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Pesticidal plants in Africa: A global vision of new biological control products from local uses

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ABSTRACT

Botanical insecticides provide a multitude of chemistries for the development of new pest management products. Despite relatively low rates of expansion of botanically based pesticides, regulatory changes in many parts of the world are driving a renaissance for the development of new natural pest control products that are safer for human health and the environment. Africa is arguably the continent with the most to gain from developing natural plant-based pesticides. Hundreds of indigenous and exotic species with pesticidal properties have been reported from Africa through various farmer surveys and subsequent research, many of which have been confirmed to be active against a range of arthropod pests. On-farm use of pesticidal plants, particularly among resource-poor small-holder farmers, is widespread and familiar to many African farmers. Until recently, the pyrethrum industry was dominated by East African production through small holder farmers, showing that non-food cash crop production of pesticidal plants is a realistic prospect in Africa when appropriate entrepreneurial investment and regulatory frameworks are established. This paper reviews the current status of research and commercialisation of pesticidal plant materials or botanically active substances that are used to control pests in Africa and establishes where major gaps lie and formulates a strategy for taking research forward.

1. Introduction

Population growth to 9 billion and rising demands for food is increasing pressure on food production, meaning that global food demand will continue to increase for the next 30 years (Godfray et al., 2010). Growing demand for natural resources that underpin production and the urgent need to produce food sustainably will increase pressure on farming, while the impacts of climate change are an additional complicating threat. Severe crop losses from pests and diseases are two of the most important challenges to achieving sustainable global food security (Poppy et al., 2014). Perhaps nowhere on earth is this growing pressure on crops more acute than in Africa where 80% of food is produced by small holders farming land areas of less than 2 Ha, often on marginal degraded lands with little mechanisation or inputs (Stevenson and Belmain, 2016; Sibhatu et al., 2015).

Arguably the most important biological constraint to crop productivity for small holders are insect pests, as these are easily noticed and understood, and their effective control can be monitored with little training. Diseases, soil nutritional deficiencies and nematodes, on the other hand, are less tangible so arguably more challenging to control. Current approaches to insect pest control rely almost exclusively on the use of synthetic pesticides partly because alternative biorational approaches are not well-established in the market place (de Bon et al., 2014; Isman, 2006). However, the former can have serious secondary impacts on the environment through misuse and on consumers through persistence on fruit and vegetables (Mutengwe et al., 2016). Pesticides may often be overlooked due to their cost (Sola et al., 2014) or poor efficacy (Midega et al., 2016). Where pesticides are used, large-scale development of resistance and broad spectrum impacts on non-target invertebrates are making it much more difficult to justify and register synthetic pesticides.

The main approach to managing insect pests in agriculture has been the application of synthetic pesticides, and while this has expanded widely during the past few decades in Africa, pesticide expenditure per hectare is still low compared to other regions, and is thus typically less successful than in other parts of the world (Abate et al., 2000; Oercke and Dehne, 2004). This may be attributable in part to a lack of user training and literacy and the use of outdated and/or adulterated products. Despite the relatively lower use there is broad agreement that current use is potentially harmful owing to the well documented

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negative impacts on users and consumers (Rother, 2013; Williamson et al., 2008) and on the environment including beneficial insects (de Bon et al., 2014; Stevenson and Belmain, 2016). In a recent study in Nigeria, for example, almost 90% of pesticides being used were classified as highly hazardous or otherwise banned in developed countries while 95% of farmers had received no training in their use and more than 80% reported symptoms associated with acute pesticide poisoning (Oluwole and Cheke, 2009). Applications to a single crop are often excessive (Ngowi et al., 2007), while equipment and practises are typically poor, for instance, equipment is not cleaned properly nor do farmers wear any protective clothing (Matthews et al., 2003). To exacerbate this problem there is an absence of instruction, poor literacy and awareness about the dangers of misuse or how to estimate application rates for small land areas, little knowledge or information about key pests, diseases and beneficial insects, or the impacts of misuse (Ajayi and Akinnifesi, 2007; de Bon et al., 2014). Major pest insects are also developing resistance to insecticides (Carletto et al., 2010). Besides their hazardous side, synthetic pesticides also represent a significant cost for small holders and may not be widely available particularly in more remote regions, where this review is focussed, increasing the needs for appropriate and reliable alternatives (Belmain and Stevenson, 2001).

Effective alternatives to hazardous synthetic pesticides do exist for small holder farmers in Africa including biological control with fungi and viruses and harnessing natural enemies (Moshi and Matoju, 2017), as well as plant product applications with scope to self-harvest these materials (Grzywacz et al., 2014; Belmain and Stevenson, 2001). Our work over the past decade has focussed on optimising the applications of pesticidal plants in smallholder agriculture in Africa, and we investigated several plant species where knowledge on phytochemistry, mode of action and application were largely absent several of which are included in Table 1. Through this approach, improved applications for pesticidal plant materials have been developed with prospects for commercial development of some plant species currently used by small holder farmers. With this foundation of knowledge, pesticide applications based upon botanically active substances provide a viable alternative to synthetic pesticides. This paper reviews the current status of research and commercialisation of pesticidal plant materials or botanically active substances that are used to control pests in Africa, establishes where major gaps lie, and formulates a strategy for taking research forward in this area.

2. Botanical insecticides and pesticidal plants in Africa

Historically, botanical insecticides were the foundation of pest control until the advent of industrially produced synthetic chemicals; these new compounds eclipsed the efficiency and efficacy of plant chemicals and were produced in bulk as required. Their environmental and health drawbacks, as described above, led to a resurgence of interest in plant chemicals for pest control in the 1980s and 1990s that predicted a new dawn for botanical insecticides, but this fell well short of expectations (Isman, 2006). Only a handful of plant materials are registered for use across the globe and these make up only a small fraction of the technologies used (Isman, 2015). However, recent changes in regulations in Europe have stimulated renewed interest in plant chemistry with a vast increase in research on plant bioactivity as well as new expectations that plant compounds might provide models for new chemistries. More products of increasingly diverse origin are being registered globally (Isman and Grieneisen, 2014; Gerwick and Sparks, 2014).

As commercial products, botanical insecticides have necessarily undergone sophisticated processing that ensures quality and consistency and are sold as high value products of uniform efficacy and provenance such as those based on neem and pyrethrum (Duke et al., 2010). To remote smallholder farmers in Africa, however, these products differ little from synthetic chemicals in terms of their cost and availability − two important considerations for low input farming (Stevenson and Belmain, 2016). The use of crude plant based materials that are home harvested and prepared using only basic technology is where plants may have most to offer small holders, and in Africa this approach is currently and has been historically widespread (Isman, 2008; Belmain and Stevenson, 2001). To illustrate this point, Kenya once provided up to 80% of the global demand for pyrethrum, yet pyrethrum products are still only registered for domestic uses on pets in Kenya. Hence, there is little evidence that the experience of commercial production of plant based pesticides has influenced agricultural practice of the continent. There is, however, considerable evidence that other pesticidal plants are used as crudely produced products among small holder farming communities in Africa (Kamanula et al., 2011; Nyirenda et al., 2011) where increasing scope to optimise pesticidal plant use, but also to identify novel chemistries might provide models for new products (Moshi and Matojou, 2017; Gerwick and Sparks, 2014). Our recent work funded under two EU projects (http://projects.nri.org/options and http://projects.nri.org/adappt) has identified numerous novel chemistries or activities in plants that have been reported as botanically active substances through direct surveys and these add to the growing knowledge about botanically active substances in Africa (Table 1). *Securidaca longepedunculata*, for example, is an indigenous multiple use small tree species growing across Africa and is reportedly used for the protection of stored grain from weevil damage (Burkill, 1997). Biological activity in this species is associated with root compounds including methyl salicylate and saponins (Fig. 1) that respectively provide rapid repellence or knockdown and longer term efficacy in laboratory based bioassays (Stevenson et al., 2009; Jayasekera et al., 2005; Jayasekera et al., 2002). Similarly, *Zanha africana* (Radlk.) Exell (Sapindaceae), another indigenous tree species across Southern and Eastern Africa (Swanepoel, 2013), was reported to be a pesticidal plant during our project surveys in Tanzania. Smallholder farmers use ground root bark powder to protect stored beans from bruchids (Mkoga et al., 2004). This genus was already known as a source of medicine (Bruschi et al., 2011) with activity in bark reported against trypanosomiasis (Nibret et al., 2010), bacterial and fungal pathogens (Kambizi and Afolayan, 2001; Fabry et al., 1996), and as an anti-inflammatory (Recio et al., 1995). Despite widespread use, several rare and novel *nor*-hopanes (Fig. 2) were only recently identified in this species (Stevenson et al., 2016) and shown to be responsible for the biological activities reported by farmers.

While novel chemistries present compelling research avenues, there are many plant species already known in Africa and globally that have recognised biological activities (Table 1), and there is a strong argument for consolidating what knowledge we already have about these species and enabling their exploitation both for small scale and commercial use (Isman and Grieneisen, 2014; Isman 2017). However, even for well-known species there are underlying issues that must be resolved to ensure that their use and exploitation is effective. One particularly pertinent example in Africa is *Tephrosia vogelii* Hook. f. (Leguminosae). *Tephrosia* Pers. is a large pantropical genus of more than 350 species, many of which have important traditional uses (Schrire, 2005). Among these species, *T. vogelii* has been used widely across Africa as a pesticide and a fish poison, but also for improving soil quality (Burkill, 1995; Kamanula et al., 2011; Mafongoya and Kuntashula, 2005; Neuwinger, 2004; Nyirenda et al., 2011; Sileshi et al., 2005; Sirrine et al., 2010). Farmer surveys in Malawi have identified this species as particularly important to farmers in stored product pest control (Nyirenda et al., 2011; Kamanula et al., 2011); however, many farmers reported that this species was ineffective (Stevenson and Belmain, 2016). Chemical analysis of plant material across Malawi identified two distinct chemotypes, one containing rotenoids well known for their biological activity against insects (Isman, 2006) and the other characterised by flavones, flavanones and flavonols (Stevenson et al., 2012) (Fig. 3). Subsequent bioassays revealed that the pesticidal and insecticidal activities of *T. vogelii* were due to the presence of rotenoids,