Industrial Crops & Products xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Industrial Crops & Products

journal homepage: www.elsevier.com/locate/indcrop

# Bridging the gap: Moving botanical insecticides from the laboratory to the farm

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ARTICLE INFO

*Keywords:*
Insecticidal plants
Commercialization
Efficacy
Chemical variation
Plant essential oils

ABSTRACT

Interest in, and research on botanical insecticides has surged since 2000 according to a recent bibliographic analysis of scientific literature. Thousands of papers have now been published documenting the bioactivities of botanicals such as neem (from *Azadirachta indica*), various plant essential oils, and innumerable plant extracts to insects and related pests, although the majority of these simply report screening studies and other observations made within the confines of laboratories. In contrast, with few exceptions, little of this knowledge has been translated to practice, i.e., utilized directly by farmers for pest management. What, then, are the prerequisites to realizing the benefits of botanical insecticides, particularly for smallholder farmers in sub-Saharan Africa?

I have previously argued that there are a number of plant species widely occurring in Africa − both endemic and introduced − that are suitable for the production of botanical insecticides, and that less attention should be paid to further discovery of bioactive plant species and more attention placed on the development of botanicals from those plants we already know. To put those plant species to work for pest management, we need the following: (i) methods for local propagation and cultivation to ensure a sustainable supply of biomass; (ii) simple methods: for extraction utilizing available resources at minimal cost; (iii) simple methods: (e.g., bioassay) to validate bioactivity and ensure some measure of efficacy; and (iv) field trials and demonstrations to learn timing and application strategies that can optimize efficacy. Appropriate technologies for the utilization of botanical preparations for insect control will differ depending on the scale, from the "do-it-yourself" smallholder farmer, to a cottage- or village-level collective, to private-sector industry.

## 1. Introduction

Despite a century of technological advancements in pest management – 1921 saw the first use of aircraft to spread insecticides over cultivated crops – insect pests, plant pathogens and weeds continue to effectively compete with humans in the production of food and fibre. Even in the most industrialized regions where the impact of technology for food production is greatest, i.e. western Europe and North America, actual pre-harvest crop losses in major crops average 20%, although crop protection technologies are estimated to reduce potential losses in these regions by close to 70% on average (Oerke, 2006). The differences between potential and actual losses have been largely attributed to the use of insecticides, fungicides and herbicides. In contrast, in sub-Saharan Africa where pest management practice is considerably less advanced and the best pesticides are either unavailable or unaffordable, actual pre-harvest crop losses on major crops average over 50%, and potential losses are reduced by less than 40% on average (Oerke, 2006). Additionally, where conventional pesticides are used in sub-Saharan Africa, safety measures that protect farm workers in advanced countries are largely absent, with the consequence that a majority of human poisonings by pesticides on a global scale occur in Africa and in developing countries in other regions (Isman, 2008). These factors provide an impetus for the development and utilization of plant-based (= botanical) pesticides in sub-Saharan Africa, which has been the focus of at least two multinational efforts in recent years (Stevenson et al., 2017Stevenson et al., this issue), both culminating in international conferences.

Ironically, botanical insecticides well predate all the major classes of synthetic insecticides (organochlorines, organophosphates, carbamates, pyrethroids, neonicotinoids) (Isman, 2006). Pyrethrum, an oleoresin obtained from the flowers of *Tanacetum cinerariefolium* (Asteraceae), has been used for insect control for well over 150 years, and continues to be the dominant botanical insecticide in use worldwide today. Rotenone, obtained from the rhizomes of *Derris elliptica* (Fabaceae), has been used as a fish poison and insecticide for over 300 years, but its use as an insecticide, at least in North America and Europe, has been greatly curtailed in recent years. Azadirachtin from seeds of the Indian neem tree *Azadirachta indica* (Meliaceae), known for centuries for its

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http://dx.doi.org/10.1016/j.indcrop.2017.07.012
Received 11 April 2017; Received in revised form 4 July 2017; Accepted 5 July 2017

insecticidal properties in the Indian subcontinent, was only commercially exploited as a botanical insecticide 25 years ago, but products based on this plant have been developed on every continent in the past decade. Nicotine, from *Nicotiana tabacum* (Solanceae), was also long used as an insecticide, but like rotenone, has fallen out of favour in many regions owing to its acute toxicity to humans.

Although these are particular striking examples of plant substances that have been utilized by humans, terrestrial plants are well recognized as a rich source of novel chemistry; the majority of plant secondary compounds likely evolved as defensive agents against insects and other herbivores and plant pathogens. There are perhaps 100,000 or more "secondary plant metabolites", and hundreds (or more) have some demonstrated bioactivity in insects (at least in laboratory tests).

Bioactivities can be broadly categorized as behavioral (repellence, feeding deterrence, oviposition deterrence) or physiological (acute toxicity, developmental disruption, growth inhibition). According to a recent bibliometric analysis, scientific interest in this area has grown dramatically over the past 30 years: in 1980 < 100 papers focusing on botanical insecticides or insect-plant chemical interactions were published, whereas in 2011 over 1100 such papers were published (Isman and Grieneisen, 2014). With so many resources directed to research in this area, why are there so few botanical insecticides in practical use? Put another way, why is this abundance of scientific knowledge not being translated to practice?

In my opinion, the problem is that published research on botanical insecticides is heavily skewed ( > 80%) toward the discovery end of the R & D spectrum (e.g., "extract or oil of plant species X kills or repels pest species Y, under laboratory conditions"). So we have a very large "inventory" of plant extracts or compounds therefrom, but far fewer investigations on (i) methods of extraction on an industrial scale, (ii) formulation of plant extracts or oils into consistent, concentrated products, and (iii) best practices for the use of such products. Therefore, the translational gap between "theory" (i.e., the identification of insecticidal plants) and "practice" (i.e., the production of botanical insecticides and their use) exists because research has been heavily weighted toward the "discovery" end of the R & D spectrum (also referred to as "basic" research) as opposed to the technology transfer end (often called "applied" research).

For example, we already know of numerous plant species in sub-Saharan Africa, both endemic and introduced, that are suitable for the production of botanical insecticides (Table 1). These include neem (*Azadirachta indica*), which has been widely introduced into Africa, and the sweetsop (*Annona squamosa*, Annonaceae), from whose seeds a commercial insecticides are made in India, another region where this is an introduced species (Ribeiro et al., 2014).

Among native African plants, botanical insecticides can be prepared from *Tephrosia vogelii* (Fabaceae) and *Lippia javanica* (Lamiaceae), among others, as borne out by farmer surveys in eastern Africa (Nyirenda et al., 2011) and South Africa (Kamanula et al., 2010), and workshop participants in southern and eastern Africa (Anjarwala et al., 2016). Interestingly, while the majority (60–90%) of farmers in northern Malawi and eastern Zambia had some knowledge of pesticidal plants useful for stored product pest management, far fewer (10–22%) actually used them (Kamaanula et al., 2011). Similarly, in the same regions, fewer than 10% of farmers used botanicals for crop protection of tomato and *Brassica* crops, although among those with small landholdings, almost 80% had used some pesticidal plants (Nyirenda et al., 2011). The latter survey also revealed a willingness among farmers to cultivate pesticidal plants, indicating that they are sufficiently valued that farmers will provide a portion of their landholding for that purpose. An earlier study conducted in Ghana (Cobbinah et al., 1999) found that only a quarter of farmers surveyed used botanicals for stored product pest management, and fewer than 10% used them exclusively. Clearly, there is a strong impetus for the promotion of pesticidal plant use at the farm level ().

## 2. Finding a solution suitable for sub-Saharan Africa

I believe that we can bridge the gap between basic and applied research on botanical insecticides with the ultimate goal of putting these crop and animal protectants into the hands of farmers. This can be accomplished in two ways. First, while it is academically attractive to discover more pesticidal plants, I argue that we should choose a select number of plants from among the many already known to be suitable for producing botanical insecticides (e.g., those in Table 1). Second, subsequent R & D should be refocused on (i) methods for propagation and cultivation of one or more of the selected species; (ii) simple but efficient methods for extraction of active principles; (iii) simple methods to evaluate/validate bioactivity against target pest species; and (iv) field trials and demonstrations to optimize efficacy.

On the face of it, this seems like a tall order. But to the contrary, there is already a strong foundation of knowledge that can address many of these needs for several plants readily available in sub-Saharan Africa (Anjarwala et al., 2016).

I have previously discussed the main challenges for the commercial development of new botanical insecticides (Isman, 2006). These are 1. resource availability/sustainability of plant biomass, principally through cultivation of pesticidal plants, 2. stability, standardization and quality control, and 3. regulatory approval, often requiring extensive data on non-target toxicology and environmental fate. While these are all prerequisite for commercialization, they do not all apply to the situation of smallholder farmers utilizing locally available plants for their own use. The latter situation is arguable more, or at least equally, relevant for improving crop protection in sub-Saharan Africa.

## 3. A question of scale

It is the scale of production and use of a botanical insecticide that largely determines what technologies are necessary and appropriate to bridge the gap between identification of a pesticidal plant and its actual

**Table 1**
Some pesticidal plant species widely available in sub-Saharan Africa and suitable for the preparation of botanical insecticides.

| | Plant species (family) | Part(s) used | Known active principles |
|---|---|---|---|
| Endemic species | *Lippia javanica* (Burm. f.) Spreng (Verbenaceae) | foliage, essential oil | monoterpenes |
| | *Melia volkensii* Gurke (Meliaceae) | seeds, foliage | limonoid triterpenes |
| | *Ocimum gratissimum* L. (Lamiaceae) | aerial parts, essential oil | monoterpenes |
| | *Strychnos spinosa* Lam. (Loganiaceae) | fruits | iridoid glycosides |
| | *Tephrosia vogelii* Hook. f. (Fabaceae) | foliage | rotenoids |
| | *Vernonia amygdalina* Delile (Asteraceae) | foliage | sesquiterpene lactones |
| Introduced species | *Annona squamosa* L. (Annonacaeae) | seeds | acetogenins |
| | *Azadirachta indica* A.Juss. (Meliaceae) | seeds, foliage | azadirachtin, other limonoid triterpenes |
| | *Eucalyptus globulus* Labill. (Myrtaceae) | foliage, essential oil | monoterpenes |
| | *Lantana camara* L. (Verbenaceae) | aerial parts, essential oil | sesquiterpenes |
| | *Tagetes minuta* L. (Asteraceae) | aerial parts, roots | monoterpenes, thiophenes |
| | *Tithonia diversifolia* (Hemsl.) A.Gray (Asteraceae) | foliage | sesquiterpene lactones |