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# Invasive weeds with pesticidal properties as potential new crops

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ABSTRACT

Plants with pesticidal properties have been investigated for decades as alternatives to synthetics, but only a handful have been commercialised and developed as non-food cash crops. One of the reasons why pesticidal plants are failing to deliver new pesticidal products is that they are often not evaluated under field conditions by farmers. Furthermore, many aspects of pesticide use related to environmental safety, such as their impact on beneficial organisms, remain under-evaluated. With a view to overcoming these bottlenecks, extracts made from six abundant weed species found across sub-Saharan Africa (*Bidens pilosa*, *Lantana camara*, *Lippia javanica*, *Tithonia diversifolia*, *Tephrosia vogelii* and *Vernonia amygdalina*) were evaluated in on-station and on-farm trials over two years (2015 and 2016) in two different countries (Tanzania and Malawi) on common bean plants (*Phaseolus vulgaris*). All plant species offered effective control of key pest species that was comparable in terms of harvested bean yield to a synthetic pyrethroid. Furthermore, the plant pesticide treatments had significantly lower negative effects on natural enemies (hover flies, lacewings, ladybird beetles and spiders). Thus, pesticidal plants were better able to support ecosystem services whilst effectively managing pests. Small holder farmer rankings on their perceived efficacy of the different plant species indicated that *T. vogelii* was the most preferred and effective, achieving bean yields as good as the synthetic, if not better. As *T. vogelii* is fast growing with a well-known and understood phytochemistry, it is an excellent candidate for commercial development to supplement pyrethrum production by African small holder farmers.

## 1. Introduction

Common beans (*Phaseolus vulgaris* L.) (Fabales: Fabaceae) are rich in protein so are a critical food source for small holder African farmers but are also a good source of key nutrients for physical and mental development (Fuente Martínez et al., 2012; Messina, 1999). Insect pests are one of the most common constraints affecting production of beans and particularly affect production in sub-Saharan Africa (Food and Agriculture Organisation Statistics Division, 2015). Due to the severity of different insect pests affecting beans, many African farmers increasingly resort to frequent use of commercial synthetic pesticides (Abate and Ampofo, 1996). Such pest management practices are increasingly criticised as unsustainable and difficult to incorporate into agro-ecological intensification programmes aimed at developing sustainable agricultural practices and promoting ecosystem services (Bommarco et al., 2013; Pretty et al., 2011; Tittonell and Giller, 2013).

Plants with pesticidal properties have been investigated for decades as alternatives to synthetics, but little progress has been made to develop new products (Isman, 2008, 2006). Although research on pesticidal plants is increasing, it is failing to address gaps in our knowledge that constrain their adoption (Isman and Grieneisen, 2014). One of these gaps is their evaluation under realistic field conditions to assess their efficacy as well as whether their use can be beneficial to farmers. In comparison to concentrated synthetic products, pesticidal plants should be more environmentally benign due to their short persistence, naturally low concentrations of a more diverse suite of active ingredients and anti-feedant/repellent modes of action. Although there are some studies highlighting the relative benefits of pesticidal plants for ecosystem services, such as increased biological control (Amoabeng et al., 2013), there are relatively few studies which provide comparative evidence of ecosystem impact of synthetics and pesticidal plants under field conditions (Grzywacz et al., 2014).

Commercial production of non-food cash crops, such as pesticidal plants, can be a way to provide small holder farmers with alternative

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income sources (Sibhatu et al., 2015; Sola et al., 2014). The best example of this in Africa is the pyrethrum industry where many small holder farmers across several East African countries grow the chrysanthemum flower *Tanacetum cinerariaefolium* (Asterales: Compositae), selling the product to an international export market (Cassida, 2012). Efforts to increase pyrethrum production and to develop neem-based (*Azadirachta indica*) (Sapindales: Meliaceae) products in Africa have faced growing international competition from Australia, China, India and Brazil (Isman, 2004; Wilson, 2014). However, many other plant species with pesticidal properties have been documented to be used in sub-Saharan Africa (Anjarwalla et al., 2016; Belmain and Stevenson, 2001), many of which could have potential to be developed as new non-food crops. Particularly fast-growing weed species that are often highly abundant and invasive could be relatively easy to propagate at large scale for processing in to new botanical pesticides. Thus the aims of our study were to: (1) investigate the field use of pesticidal plants, particularly weed species that are widely available and abundant in bean production ecosystems, for insect pest control on common bean; (2) compare the effects of a common synthetic pesticide and pesticidal plants on the level of pest control and their potential effects on beneficial insect species; and (3) determine which plant species may be most suitable for development in to a natural pesticide as a non-food cash crop.

## 2. Materials and methods

### 2.1. Study site

The study was conducted at field sites in Tanzania and Malawi over two years. During 2015, a central field trial was carried out at Lyamungo, Hai District, Tanzania (Latitude 3°13′59.59″S Longitude 37°14′54″E). This was supported by 40 additional smaller field plots (< ha) provided by 40 different small holder farmers around Hai District carrying out field trials over two cropping seasons (March–June 2015 and 2016). All field sites in Tanzania were at an elevation between 1100–1300 masl with a mean annual rainfall of 1200 mm, mean maximum temperature of 21.7 °C and mean minimum temperature of 13.6 °C. For Malawi, a central field trial was carried out during 2015 at Bunda, Mitundu, Malawi (Latitude 14°13′.200 S Longitude 33° 48.218 E). This was supported by 40 additional smaller field plots (< ha) provided by 40 different small holder farmers around Mitundu carrying out field trials over two cropping seasons (January to April 2015 and 2016). All field sites in Malawi were at an elevation between 1100 and 1200 masl with a mean annual rainfall of 700 mm, mean maximum temperature of 29 °C and mean minimum temperature of 17 °C.

### 2.2. Experimental design

The central field trials were disc harrowed and ridged prior to planting. The common bean (*P. vulgaris*) seeds used for planting were of the variety Lyamungo 90 in Tanzania and Kalima in Malawi. The seeds were planted at a spacing of 50 cm between rows and 20 cm within rows in 5 × 5 m plots which were 1 m apart. Three seeds were seeded per hill and then thinned to two plants. Diammonium phosphate fertilizer was applied according to manufacturer's instructions during planting of the seeds. The experimental layout was a randomized complete block design, and the treatments were replicated on four blocks.

The 40 farmer fields in both countries had considerable variation in terms of land preparation and in the spacing of plants and we made no attempt to control these variables as we wanted to understand whether the pesticidal plant treatments would perform similarly under farmer field conditions. Furthermore, in order to reflect common bean growing practices in Tanzania, half of the farmers (20) planted beans as a monocrop whilst the other half (20) planted beans as an intercrop with maize (*Zea mays*).

### 2.3. Plant species collection and processing

Fresh leaves of *Tephrosia vogelii* (Hook f.) (Fabales: Fabaceae), *Vernonia amygdalina* (Delile) (Asterales: Asteraceae), *Lippia javanica* (Burm.f.) Spreng. (Lamiales: Verbenaceae), *Tithonia diversifolia* (Hemsl.) A. Gray (Asterales: Asteraceae), *Bidens pilosa* L. (Asterales: Asteraceae) and *Lantana camara* L. (Lamiales: Verbenaceae) were collected from different locations around Hai District and Mitundu District (voucher specimens and GPS coordinates lodged at Nelson Mandela African Institution of Science and Technology, Arusha, Tanzania and Lilongwe University of Agriculture and Natural Resources, Bunda, Malawi). The first four plant species were included in all field and farm trials over 2015 and 2016. *B. pilosa* and *L. camara* were added to the farmer trials carried out in 2016. These six species were chosen due to their wide abundance around farms, roadsides and bushland, their familiarity to farmers and considerable existing knowledge on their efficacy, bioactive constituents and safety (Adedire and Akinneye, 2004; Adeniyi et al., 2010; Ambrósio et al., 2008; Asawalam et al., 2008; Bagnarello et al., 2009; Belmain et al., 2012; Gadzirayi et al., 2009; Ganjian et al., 1983; Gu et al., 2002; Kawuki et al., 2005; Madzimure et al., 2011; Mujovo et al., 2008; Oyewole et al., 2008; Pereira et al., 1997; Stevenson et al., 2012; Viljoen et al., 2005). To ensure uniformity, the leaves from each seasonal collection were mixed together for each species before drying. Leaves were dried under shade for a week and then crushed using a mill and sieved into a fine powder. Powders were stored in black plastic bags in dark, dry conditions until required.

### 2.4. Field treatments

For the 2015 field trial carried out in Tanzania and Malawi, three different concentrations of each of the four plant species (*T. vogelii*, *V. amygdalina*, *L. javanica*, *T. diversifolia*) were made (0.1%, 1.0% and 10% w/v) in order to determine potential concentration effects. In making all extracts, the correct amount of plant powder was weighed and added to water to extract at ambient temperature (20 ± 5 °C) for 24 h. In all cases 0.1% soap was added to the water during extraction as this has been shown previously to increase the extraction efficiency of nonpolar compounds present in the plant materials (Belmain et al., 2012). Extracts were kept in 10 l buckets with lids in the shade and filtered through a fine cloth to remove all plant material that may inadvertently clog the sprayer. Negative controls consisted of water + 0.1% soap and water only. The positive control in all trials was synthetic pesticide Karate 5 EC (lambda-cyhalothrin pyrethroid, Syngenta) which was applied as per the manufacturers' instructions (20 g/ha). All treatments and controls were replicated across four blocks. All treatments were sprayed throughout the growing season at an interval of 7 days starting one week after bean plant emergence. A 15-l knapsack sprayer was used to apply the various treatments, and the sprayer was thoroughly cleaned with soap and water prior to being re-filled with another formulation for application.

For the 2015 farmer trials, each farmer had eight treatments which were applied to different delimited areas of the crop field. To simplify the on-station protocol, farmers applied each of the four plant materials only at the highest rate of 10% w/v + 0.1% soap. Each farmer also had three negative control plots (untreated, water only, water + soap) and a positive control (Karate). Each plot size was approximately 5 $m^2$, with at least 2 m distant between plots and all plots were at least 2 m away from the crop field edge. Plot corners were staked, with string drawn around perimeter and labelled with the treatment name so that farmers would not confuse treatments. A further parameter at the farm level (in Tanzania only) was to involve farmers that planted beans as an intercrop with maize where rows of beans and maize alternated with each other, as well as farmers planting beans as a mono-cropped field. Individual plant spacing on farmer fields was not controlled but was similar to plant spacing used for the central field trials. As with the central on-station field trial, all farmer field treatments were sprayed at