
Zanha africana	Root bark	Dry and grind	Can be used both pre- and post-harvest	Against broad range of insects

CHAPTER 5 Other uses of pesticidal plants

Table 6: Other uses of pesticidal plants

Species	Other uses of pesticidal plants
Aloe ferox	*Medicinal:* In humans *A. ferox* regenerates injured nerves and new skin cells, soothes sunburn, wounds, insect bites, eczema, ringworm, rashes, acne, reduces pain and swelling of arthritis and rheumatism, and is used to treat opthalmia and syphilis. In cattle, it is used to treat jaundice, red water and expels worms.
Azadirachta indica	*Food*: Fruits, twigs and flowers can be eaten *Fodder*: Leaves *Fuel*: Charcoal, firewood, oil in lamps *Timber*: Wood is used to make wardrobes, bookcases, packing cases, fencing posts *Cosmetics*: Oil is used to make soap, in cosmetics and in the pharmaceutical industry as a spermicide
Bobgunnia madagascariensis	*Wood*: For poles and posts for houses and fences. Wood for furniture, musical instruments, tool handles, flooring, joinery, heavy construction. Slow burning firewood and charcoal making. *Traditional medicine*: Fruits used to treat bilharzia, leprosy and ear aches. Roots used to counteract venomous stings and bites, venereal diseases, cataract and dysentery. Leaves used for headache and against cough. Bark used to treat diarrhoea, dysentery and as a disinfectant. *Fibre:* Bark used to make bark cloth in Malawi and to obtain fibre for various purposes.
Cissus quadrangularis	*Traditional medicine:* Used for joint and bone health and to treat feminine disorders and menopausal symptoms.
Dysphania ambrosioides	*Medicinal:* Tea made from *D. ambrosioides* is drunk to expel parasitic worms from the body of humans and livestock. It is also used as a remedy for stomach pains, to detoxify snakebites and other poisons and to clean wounds and haemorrhoids. The oil derived from the plant is used to treat athlete's foot and insect bites.

Species	Other uses of pesticidal plants
Euphorbia tirucalli	*Medicinal uses:* In East Africa, *E. tirucalli* latex is used against sexual impotence, warts, epilepsy, toothaches, haemorrhoids, snake bites, extraction of ecto-parasites and coughs. In Malaysia, a poultice of roots and stems can be applied to nose ulcerations, haemorrhoids and swellings. In India, it is a remedy for spleen enlargement, asthma, dropsy, leprosy, biliousness, leucorrhoea, dyspepsia, jaundice, colic, tumours and bladder stones. The branch and root decoction can be used for colic, and its ashes applied on open abscesses. *Use as an energy source: E. tirucalli* latex is composed of petroleum-like hydrocarbons, largely C_{30} triterpenoids, which on cracking yield high octane gasoline. It is a potential source of biodiesel due to its high biomass and growth in marginal areas unfit for other crops. Its ease of fermentation implies that it is a potential source of methane and biogas. It can be used as compost, charcoal and fuel wood, especially since it can grow in semi-arid areas devoid of forests and due to its fast growth rate which implies high productivity and quick acclimatization to an area and ease of drying. *Use for rubber*: Its hydrocarbon polymers can be used for manufacturing rubber substitutes. Its latex is an emulsion of terpenes and resins in water, which can easily be transformed into rubber at low cost. Along the East African coast, it is used in the manufacture of local gum, for fastening knife blades to wood handles and spearheads to shafts. It can also be used as a wood-based glue and adhesive. *Use in conservation and agroforestry:* Its drought resistant nature makes *E. tirucalli* a good species to use in semi-arid areas for afforestation and reforestation for soil conservation. There has been some success in Tanzania, Kenya and Sri Lanka. It is used as a hedge plant due to the irritant properties of its latex to potential invasive animals in homesteads and fields, as a boundary demarcation and as a windbreak. *Ornamental:* It is popular as an ornamental plant.
Lantana camara	*Medicinal:* Herbal medicines with antimicrobial, fungicidal, insecticidal and nematicidal properties. *Fuel:* Firewood for cooking. *Food for birds:* Many birds, including endangered ones, feed on lantana thickets. Butterflies and moths also feed on it. *Ornamental:* It is popular as an ornamental plant.

Species	Other uses of pesticidal plants
Lippia javanica	*Medicinal:* Leaves are medicinal and used as a herbal tea to treat coughs, aching muscles and sometimes, malaria. Skin disorders, such as heat rash and other rashes, as well as scratches, stings and bites and parasites such as lice and scabies can be treated with the *Lippia javanica* leaves mixed in hot water tea that is usually cooled and then applied like a lotion. Leaves, twigs, and sometimes roots, can be used. *Cosmetics:* the Maasai people use its red ointment to decorate their bodies. Gardeners use it in pot-pourri and some people use it to make perfume.
Melia volkensii	*Fodder*: Popular with farmers for their goats and cattle. The tree is pruned to produce fodder during the dry season. *Apiculture*: Used to make log hives since wood is easily shaped. Flowers are good for bee forage. *Timber*: Since the wood is easily shaped, is termite resistant, durable and decay resistant, it is used to make acoustic drums, containers, mortars, doors and window frames, shutters, poles and furniture. *Fuel*: Branches cut for fodder are left to dry then used for firewood. *Soil improver*: Some farmers have suggested that heavy leaf fall may increase crop yields at a later stage of development.
Securidaca longepedunculata	*Medicinal:* Violet tree is a very popular traditional medicinal plant in many African countries. Powdered roots and bark or infusions are traditionally used to treat headaches, stomach and chest problems, inflammation, tuberculosis, venereal diseases, constipation, and toothaches. It is reported to have antimicrobial activities against protozoa, bacteria and fungi. The active compound securinine has activity against the malaria causative agent *Plasmodium falciparum.* Xanthone compounds from the root bark confer action against erectile dysfunction. *Soap:* The bark is used in the manufacture of soap. *Fibre:* The strong and durable fibres from the inner bark are used for fishing nets, baskets, bark cloth and strong threads. *Food:* Young leaves are used as vegetables and in sauces. Root infusions with maize or sorghum can be used as a beverage. *Fodder:* Animals feed on the roots. *Apiculture:* The flowers are frequented by bees for honey production.

Species	Other uses of pesticidal plants
Solanum incanum	*Medicinal:* The fruits of *S. incanum* are used in Kenya for the treatment of skin mycotic infections. *Soil fertilizer*: The leaves and stems are useful as green materials in compost. *Other*: The Samburu people of Kenya use its fruit juice to clot milk.
Strychnos spinosa	*Medicinal:* Compounds from *S. spinosa* tree have been shown to have anti-trypanocidal activity. A decoction of the leaf or root is used as an analgesic in Central Africa. *Food*: The fruit is edible and often sun dried as a food preserve. *Other uses:* The wood can be used for general carpentry. Timber from *S. spinosa* produces handles, fighting sticks and hut poles. It is also used for carving. Dried fruit, after the seeds are removed, are often used as sounding-boxes for musical instruments such as the *marimba*. They are also carved and sold as curios.
Tagetes minuta	*Medicinal:* It is used to treat gastritis, indigestion and intestinal worms. Externally it is used to treat skin infections and haemorrhoids. The essential oil treats fungal infections like athlete's foot and boosts the respiratory system. It has antimicrobial, antiphlogistic, antiseptic, antispasmodic, cytophylactic, sedative, emollient, fungicide and hypertensive properties. *Other:* It is used in perfumery and as flavour in beverages and the food industry.
Tanacetum cinerariifolium	The flowers have been shown to possess weak antibiotic activity though it is not used medicinally.
Tephrosia vogelii	*Soil fertilizer: T. vogelii* is a known nitrogen-fixing species, cultivated as green manure in Indonesia and in many parts of Africa. *Other*: It is also planted as a windbreak and as a temporary shade crop.

Species	Other uses of pesticidal plants
Tithonia diversifolia	*Medicinal*: Infusion of *T. diversifolia* is suitable for constipation, stomach pains, indigestion, sore throat, liver pains and treating malaria. The plant also exerts anti-inflammatory, analgesic, antimalarial, antiviral, antidiabetic, antidiarrhoeal, antimicrobial, antispasmodic, vasorelaxant and cancer-chemopreventive properties/effects. *Fodder*: Leaves, soft branches, and flowers are used as fodder due to its high nutritive-quality index. *Fuel*: Farmers use *T. diversifolia* for firewood.
Vernonia amygdalina	*Food*: Bitter leaves of *V. amygdalina* are eaten as raw vegetables and cooked in soups. Roots and twigs are chewed as appetizers. *Medicinal*: It is used as a medicine for relieving fevers, stomach disorders, to treat hepatitis, malaria, bilharzias, spots on skin and nausea. *Fodder*: Leaves and shoots are used as fodder. *Fuel*: The tree is used for firewood and charcoal. *Apiculture*: It produces very light honey. *Timber*: The termite-resistant branches are used as stakes to line plantations or as live fences.
Zanha africana	*Timber*: Wood is used for construction, door frames, tool handles, flooring, ship building, furniture, toys and agricultural implements. *Food*: The fruits are eaten by man but can cause severe diarrhoea if eaten in excess. The seeds can be poisonous. *Soap*: Saponins are present in the root bark, stem bark and fruits. *Medicinal*: It is traditionally used as a medicine in many African countries. In Tanzania, the root decoction can be used to facilitate childbirth, treat constipation and fits. Root preparations are also used to treat toothaches, rheumatic pains, pneumonia, vertigo, fungal infections headaches, colds and fever. *Fodder*: Leaves are eaten by cattle, goats and sheep. *Apiculture*: The tree is planted for nectar for honey bees.

CHAPTER 6

Propagation and cultivation of pesticidal plants

Table 7: Propagation and cultivation of pesticidal plants

Species	Propagation and cultivation
Aloe ferox	*A. ferox* is easy to cultivate. It grows best in free draining compost which should be soaked and allowed to dry out between watering. It requires light watering in winter. The plant grows well in a cool/warm glasshouse and outside in summer. It can be propagated by seed and planting of the tops of old plants. It can also regenerate from root and embryo tissue.
Azadirachta indica	*A. indica* is grown mostly from seeds. Stored seeds should be rehydrated slowly before germinating. Seeds are removed from mature seeds and seed covering removed. It grows slowly in the first year. Fruiting starts 3-5 years later and the tree is fully productive at 10 years. It can also be propagated by root cuttings using growth hormones.
Bobgunnia madagascariensis	Soak *B. madagascariensis* seeds in hot water for 10 minutes, cool for 24 hours, and then germinate. Propagation by stem cuttings and root suckers is also possible.
Cissus quadrangularis	*C. quadrangularis* is propagated with seeds. It can also be propagated with stem cuttings by using three internodes, left to dry, and then planted in sandy soil.
Dysphania ambrosioides	*D. ambrosioides* grows easily in most soils but prefers sandy loam and sunny dry zones and soil pH 5.2-8.3. Seeds germinate easily when sown fresh. Germination rates are good and seedlings appear within a few days of sowing the seed.
Euphorbia tirucalli	Stem cuttings of *E. tirucalli* grow fast, forming dense bushes which become naturalized and form a small tree. Seed germination is epigeous.
Lantana camara	Highly invasive and damaging to local habitats; not to be cultivated or propagated. Simply collect from abundant existing sources.
Lippia javanica	*Lippia javanica* grows easily from seeds and from cuttings too. It grows relatively fast and prefers sunny areas. Lemon bush is not very particular and seems to do well in most soil types.
Melia volkensii	*M. volkensii* is naturally dispersed by giraffe, kudus and goats which eat the fruits. Seed germination is difficult. Some have reported germination of seeds after removal of fleshy seed coat and hard shell and soaking of softer inside seed in water and anti-fungal treatment. The seeds are then germinated in sterile, sandy soil. Germination can also be done using root suckers.

Species	Propagation and cultivation
Securidaca longepedunculata	Propagation is done by seeds, best collected when mature. Seeds are recalcitrant, thus need processing as soon as collected. Seed coat is removed with a scalpel, and seeds are best sown in cocopeat or vermiculite or forest soil. Transplant to a media of sand:soil in polythene bags for growth. Root cuttings are also used for propagation.
Solanum incanum	Ideally, the seeds should be soaked for 24 hours before sowing as this increases germination rate to above 75%. (Unpublished data, ICRAF 2012).
Strychnos spinosa	*S. spinosa* species can be regenerated from root suckers and coppice or seeds. Seeds are soaked in hot water or the hard coat is burned to facilitate and improve germination. It can also be propagated vegetatively.
Tagetes minuta	Seeds germinate readily when sown fresh, without treatment. Seeds are sprinkled directly on soil or covered with soil. Germination takes place within one week. Seedlings can also be transplanted to pots. It grows well in disturbed areas, in heavy clay soils or sandy soils.
Tanacetum cinerariifolium	Propagation by seeds by covering lightly in damp soil
Tephrosia vogelii	The seeds should be soaked in cold water for 24 hours before sowing to enhance germination. For maximum leaf yield, 35,000 seeds can be sown per hectare.
Tithonia diversifolia	*T. diversifolia* can be propagated from seeds and cuttings. Seeds germinate readily when sown fresh, without treatment, all year round. Seeds are sprinkled directly on soil or covered with soil. Stem cuttings of 20-40cm length establish readily. The cuttings should be planted into moist soil immediately after collection and not allowed to dry in the sun.
Vernonia amygdalina	Propagation of *V. amygdalina* is possible by seed collected from dry flower heads. Stem cuttings are used as they grow faster. Cuttings are selected on leaf size, bitterness and growth characteristics. It is planted erect or slanted at 45° to obtain more side shoots. Seeds can be sown on nursery beds prepared from humus-rich soil, shaded from excessive heat or sunlight and watered regularly to germinate. Seedlings can be transplanted 4-6 weeks after emergence. Commercial farmers prefer to plant new crop at the beginning of a season or after the second year. It has also been micro-propagated in vitro.
Zanha africana	Propagation is done with fresh seeds which are recalcitrant. Propagation has been shown to be successful with root and stem cuttings.

CHAPTER 7 Seed collection and storage

Table 8: Seed collection and seed storage for pesticidal plants

Species	Seed collection	Storage
Aloe ferox	Seeds can be collected in winter or spring.	Seed storage is orthodox. The seeds of *A. ferox* can survive drying without significantly reducing their viability, and are therefore amenable to long-term cold storage.
Azadirachta indica	Seeds are removed from mature, fresh fruits.	Seeds are orthodox. They are dried to 15-20 eRH and stored at -20°C. Seeds collected at point of natural dispersal, then dried carefully, can be stored at sub-zero temperatures without loss of viability.
Bobgunnia madagascariensis	Seeds are released from inside the fruits when they fall to the ground and rot.	Seeds stay viable for several years if kept dry and insect-free.
Cissus quadrangularis	One seed is formed in each fruit pod.	
Dysphania ambrosioides	The fruits are sieved to remove the husks.	Seed behaviour is orthodox. Viability of air-dried seeds can be maintained for several years in hermetic storage.
Euphorbia tirucalli	*E. tirucalli* is usually propagated with cuttings. However, when collecting seeds from fruits, they should be cleaned with water, dried and stored in a cool place.	There is no information on viability of the seeds with storage.
Lantana camara	Highly invasive and damaging to local habitats; not to be cultivated or propagated.	
Lippia javanica	Seeds are tiny nuts and brown in colour. Collection of fruits at onset of natural dispersion. After harvesting, fruits are placed in open trays at room temperature to dry and open to release the seeds. Seeds are separated from the fruits by light threshing and hand sorting.	

Species	Seed collection	Storage
Melia volkensii	Seeds are extracted from the large fruit by hand.	Seed storage is orthodox and viability can be maintained in hermetic storage at 11-15% mc at room temperature for several years.
Securidaca longepedunculata	Harvesting of seeds is done by hand, and is best when seeds are mature. Seeds are released from the seed coat using a scalpel.	Seeds are recalcitrant and thus cannot be stored for a long time.
Solanum incanum	Ripe yellow fruits are hand collected from the tree branches using secateurs. Fruits are dried under shade at a temperature of 35°C for two days. Extraction is started as soon as the fruit turns brown, fruits are squeezed between the fingers, crushed and seeds removed, the seeds are washed in running water to clear off the pulp and spread on open trays to dry.	Seed storage behaviour is orthodox; viability can be maintained for over one year in air-dry hermetic storage at 5°C at a moisture content of 6-8%.
Strychnos spinosa	Fruits are harvested when the colour turns from green to yellow brown. Harvesting is by cutting the branches holding the fruit using a pair of secateurs. A canvas could be spread on the ground to hold the fruits during harvesting. After collection, fresh fruits are soaked in water to soften the fresh pulp and are extracted by rubbing with hands to remove the pulp; they are then squeezed to release the seeds. After extraction and cleaning, seeds must be dried under shade by spreading them out in a thin layer with regularly turning to avoid overheating.	Seed storage behaviour is orthodox; long-term storage. There are about 1800 seeds/ kg.
Tagetes minuta	In Kenya, the seeds can be harvested in February, May and October. The fruits are sieved to remove the husks. One pod has several seeds.	Seed behaviour is orthodox. Viability of air-dried seeds can be maintained for several years in hermetic storage.
Tanacetum cinerariifolium	Seeds are collected from the tightly packed flower heads.	Dry seeds are stored in dark, dry cool environment with paper bags.

Species	Seed collection	Storage
Tephrosia vogelii	Harvesting is done by shaking the branches and pulling the pods with a hook in order to release them on canvas spread on the ground. Pods should be dried in the sun for a few days, and then threshed in a gunny bag by using a stick. After extraction, the seeds are cleaned by sieving, winnowing or using a mechanical blower. Cleaned seeds are dried to moisture content of 6-10% prior to storage.	Seed storage behaviour is orthodox; viability can be maintained for several years in hermetic storage at 10°C. Seed can also be stored for at least a year if kept dry and insect-free through addition of ash.
Tithonia diversifolia	The dried fruits are sieved to remove the husks, to obtain seeds	Seed storage behaviour is orthodox, therefore amenable to long-term cold storage
Vernonia amygdalina	Fresh mature fruits appear yellow and ripen in various sizes. Fruits are dried at temperatures of 30°C to 35°C for three to four days. When the fruit turns brown, seeds are extracted by gently rubbing the fruit between fingers to squeeze out the mucus-like paste that cushions the seeds. The seeds are then washed in running water to separate seed from the pulp. Clean seeds are placed on an open tray to dry under shade for a period of two to three days.	There is no information on germplasm collection and viability of the seeds with storage.
Zanha africana	Fruits are collected when mature. Seeds are harvested by hand. Seeds are recalcitrant and should be used fresh. Care should be taken as seeds can be poisonous.	Recalcitrant seeds cannot be stored for long periods of time.

CONCLUSION

Traditional methods of pest control, such as using pesticidal plants, contribute significantly to food production and sustaining livelihoods. Using pesticidal plants is also an affordable and economically viable pest control method (Amoabeng *et al*., 2014; Mkenda *et al*., 2015). Most pesticidal plants are gathered locally from the wild, e.g. around homesteads, road sides, in forest reserves and farm fallows. For some, the method of harvesting is unsustainable due to the fact that the parts used are the vital organs of anchorage, transportation and regeneration such as roots, bark, fruits and seeds. In addition to poor harvesting practices, other threats faced are the actual removal of the plant species from areas they grow due to uncontrolled bush fires, overgrazing, deforestation and agricultural expansion. Furthermore, the elders who possess the knowledge of their use and conservation are vanishing without adequate documentation and passing on of their knowledge. In order to conserve the remaining germplasm of these pesticidal plant species, the distribution, phenology, flowering, fruiting patterns and propagation methods require further study to increase our ability to maintain ecosystem services.

Stakeholders recognize that the use of pesticidal plant species is a cost effective method to manage pests and wish to see more research to improve their use and efficacy. Particularly the interaction of plant species with location and season has been found to influence the content of active ingredients in the materials. Preparation of extracts, storage and application also needs to be fine-tuned to make their use reliable and easy for farmers. Furthermore, there is need to promote policy that would facilitate the use of pesticidal plants use through commercialization at local village levels using crude preparations but also for larger scale production.

Closing the considerable knowledge gaps and surmounting the lack of commercial incentives or revenues to drive policy and uptake of pesticidal plant products remain the key challenges. Influencing policy is a particular challenge as most regulation is based on those designed for large-scale synthetic pesticide products that have been the mainstay of pest management in North America, Europe, Japan and Australia (Isman, 2006; Sola *et al*., 2014). Multistakeholder engagement to improve regulation and registration policies is needed. Farmers should be exposed to a broader knowledge on crop yield and quality and also on food security, nutrition, environmental protection and consumer safety.

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Appendix 1: Supplementary technologies to support the use of pesticidal plants

Ensuring grain is dry before storing

More details on good storage practices can be found in WFP's Training Manual for Improving Grain Postharvest Handling and Storage (Hodges and Stathers, 2012).

It is not always easy to tell if grain is dry enough to store. Reducing grain moisture content is essential to prevent insect and fungal infestation during storage. Insect numbers will increase rapidly in grain with high moisture content, and neither synthetic pesticides nor pesticidal plants will be able to control the infestation. So before using pesticidal plants for post-harvest protection, ensure that the grain is dried to less than 15% moisture content. A simple way of testing whether grains are dry is given below:

a. Fill one-third of a bottle with grain sample (250-300g)
b. Add two tablespoons of sun-dried salt (20-30g)
c. Close the bottle tightly
d. Shake vigorously for 1 minute
e. Leave the bottle to rest for 15 minutes.

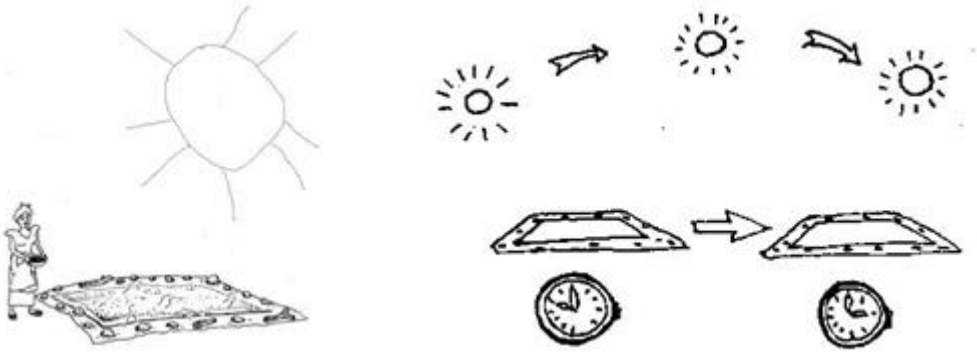
If salt sticks to the sides of the bottle, the moisture content is above 15% and the grains are not safe for storage. If salt does not stick to the bottle, the moisture content is below 15% and grains are safe for storage.

Solarisation to dry and disinfest grain before storing

This is the process of using the sun to dry grains and kill insects that might be developing in the grains. It is the most effective, low cost way to control insects in stored products. More details can be found in Tran and Andan (2001).

a. Select a flat area with no shade
b. Lay a straw mat on the flat surface to prevent heat from being lost to the ground
c. Lay jute sacks all over the mat or, ideally, a black plastic sheet
d. Pour grains over jute sacks in a thin layer (less than 2cm thick)
e. Place a large transparent plastic sheet flat over the grains, using stones to hold down the edges of the sheet. The plastic sheet increases the temperature under the sheet, killing any insect larvae or eggs in the grains

f. Leave in the sun for as long as it is hot, for example, from 10 a.m. to 3 p.m.



Images reproduced courtesy of Tran and Andan (2001) Natural Resources Institute.

Figure 6: Solarisation

Figure 7: Drying food products in a sun dryer in Tanzania (Photo by D. Ofori)

Using live pesticidal plants as inter-crops or in push-pull systems

A number of pesticidal plants species can be grown alongside crops, providing living sources of repellent odours that often prevent insects from accessing the crops they want to attack. This is particularly common with marigold and other flowering species with a strong odour. The strong odour interferes with how insects find the plant they want to infest. In East Africa, *Tagetes minuta* is intercropped with maize and kale to repel nematodes (Figure 8.)

Figure 8: Tagetes minuta intercropped with kale at Kakuzi in Kenya (Photo by Parveen Anjarwalla)

Building on the idea of intercropping repellent plants, a push-pull system was developed by ICIPE and partners in Kenya and Rothamstead Research in the United Kingdom to control pests of maize, particularly stem borer pests. This involves using repellent and attractive crops planted near maize. Specifically, it involves intercropping maize with a repellent plant, Desmodium *(D. uncinatum and D. intortum)* and bordering this with another plant, Napier grass (*Pennisetum purpueum*) which is attractive to the stem borer pest. The pests are pushed away from the maize crop (push) by the repellent plant, and pulled to the trap crop (pull) which produces attractive amounts of volatile compounds, thus keeping the main crop protected. An added advantage is that Desmodium helps to controls parasitic striga weed and increases soil fertility. More information about push-pull can be found at http://www.push-pull.net/

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