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Cost:benefit analysis of botanical insecticide use in cabbage: Implications for smallholder farmers in developing countries

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ABSTRACT

Botanical insecticides based on plant extracts are not widely used as crop protectants even though they can be produced simply from locally available plants. Many studies have examined efficacy but there is a paucity of information on the cost:benefit ratio of their use compared with conventional insecticides. In the present study, crude extracts of *Ageratum conyzoides* (Asterales: Asteraceae), *Chromolaena odorata* (Asterales: Asteraceae), *Synedrella nodiflora* (Asterales: Asteraceae), *Nicotiana tabacum* (Solanales: Solanaceae), and *Ricinus communis* (Malpighiales: Euphorbiaceae) were compared with the synthetic insecticide, emamectin benzoate (Attack®) against insect pests of cabbage in randomised, replicated field experiments during the major and minor rainy seasons of 2012 in Ghana. The cost of each treatment including material and labour was calculated and the revenue of each derived using the value of the marketable yield of cabbage. The cost:benefit ratios of sprayed treatments were derived by comparing the cost of each plant protection regime against the additional market value of the treatment yield above that obtained in the control treatment. With the exception of plots sprayed with *N. tabacum*, the cost of plant protection using Attack® was higher than any of the botanicals in both seasons. The highest cost:benefit ratio of 1: 29 was observed for plots sprayed with *C. odorata* and was followed closely by *N. tabacum* treatment with 1: 25 and Attack® with 1: 18. In the minor season, plots sprayed with Attack® had the highest cost:benefit ratio of 1: 15 and was followed closely by *N. tabacum* with 1: 14. Botanical insecticides differed markedly in levels of pest control and cost:benefit but some were comparable to that from conventional insecticide use whilst being produced easily from locally available plant materials and are likely to be safer to use for smallholder farmers and consumers in developing countries.

1. Introduction

To reduce the negative impacts of synthetic insecticides, safer alternative approaches to managing pests of vegetables must be considered by growers, especially those who do not have the expertise and equipment for safe handling and use of synthetic insecticides (Ntow et al., 2006; Coulibaly et al., 2007). Whilst novel, less hazardous forms of insecticides such as insect growth regulators (Valentine et al., 1996) a range of non-chemical pest management techniques is available (Gurr and Kvedaras, 2010), approximately three million agricultural workers experience pesticide poisoning each year globally, and about 20,000 deaths are directly linked to agrochemical use (Dinham, 2003; Darko and Akoto, 2008). Less than 1% of pesticides applied on crops reach the target pest, the rest can contaminate soil, water, air and food (Koul et al., 2004). In developing countries such as Ghana food commodities often contain pesticide residues, often above the maximum residue limit (Darko and Akoto, 2008; Armah, 2011). In Ghana pesticides have been found in water, sediments, food commodities and even breast milk in areas where intensive vegetable production occurs due to injudicious use of synthetic insecticides (Ntow et al., 2006; Essumang et al., 2008; Bempah et al., 2011).

In many developing countries, farmers are illiterate or speak and read indigenous dialects, whilst pesticides labels are printed in

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foreign languages (Isman, 2008). For example, even though Ghana's official language is English, it is not uncommon to find pesticides on the market that are labelled in French or Chinese (Asante and Ntow, 2009), a practice which exacerbates the inability of farmers to understand pesticides labels. This leads to unacceptable practises in handling and use of pesticides by some farmers such as tongue-testing of diluted insecticides to determine their potency (Ntow et al., 2006; Timbilla and Nyarko, 2006; Williamson et al., 2008; Asante and Ntow, 2009).

Nearly 75% of all deaths associated with pesticidal poisoning occur in developing countries even though they use only 15% of global pesticide supply (Koul et al., 2004; Darko and Akoto, 2008; Armah, 2011). The use of banned insecticides, applying insecticides in excess of the recommended rates due to insects resistance, using insecticides meant for industrial crops such as cocoa and cotton for vegetables, using empty pesticides containers for storing drinking water are practised in Ghana and often lead to pesticidal poisoning (Ntow et al., 2006; Williamson et al., 2008).

Botanical insecticides based on specific compounds or crude extracts from plants with activity against insects offer a safer alternative for managing pests such as the diamondback moth (DBM), *Plutella xylostella* L. (Lepidoptera: Plutellidae), a key pest of crucifers which has developed resistance to most of the available synthetic insecticides (Kianmatee and Ranamukhaarachchi, 2007; Isman, 2008; Ogendo et al., 2008; You et al., 2013). Botanicals are also usually safer for non-target organisms, making them preferable to the synthetic insecticides (Charleston et al., 2006).

In a survey, Gerken et al. (2001) showed that between 14% and 25% of farmers in Ghana, used traditional products for crop protection. Plants such as *Azadirachta indica* A. Juss. (Sapindales: Meliaceae), *Cassia sophera* L. (Fabales: Fabaceae), *Cymbopogon schoenanthus* (L.) (Poales: Poaceae), *Ocimum americanum* L. (Lamiales: Lamiaceae), *Securidaca longepedunculata* Fres. (Polygalales: Polygalaceae), *Synedrella nodiflora* Gaertn. (Asterales: Asteraceae), *Chromolaena odorata* (L.) L. M. King & Robison (Asterales: Asteraceae), *Capsicum frutescens* L. (Solanales: Solanaceae), *Allium sativum* L. (Asparagales: Amaryllidaceae) and *Carica papaya* L. (Brassicales: Caricaceae) have been used in Ghana (Owusu, 2000; Belmain and Stevenson, 2001; Obeng-Ofori and Ankrah, 2002; Fening et al., 2011). A study in Uganda revealed that crude aqueous extracts of locally available plants such as tobacco and *Tephrosia* sp. were as efficacious as Cypermethrin® and Fenitrothion® (synthetic insecticides) in reducing damage caused by bruchid beetle, *Callosobruchus* sp. in cowpea (Kawuki et al., 2005). In Nigeria, extracts of garlic, chilli pepper, neem, ginger *Zingiber officinale* Rosc. (Zingiberales: Zingiberaceae), tobacco, *Nicotiana tabacum* L. (Solanales: Solanaceae) and sweetsop, *Annona squamosa* L. (Magnoliales: Annonaceae) have been used to manage field pests of cowpea (Ahmed et al., 2009).

Farmers who adopt botanicals as a means of plant protection may enhance the activity of natural enemies. For example extracts of neem and *Melia azedarach* L. (Sapindales: Meliaceae) were sprayed on the parasitoids, *Cotesia plutellae* (Kurdjumov) (Hymenoptera: Braconidae) and *Diadromus collaris* (Gravenhorst) (Hymenoptera: Ichneumonidae) in a laboratory bioassay and found not to cause harm (Charleston et al., 2006). Similarly, application of *A. squamosa* L. (Magnoliales: Annonaceae) and *Aglaia odorata* Lour. (Sapindales: Meliaceae) controlled DBM whilst having no negative impact on natural enemies (Dadang and Prijono, 2009). Ayalew and Ogol (2006) advised that the use of harmful pesticides be discontinued in favour of less harmful ones such as neem-based products to achieve the potential of natural enemies in managing DBM and other pests of crucifers. Reflecting this, DBM was not a major pest of brassicas in China until the early 1960s when large scale application of synthetic insecticides was introduced to commercial vegetable farming (Liu et al., 2000).

Despite the foregoing potential advantages of botanical insecticides, they have not gained widespread usage globally. The causes of this are complex. Farmers usually want a very rapid knock-down to demonstrate effective application to the crop yet many botanical insecticides operate more slowly and some by modes of action other than toxicity (repellence for example) (Isman, 2006). Second, the availability of many potentially effective botanicals is constrained in many countries by the need to meet expensive regulatory requirements that mean only products that can service a large market are registered. Further, the costs, availability and consistency of plant materials may be a limiting factor. One aspect of this is inconsistent activity of different provenances in the same plant species which can mean that farmers often use plant materials that do not always work (Stevenson et al., 2012). The approach of smallholder farmers preparing their own inexpensive botanical insecticides from locally-available plant materials offers a solution to these problems. The use of botanicals must, however, be economically viable if their potential is to be realised. The plant materials from which botanical insecticides are made are often available locally and are usually obtained without cost (Belmain et al., 2001) making them cheaper compared to their synthetic counterparts. Though the efficacy of various botanical insecticides has been explored in many studies that report pest numbers and, often, effects on natural enemies, there are few reports of the yields from crops treated with botanical insecticides and a dearth of information on the cost:benefit ratios for botanical insecticides compared with conventional insecticide use. This study quantified the costs and benefits of using crude extracts of readily available insecticidal plant materials, an untreated control and a synthetic insecticide in controlling insect pests of cabbage in Ghana.

2. Materials and methods

2.1. Costs

The costs of plant protection were recorded in two field experiments conducted during the major and minor rainy seasons of 2012 at the Crops Research Institute, Kumasi, Ghana. Plant protection treatments of crude extracts of readily available insecticidal plants (botanicals) were compared with the synthetic insecticide, emamectin benzoate (Attack®) and an unsprayed control. Botanicals involved in the study were the goat weed (*Ageratum conyzoides* L.) (Asterales: Asteraceae), Siam weed (*C. odorata*), Cinderella weed (*S. nodiflora*), tobacco (*N. tabacum*), and castor oil plant (*Ricinus communis* L.) (Malpighiales: Euphorbiaceae). Most plant materials were collected from weedy, uncultivated areas in the immediate vicinity of the test site and without purchase therefore the associated costs were only labour for the collection, preparation and application plus the value of the soap for extraction. However, since tobacco has commercial value and leaves that could have been sold were used in preparing the extract, the amount that would have been realised from the sale of the leaves was added as a cost in addition to other costs as described above for other botanicals. For plant protection using Attack®, the cost of the insecticide was added to the labour cost of spraying. Throughout the study, labour cost was based on the existing wage for an unskilled labour at the locality at the time of the study which was equivalent to US$ 8.33 per man day. Treatments were prepared as detailed in Amoabeng et al. (2013) and compared in field experiments with four replicates and plot size of 1.5 m × 2.5 m at spacing of 0.5 m × 0.5 m resulting in 24 plants per plot. For the purposes of the economic analyses, values were calculated on a per hectare basis. In the major season, a total of 2 days of labour were used for collecting and preparing the botanicals afresh for each of the botanical treatments.

There were six sprayings in the major rainy season whilst the minor season experiment received seven sprayings. This frequency of spraying was used to give comparability with local practice in the use of synthetic insecticides. A total of 18 days of labour was costed for spraying each of the treatments. Sunlight® liquid soap for extraction of each botanical was purchased for US$ 2.00. Attack® was costed at US$ 99.11/ha for six applications.

In the minor season, 14 man days were used for the collection and preparation of each botanical whilst 20 man days were used for spraying. Sunlight® liquid soap was purchased for US$ 2.00 whilst US$ 19.44 was used to purchase tobacco leaves. Cost of Attack® was US$ 122.33 and 20 man days were required for spraying. The externalities such as potential impacts on the environment, natural enemies, and farm worker and consumer safety associated with each of the treatments were not considered in the analyses.

At harvest, plot yields were weighed and recorded. Cabbage heads from each plot were sorted into undamaged or with caterpillar feeding damage, individually weighed and sold at the prevailing price on the local market. The Ghanaian currency, Cedi (¢) was converted to US$ at the prevailing exchange rate of US$ 1: ¢1.8 during the study period. Undamaged heads fetched US$ 0.56 and US$ 0.83 per kg for the major and minor seasons respectively whilst damaged heads fetched one-third of these prices. Revenue was converted to a per hectare basis by extrapolating the plant population of plots based on a plant spacing of 0.5 m × 0.5 m taking into account unplanted alleys to facilitate movement within the field. This resulted in a total plant population of 35,000 per hectare.

2.2. Economic analysis

Mean head weight per plant, percentage of damaged heads and undamaged head yield per hectare were subjected to analysis of variance of statistical analysis system (SAS) (SAS, 2005). Percentage data were arcsine square root transformed prior to the statistical analysis. On achieving significant differences ($P < 0.05$) mean separation was performed using Student Newman–Keuls test. The number of undamaged heads per treatment was multiplied by average head weight per plant to obtain yield per hectare for each treatment. Total income was obtained by adding incomes from undamaged heads and that of damaged heads. Income from undamaged yield was obtained by multiplying the head yield per hectare by the selling price per kg of cabbage head. Income from damaged heads was obtained by multiplying damaged head yield by selling price per kg of damaged heads. No premium was achieved for the botanical-sprayed produce. Net benefit per hectare for each treatment was derived by subtracting the total cost of plant protection from total income (Shabozoi et al., 2011). Benefit over unsprayed control for each sprayed treatment was obtained by subtracting the income of the control treatment from that of each sprayed treatment. The cost:benefit ratio of each treatment was derived by subtracting the income of the control treatment from the net income of each sprayed treatment and the products were divided by total cost of plant protection for each treatment (Shabozoi et al., 2011).

3. Results

3.1. Yield and income

All botanical treatments and the synthetic insecticide in both seasons were superior financially compared to the control treatment in which cabbages were heavily attacked by DBM and cabbage aphid, *Brevicoryne brassicae* (L.) (Hemiptera: Aphididae). Accordingly, treatments other than the control had higher undamaged head yields which resulted in revenue that exceeded the cost of the plant protection regime (Tables 1and 2). The cost of plant protection using Attack® was higher than all of the botanicals for the two seasons except tobacco. There were differences in the total cost of plant protection between the major and the minor rainy season because there was one spray more in the minor season than in the major rainy season. In the major rainy season, plots sprayed with an extract of Siam weed or tobacco recorded the highest undamaged cabbage head yield of 22.1 and 20.9 t/ha respectively; significantly higher than other treatments including Attack® at 18.0 t/ha (Table 1). Yields of plots sprayed with goat weed and castor oil plant extracts were 13.7 and 11.8 t/ha respectively which were not significantly higher than the control which yielded 9.9 t/ha. In the minor rainy season, Attack® gave an undamaged yield of 12.2 t/ha and was followed by tobacco at 12.0 t/ha. However, there were no significant differences in undamaged yield per hectare between the treatments though all had significantly higher undamaged yields than the control which produced just 6.3 t/ha (Table 2).

Undamaged head yields were higher in the major rainy season than the minor season but total income for the minor rainy season was comparatively higher due to the higher market price. Whilst a yield of 11.8 t/ha in the major rainy season gave a total income of US$ 7171 a slightly lower yield of 11.4 t/ha had total income of US$ 9858 in the minor rainy season. Even though income from damaged heads contributed to the total income for all treatments, the amounts were small and not markedly different among the treatments. The highest benefit over the control treatment of US$ 6700 was obtained from plots sprayed with an extract of Siam weed in

Table 1
Major rainy season evaluation of the cost and benefit of managing cabbage pests with botanical and synthetic insecticides.

Treatment	Mean head weight per plant (kg)[a]	Percent damaged heads	Undamaged head yield (t/ha)	Cost of plant protection (US$/ha)	Income from un-damaged heads (US$/ha)	Income from damaged heads (US$/ha)	Total income (US$/ha)	Net benefit (US$/ha)	Benefit over unsprayed treatment (US$/ha)	Cost:benefit ratio
Goat weed	0.44 ± 0.08bc	11.1 ± 3.26abc	13.7 ± 2.70bc	231.89	7244	324	7586	7355	1446	1:6.2
Siam weed	0.70 ± 0.05a	9.7 ± 1.37bc	22.1 ± 1.75a	231.89	12,389	451	12,840	12,608	6700	1:28.9
Cinderella weed	0.53 ± 0.06ab	11.1 ± 3.26abc	16.5 ± 2.10b	231.89	9234	391	9626	9394	3486	1:15.0
Tobacco	0.67 ± 0.03a	11.1 ± 1.41abc	20.9 ± 1.05a	248.56	11,805	494	12,300	12,051	6143	1:24.7
Castor oil plant	0.42 ± 0.05bc	19.5 ± 1.38ab	11.8 ± 1.75bc	231.89	6626	544	7171	6939	1031	1:4.4
Attack®	0.56 ± 0.03ab	8.0 ± 0.00c	18.0 ± 1.10b	238.00	10,097	297	10,395	10,157	4249	1:17.9
Control	0.35 ± 0.03c	21.0 ± 2.39a	9.9 ± 1.21c	0.00	5419	488	5908	5908	0	–

Means within columns with different letters differ significantly ($P < 0.05$).
[a] Means calculated from the same raw data used in Amoabeng et al., (2013).

Table 2
Minor rainy season evaluation of the cost and benefit of managing cabbage pests with botanical and synthetic insecticides.

Treatment	Mean head weight per plant (kg)[a]	Percent damaged heads[a]	Undamaged head yield (t/ha)	Cost of plant protection (US$/ha)	Income from un-damaged heads (US$/ha)	Income from damaged heads (US$/ha)	Total income (US$/ha)	Net benefit (US$/ha)	Benefit over unsprayed treatment (US$/ha)	Cost:benefit ratio
Goat weed	0.35 ± 0.01a	16.0 ± 1.07ab	10.3 ± 0.35a	287.01	8540	584	9089	8802	3090	1:10.8
Siam weed	0.36 ± 0.02a	13.5 ± 1.04bc	10.9 ± 0.70a	287.01	904	476	9522	9235	3523	1:12.3
Cinderella weed	0.35 ± 0.03a	11.5 ± 2.01bc	10.9 ± 1.05 a	287.01	8998	394	9392	9106	3393	1:11.8
Tobacco	0.39 ± 0.02a	12.5 ± 1.71bc	12.0 ± 0.70a	306.44	9913	477	10,391	10,089	4372	1:14.3
Castor oil plant	0.37 ± 0.01a	12.5 ± 1.7bc	11.4 ± 0.35a	287.01	9404	453	9858	9571	3859	1:13.4
Attack®	0.38 ± 0.01a	8.5 ± 2.10c	12.2 ± 0.35a	289.00	10,100	316	10,417	10,128	4416	1:15.3
Control	0.23 ± 0.01b	21.9 ± 2.45a	6.3 ± 0.35b	0.00	5218	493	5711	5712	0	–

Means within columns with different letters differ significantly ($P < 0.05$).
[a] Means calculated from the same raw data used in Amoabeng et al., (2013).

the major rainy season whilst the lowest was US$ 1031 obtained from plots sprayed with an extract of castor oil plant. The Attack® treatment had an intermediate benefit over control treatment of US$ 4249. The difference between the highest and the lowest benefit over control treatment was US$ 5669. In the minor rainy season, the highest benefit over the control treatment of US$ 4416 was obtained from plots sprayed with Attack®. Plots sprayed with an extract of tobacco had benefit over control of US$ 4372. There were only slight differences in the benefit over the control treatment obtained from the treatments. Difference between the highest and the lowest benefit over the control in the minor rainy season was US$ 1326.

3.2. Cost:benefit

In the major rainy season, the best cost:benefit ratio of 1:29 was for Siam weed treatment in the major rainy season. It was followed by the tobacco treatment with a cost:benefit ratio of 1:25. Plots sprayed with Attack® had a cost:benefit ratio of 1:18. The lowest cost:benefit ratio of 1:4 was obtained for plots sprayed with an extract of castor oil plant. In the minor rainy season, the highest cost:benefit ratio of 1:15 was observed for plots sprayed with Attack® which was followed closely by plots sprayed with an extract of tobacco with 1:14. The lowest cost:benefit ratio in the minor rainy season was 1:11 and observed on plots sprayed with an extract of goat weed.

4. Discussion

In the major season, Siam weed and tobacco gave higher total income than Attack®. These two treatments produced significantly higher undamaged head yield than the rest of the treatments and resulted in higher incomes. In the minor rainy season only slight differences in income was observed among the treatments. This was because there were no significant differences between sprayed treatments in undamaged yields to result in higher differences in income. In this study tobacco was more costly to use than Attack®. This is because tobacco is a commercially valuable crop and marketable leaves were used in preparing the extracts, thus, attracting cost. The labour cost of preparation in addition to the cost of purchase of tobacco leaves accounted for higher cost in using tobacco in this study. However, tobacco was more financially beneficial to use than Attack® in the major rainy seasons. This was because plots sprayed with extract of tobacco produced significantly higher yields with corresponding higher total income enough to offset the higher cost associated with its use. If extracts of tobacco based on crop residues and malformed leaves were shown to be efficacious, the cost associated with their use could be reduced so giving a still more attractive cost:benefit ratio.

4.1. Labour cost

Even though farmers may obtain insecticidal plant materials without material cost, the labour associated with collection and preparation is usually significant which makes the total cost of plant protection with botanicals close to that of purchasing and using the synthetic insecticide option. In a study to develop simple botanicals for farmers in Ambon (Indonesia), Leatemia (2003) reported that less economic benefit may be derived from the use of botanicals due to the labour cost involved in collection and preparation. Labour cost at the location where botanicals are used will be an important factor of the overall benefit that would be derived from their use. In several parts of the developing world, many resource-limited farmers do not have the financial capacity to purchase synthetic insecticides or commercially formulated botanicals but have free and adequate labour to prepare and use botanicals irrespective of the labour requirements. Thus, they will still find the use of locally prepared botanicals more convenient.

4.2. Cost:benefit ratio

Cost:benefit ratio is an indicator of the relative economic performance of the treatments (Aziz et al., 2012). A ratio of more than one indicates the economic viability of the treatment compared with the control treatment. In this study, cost:benefit ratios of between 1:29 and 1:4 indicate that treatments were biologically effective and resulted in significant return on investment in plant protection. Siam weed and tobacco were more economically viable than Attack® in the major rainy season but Attack® was marginally superior to the most active botanicals in the minor rainy season. Siam weed and tobacco consistently gave better cost:benefit ratio than other botanicals. However, since all the botanicals gave cost:benefit ratios more than one, farmers have the option of selecting from an array of botanicals to make beneficial spray extracts.

The cost:benefit ratios calculated in this study are similar to those obtained by Patel et al. (1997) but higher than that obtained by Shabozoi et al. (2011). These three studies calculated the ratios in the same manner (economic analyses only on cost of plant protection). Whilst Shabozoi et al. (2011) obtained a cost:benefit ratio of 1:4.1 from application of a neem-based botanical, Patel, et al. (1997) obtained a ratio of 1:14.2 and 1:12.6 for botanical (neem extract) and synthetic insecticide (endosulfan) respectively in managing insect pests of pigeon pea. Arivudainambi et al. (2010) reported a much less favourable ratio of 1:1.3 which was lower than that in this study. This could be because this study and others analysed only the cost of plant protection and calculated the cost:benefit ratio based on the income of the control treatment. Arivudainambi et al. (2010) who used extracts of *Cleistanthus*

collinus Benth., *Cleome viscosa* L., *Gynandropsis pentaphylla* (L.) Briq., *Andrographis paniculata* (Burn.f.) Wallich ex Nees and commercial neem extract in comparison with the synthetic insecticide endosulfan in managing pests of amaranth, on the other hand, analysed both cost of cultivation and plant protection and did not make reference to the income obtained from the control treatment in calculating the cost:benefit ratios. However, economic analysis in this study was useful because, besides the spray type applied; all other input costs were constant for all treatments.

The cost:benefit ratio, the total income and the benefit obtained from each treatment is greatly influenced by the price of the commodity. The results of this study show that whilst some of the treatments had higher yield in the major season than the minor season, total income and cost:benefit ratios were lower in the major season compared to the minor season. This was because price for cabbage heads was 50% higher in the minor rainy season harvest than the major season one. It must be stated that cost of plant protection was even higher in the minor season than in the major season as a result of the additional spray application whilst total income for the controls in the two seasons did not differ markedly.

In the current study, cabbage heads from plots sprayed with synthetic insecticide and those from botanical plots were sold for the same price. If cabbage heads from plots protected with botanicals were sold for premium price there would be corresponding increases in economic benefit. In developed countries where human health is of paramount importance, there are premium prices for food commodities that do not have pesticide contamination and health-conscious consumers eagerly patronise (Njoroge and Manu, 1999). In Ghana, however, food commodities including vegetables such as cabbage on the market are not currently identified as organic and inorganic. Reasons for this include the relative lack of sophistication in the market (simple marketing chains lacking quality control measures) and a lack of any organic certification scheme or residue monitoring program for food commodities. As a result of the absence of such regulatory factors, it is difficult to establish a pattern of price premiums for organic produce because it would be difficult to gain customer trust, easily corrupted and impossible to police. Increasing awareness of health hazards of insecticide-contaminated food commodities is gradually changing consumers' perception of food commodities even in the developing countries. For instance, vegetable consumers in Ghana and Benin expressed their desire to pay more than 50% premium prices for vegetables that will be certified as free from pesticide contamination (Coulibaly et al., 2007). Organic food producers in developing countries should raise awareness of the benefits of pesticide-free food commodities to obtain the deserved prices for their commodities and subsequently obtain higher benefits. In addition, organic food producers may also have access to the US and the EU markets where strict compliance to pesticide levels in food commodities is a requirement (Njoroge and Manu, 1999).

Some plant compounds, including some tested in this study may be toxic to humans but this bald fact needs to be tempered by some more specific aspects of detail. First, the extracts used in this study (and the form of use we advocate as a result of our findings) were crude, 3%, water-based extracts rather than being the concentrated form of the specific compounds that some plants are known to synthesise and that can be toxic to mammals at high concentrations. It is known that the harmful effects associated with plant compounds are largely alleviated through the use of crude plant preparations in which concentrations of the substances usually range from 1% to 5% (Isman, 2008). Second, the level of risk associated with the use of plant extracts at worst poses no greater risk to human health than does use of conventional insecticides. Finally, we demonstrate efficacy of crude extracts from several plant species in addition to those, such as tobacco, for which toxicity is known to be an issue.

In conclusion, this study has shown that crude extracts of readily available plants offer cost-effective plant protection alternatives to synthetic insecticides. This was evident in the favourable cost:benefit ratios of the botanical treatments. Of these, Siam weed and tobacco extracts gave significantly higher undamaged head yields and commensurately more favourable economic benefit and cost:benefit ratio, than Attack®. Smallholder farmers especially those in the developing countries who have free access to such plant materials and have the labour availability stand to gain immensely. The use of synthetic insecticides has been linked with causing hazards to humans, animals and the environment. Botanicals are generally regarded as safer to users, consumers, animals and the environment due to their non-persistent nature (Buss and Park-Brown, 2002). In contrast, synthetic insecticides are often inaccessible to resource-limited farmers or are hazardous to use due to poor access to safety equipment and adequate training in safe use. Tempering this generality, however, some botanical compounds are as toxic as their synthetic counterparts. For instance, nicotine from *Nicotiana* sp. has LD_{50} (lethal dose) of 50 mg/kg in rats and is acutely toxic so extracts of this plant are not completely safe to users and the environment (Isman, 2008; Rosell et al., 2008) though compounds that are hazardous in pure form are safer to use in a crude extract state (Isman, 2008) where concentrations of the active components are usually below 5%. Rechcigl and Rechcigl, 2000 stated that "if botanicals insecticides are to be widely used, many ecological and environmental problems will be overcome; even the best known products; pyrethrin and rotenone are not persistent, and none of the botanicals has shown to have negative impact on the environment".

The current study has demonstrated that the use of locally available plant materials as crop protectants could be less expensive and give financial benefits that are higher or comparable to synthetic insecticides. This justifies further evaluation at a larger scale and over multiple years as well as work on efficacy in a wider range of pest/crop systems.

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