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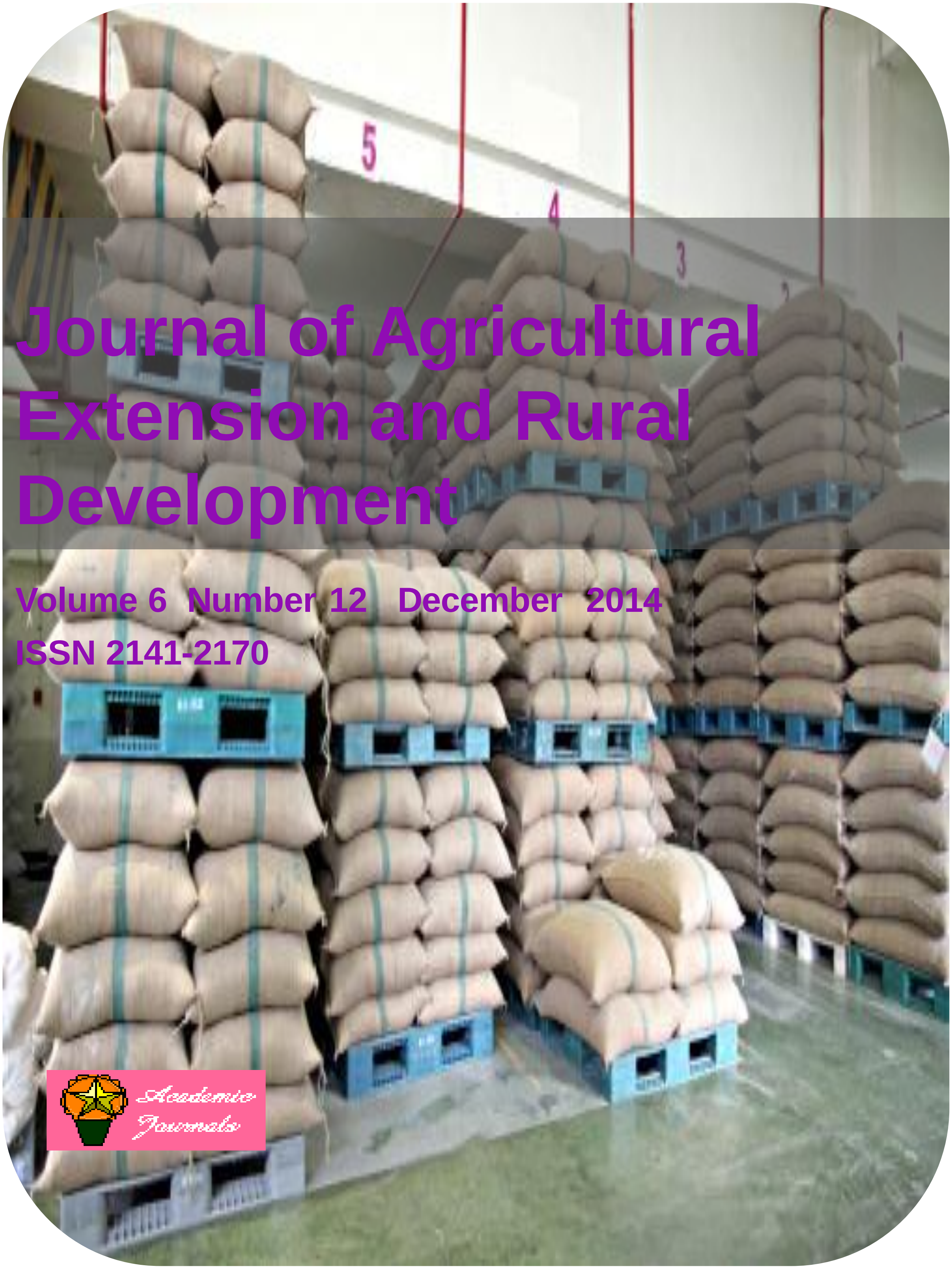

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Journal of Agricultural Extension and Rural Development

Full Length Research Paper

Achieving rational pesticide use in outdoor tomato production through farmer training and implementation of a technical guideline

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Smallholder farmers were trained by frontline extensionists and local experts on how to apply Integrated Pest Management (IPM) in outdoor tomatoes, *Solanum lycopersicum*, during farmer field schools in Northern Tanzania between 2005 and 2008. Farmers were also organised into newly-established vegetable producer clubs within which they developed a technical guideline defining the minimum requirements for integrated tomato production. Unaligned, clustered sample surveys conducted among farmers trained in IPM and conventional farmers between 2009 and 2010 revealed that IPM farmers adopted and/or more frequently used non-hazardous preventive measures for pest (arthropod, disease and weed) control than non-IPM farmers. However, pest incidence was so severe during these years that nearly every IPM and non-IPM farmer had to use synthetic pesticides as a direct control measure. Overall, IPM farmers sprayed synthetic pesticides in smaller quantities and less frequently than non-IPM farmers, but they applied natural source pesticides more frequently and in larger amounts. IPM farmers used 85% less often the more hazardous pesticides (WHO toxicity Class I and II) than non-IPM farmers, as well as 42% more often the less hazardous pesticides [Class III and U (=IV)], and 84% more often 'green' products (for example, biological, safe botanicals). In conclusion, the training of farmers in IPM, together with the implementation of a technical guideline and the establishment of producer clubs, is highly recommended for reducing the use of hazardous pesticides and improving the production of vegetables that are safer for producers, consumers and the environment.

Key words: Integrated pest management (IPM), farmer training, technical guideline, project monitoring and evaluation, vegetable producer clubs, *Solanum lycopersicum*, pesticide reduction, Tanzania.

INTRODUCTION

The tomato (*Solanum lycopersicum* L.) is of great importance to smallholder farmers in the Kilimanjaro and Arusha regions of the northern zone of Tanzania in terms of local consumption and income generation (Barry et al., 2009; Djurfeldt et al., 2010). Smallholder farmers usually grow tomatoes outdoors all year round in Northern Tanzania if there is sufficient rainfall or the availability of irrigation. Main production periods are from March to May and during November and December when regular rainfall is expected. A tomato cropping cycle lasts 11 to 13 weeks. A dry period usually occurs from July to September and can occasionally be so serious that vegetable production becomes impossible (Page et al., 2010). Typically, smallholder farmers own 0.2 to 10 acres of land of which 0.05 to 3 acres are under tomato production (Table 1). In terms of education, most farmers have completed at least primary school level education (Table 1) and some family members can read and write. 65 to 84% of farmers are males. Farmers usually sell their produce in local rural markets often on roadsides, or to urban markets through middlemen (Fleuret, 1984; Barry et al., 2009; Black et al., 2001; Djurfeldt et al., 2010). Successful tomato growing and marketing can generate a significant income for farmers (James et al., 2010).

Tomato varieties and their pests

A large number of tomato varieties are grown in Northern Tanzania, including Onyx, Tengeru, Marglobe, Cal J and Tanya, of which most are resistant to various forms of blight, virus and wilt (Dobson et al., 2002; TOSCI, 2009). Several of these varieties, such as Tengeru 97, are tolerant to late blight, fusarium wilt, tomato mosaic virus, tomato yellow leaf curl virus (TYLCV) and/or root-knot nematodes. Others, such as Rio Grande, can tolerate early and late blight, as well as fusarium wilt. The Kentom variety is tolerant to bacterial wilt, root-knot nematodes and tomato mosaic virus. The Roma VFN variety is tolerant to fusarium and verticillium wilt, root-knot nematodes and red spider mites, and the Roma VF variety is tolerant to fusarium and verticillium wilt (Dobson et al., 2002; TOSCI, 2009).

Tomato production in Northern Tanzania suffers from arthropod pests such as *Bemisia tabasi* (white flies), *Agrotis* spp. (cutworms), *Helicoverpa armigera* (bollworm/tomato fruit worm), *Tetranychus* spp. (spider mites), *Bactrocera cucurbitae, Bactrocera zonata* and other *Bactrocera* species (mango fruit flies) and several flower and leaf thrips (Bohlen, 1978; Swai et al., 2000; Kaoneka et al., 2004; ICIPE, 2005, 2006; Ekesi et al., 2010). Major diseases include *Phytophthora, Pythium, Alternaria, Rhizoctonia,* and *Fusarium* spp. (all water moulds or damping-off fungal diseases). These include *Alternaria solani* (early blight fungus), *Phytophthora infestans* (late blight water mould) (Mlungu and Godwin, 1996), *Fusarium oxysporum f.s. lycopersici* (fusarium wilt or basal rot fungus), *Ralstonia solanacearum* (bacterial wilt) (Black et al., 1999; Fleuret, 1984), *Xanthomonas campestris pv, vesicatoria* (bacterial spot) (Black et al., 2001), *Sclerotinia sclerotiorum* (soft rot fungus), *Leveillulataurica* (powdery mildew fungus), tomato mosaic virus (Chiang et al., 1997) and TYLCV (Nono-Womdim et al., 1996).

Meloidogyne nematode species can cause serious damage to tomato roots (Ijani and Mmbaga, 1988; Swai et al., 1996). A number of weeds can be frequently found in tomato fields, but can usually be managed through mechanical control.

Management of inappropriate use of chemicals through training in integrated pest management (IPM)

A certain lack of farmer knowledge in controlling the numerous tomato pests, together with inadequate access to information on safe pesticides (WHO, 2009; TPRI, 2010) and their use had led to inappropriate use of these chemicals (Ngovi, 2002). This was characterised by the application of large quantities of pesticides, the use of hazardous products, incorrect formulations/preparations and dosages, mixing of various products with different active ingredients and toxicity classes, and a lack of awareness of pre-harvest intervals (Kaoneka et al., 2000; Ngovi et al., 2007). This in turn had resulted in the sale of tomatoes that were contaminated with pesticide residues (Kaoneka et al., 2000; Ngovi, 2002; Ngovi et al., 2007). Therefore, farmers were trained in IPM during four to six season-long outdoor sessions between 2005 and 2008 using discovery-learning approaches in farmer field schools (FAO, 2000; Mbwaga and Hayden, 2003; Kilimo 2005).

In order to improve farmer knowledge about the safe use of pesticides, 18 village extension officers from of the Ministry of Agriculture and Cooperatives attended two training courses in 2005 and 2006 to become trainers for farmer participatory IPM training. As a result, extension officers learned about integrated production of tomatoes and non-formal education methods (Pretty et al., 1995; Mbwaga and Hayden, 2003; Kilimo, 2005), and also developed an IPM training curriculum for farmer field schools including information on alternatives to synthetic pesticides. With the support of these trained extension officers and IPM experts of the National Horticultural Training Institute (HORTI) at Tengeru, Tanzania, eight tomato farmer field schools were established between 2005 and 2008 and farmers were trained over the course of four to six tomato cropping cycles. Each farmer field school consisted of 10 to 25 farmers and therefore a total of 150 to 170 farmers were trained in integrated outdoor tomato production. During the training period, scientific and indigenous knowledge was exchanged between farmers, frontline extension officers, and local and

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external IPM experts. Sustainable pest management solutions (Boller et al., 2004; Kaoneka et al, 2004; Malavolta et al., 2005; Pesticide Action Network, 2005) were selected, validated and adapted to local conditions and beneficiaries' needs. Alternatives to broad-spectrum pesticides and other hazardous products were also identified.

Implementation of a technical guideline

Between 2008 and 2009, a technical guideline for integrated tomato production in northern Tanzania was developed (Massawe et al., 2010) defining the minimum agricultural requirements for a more sustainable production system (Kilimo, 2005; Malavolta et al., 2005; Ernest and Njogu, 2007; WHO, 2009; TPRI, 2010). This was achieved through the joint efforts of IPM experts of HORTI Tengeru, frontline extension officers of the Ministry of Agriculture and Cooperatives of Tanzania, tomato farmers of vegetable producer clubs, agro-input dealers, CABI Africa, and CABI Europe- Switzerland. The technical guideline was compiled using experiences and lessons learned from 2005 to 2008, as well as international standards, such as those defined by the International Organisation of Biological Control (Boller et al., 2004; Malavolta et al., 2005), and local standards (TPRI, 2010; TOSCI, 2009). Overall, it defines and explains the minimum requirements for the implementation of integrated production (Boller et al., 2004) of fresh outdoor tomatoes (WHO, 2009; Ernest and Njogu, 2007; TPRI, 2010) based on local and regional knowledge obtained during the 3 years of farmer IPM training from 2005 to 2008, as well as international standards as defined by the Commission of the International Organization of Biological Control (IOBC) (Boller et al., 2004; Malavolta et al., 2005) and other relevant local standards. The requirements relate to biological diversity and landscape, site selection and management, cultivars, seeds, seedling production and transplanting, nutrition, irrigation, IPM, harvest, post-harvest management and tomato storage. Two of the major IPM requirements include the implementation of preventive (= indirect) measures, and the monitoring and consideration of pests and weather conditions prior to intervention with direct pest management measures. To support these principles, a list of economically important pests (arthropods, diseases and weeds) that require regular control measures in northern Tanzania was developed, as well as lists of nutrient deficiency symptoms and the most important site-specific natural enemies. A *Green and Yellow Lists* were also developed to guide the choice of relevant preventive and direct plant protection measures. The Green List consists of preventive and selective direct control measures, which have no negative impact on humans, non-target organisms and the environment (for example, biologicals, safe botanicals, minerals, soaps, bio-technicals). It also defines action thresholds to facilitate the decision for or against direct control measures. The *Yellow List* defines direct plant protection products that may be used, including their restrictions if applicable, by the producer if pest monitoring signifies a need for intervention. Direct plant protection measures selected for the *Yellow List* were the least hazardous to humans, livestock and the environment (WHO toxicity Classes III and IV (=U)). Hazardous pesticides of WHO toxicity Classes I and II pesticides were considered as '*Red'* products with the intention of them being phased out. All products recommended on the *Yellow List* had to be officially registered, and were only to be used in compliance with their maximum permitted total dose and pre-harvest interval. The use of chemical herbicides was not permitted within the integrated production system.

The IPM practices, defined in the technical guideline, were implemented by farmers in vegetable producer clubs for integrated tomato production from 2009 onwards in the Hai, Moshi, and Arusha districts of Northern Tanzania by which time the farmers were expected to have obtained sufficient knowledge and skills to produce tomatoes using IPM. The guideline was enforced via a producer club-endorsed self-evaluation checklist for successful IPM implementation.

Establishment of vegetable producer clubs

Farmers transformed seven of the eight above-mentioned farmer field school groups into officially registered vegetable producer clubs for integrated tomato production in 2009 and 2010 with the primary aim of developing and implementing a marketing system for their tomatoes based on the work of Djurfeldt et al. (2010) and Mithoefer and Waibel (2011) (Table 1). The concept of establishing producer clubs was adopted for several reasons, including to increase the power of farmers, to ensure the production of tomatoes according to an agreed technical guideline (see above), and to help farmers penetrate existing tomato markets with their improved product (Agwanda et al., 2010; Mithoefer and Waibel, 2011). The accessing of such markets would in turn help to ensure a secure and safer income for the farmers (Table 1). It was hoped that farmers would profit due to reduced production costs resulting from decreased pesticide use. The vegetable producer clubs were located in Kimbima, Kiwanyamu, Faru, Nduruma, Nguvukazi, Songambele and Upeneema of the northern zone of Tanzania (Table 1). Each one consisted of 10 to 25 farmers, that is, 130 to 150 IPM farmers in total.

Does IPM training affect farmer behaviour?

The extent and quality of IPM implementation after

Table 1. Characteristics of tomato-growing farmers in the northern zone of Tanzania between 2009 and 2010.

Category	Age of farmers (years) (Mean ± SD)	Gender % males (Mean ± SD)	Highest formal education (%)				Land owned (acres[x]) (Mean ± SD)	Under tomato (acres[x]) (Mean ± SD)
			None or non-formal	Primary school	Secondary school	Post-secondary		
IPM farmers(n = 204)	47 ± 10	65 ± 48	27	63	6	4	1.9 ± 1.7	0.6 ±0.5
Non-IPM farmers(n = 70)	41 ± 10	84 ± 37	4	87	9	0	1.8 ± 1.7	0.6 ± 0.5
All (n = 274)	45 ± 10	70 ± 46	21 ± 12	70 ± 11	7 ± 3	2 ± 1	1.8 ± 1.7	0.6 ± 0.5

[x], 1 acre = 0.4 ha

training was still unknown as it is often difficult to tell to what extent the farmer training activities exhibit real differences often claimed by farmer field school practitioners (Federer et al., 2004; Van der Burg, 2004; Tripp et al., 2005; Erbaugh et al., 2010). Moreover, it was uncertain whether farmer education, the implementation of a technical guideline and/or the establishment of vegetable producer clubs with production rules had indeed led to more rational use of pesticides. In other words, it was not possible to tell whether the international development projects and donor investments behind these activities had really made a change (Tripp et al., 2005; Erbaugh et al., 2010; Gilbert, 2013). International development projects have recently come under the microscope and many question the efficacy of farmer training programmes (Erbaugh et al., 2010; Gilbert, 2013).

In order to address this question unaligned, clustered sample surveys were conducted among IPM farmers and non-IPM farmers in the Kilimanjaro and Arusha regions of Northern Tanzania between 2009 and 2010 using questionnaires and interviews for obtaining quantitative and semi-quantitative impact indicators. Survey results were anticipated to clarify whether the training of farmers in IPM, the implementation of a technical guideline and the establishment of producer clubs had led to a reduced use of hazardous pesticides and thus the production of tomatoes that were more likely to be safe for producers, consumers and the environment. This would in turn help to assure the donor that its investments are paying off.

MATERIALS AND METHODS

Survey area

The surveys were conducted with IPM- trained tomato-growing smallholder farmers organized in seven vegetable producer clubs in or around six villages, as well as with non-IPM smallholder farmers in or around seven villages (Table 2). Villages were in the Moshi and Hai district of the Kilimanjaro region, and in the Arusha district of the Arusha region, all in the northern agri-ecological zone of Tanzania (Table 2). Surveys were implemented between 2009 and 2010 through questionnaires and interviews carried out by local extension officers as next shown.

Survey on effects of farmer training, technical guideline implementation and producer club establishment on rational use of pesticides

To investigate the extent and quality of implementation of the IPM practices by the trained farmers and whether farmer training, technical guideline implementation (Massawe et al., 2010), and producer club establishment had indeed led to a more rational use of pesticides (Van der Burg, 2004), surveys were conducted among two target populations; (a) farmers trained in IPM and organized in seven vegetable producer clubs as described above, and (b) non-IPM farmers in the same project districts of Moshi and Hai in the Kilimanjaro region, and Arusha in the Arusha region of northern Tanzania.

The survey followed an unaligned, clustered sample design (Bharati et al., 2004; Haarstad et al., 2009) as farmers were organized into unaligned producer clubs (clusters) in the three target districts. The sampling unit was the farmer, which in most cases equalled a farm household. Three surveys were implemented over time to allow the analysis of possible temporal changes. The study populations were as follows: i) 51 IPM farmers fully trained in IPM procedures but not organized into producer clubs and without a technical guideline, (surveyed in January/February 2009); ii) 83 IPM farmers just starting to produce according to a technical guideline (surveyed in November/December 2009); and iii), 70 IPM as well as 70 non-IPM farmers were surveyed in July/August 2010 to allow the analysis of change between IPM and non-IPM farmers (Table 2). Farmers were arbitrarily chosen. Occasionally though, the same or different farmers were interviewed over time.

Surveys were implemented through structured interviews with single or pairs of farmers and based on questionnaires. They were carried out by local extensions officers, facilitated by IPM experts of the HORTI Tengeru centre in Arusha and survey experts of CABI Africa from Nairobi. Surveys followed the methods devised by Bharati

Table 2. Location and number of surveyed IPM and non-IPM farmers in the northern zone of Tanzania.

District	Village	Interviewed IPM-trained farmers Jan/Feb 2009	Interviewed IPM-trained farmers with technical guideline Nov/Dec 2009	Name of producer club	Interviewed IPM-trained farmers with technical guideline Jul/Aug 2010	Interviewed non-IPM farmers Jul/Aug 2010
Arumeru	Nduruma	9	19	Nduruma	11	8
Arumeru	Kivululu	10	13	Songambele	10	10
Arumeru	Uwiro	10	5	Nguvukazi (Ngare Nanyuki)	9	10
Moshi	Kilema Pofo	10	12	Upeneema	10	10
Moshi	Kilema Pofo	10	14	Faru	10	11
Hai	Mungushi	2	10	Kimbima	10	11
Hai	Mudio	0	10	Kiwanyamu	10	10
Total	7	51	83	7	70	70

et al. (2004), Haarstad et al. (2009) and Tongco (2007) and reviewed by Gilbert (2013). In total, 274 interviews were conducted. Questions aimed to clarify whether the tomatoes produced according to IPM methods were likely to be safe for producers, consumers and the environment due to reduced use of hazardous pesticides. The questions were in most cases open questions, and largely indirect, that is, requesting costs of control measures, such as pesticides. But overall, they were designed to quantify the extent to which IPM or non-IPM measures were implemented and whether the use of hazardous pesticides was reduced as a result of IPM implementation. Questions focused on obtaining quantitative and semi-quantitative impact indicators for: (a) the adoption of non-hazardous preventive measures against pests, (b) the support of plant health using balanced fertilization, (c) the implementation of pest monitoring for improved decision making regarding the application of control measures, (d) the phase-out of hazardous direct pest control measures and the adoption of less- or non-hazardous methods, (e) the reduction in quantity and frequency of pesticide use, and finally, (f) the misuse of pesticides. The survey did not investigate qualitative learning processes, but quantifies learning outputs and impact as a result of learning successes.

Analyses of survey data

Data of survey variables were visually analysed for normal distribution using histograms and Q-Q plots (Kinnear and Gray, 2000). The influence of time since becoming an IPM farmer was analysed on the assessed survey variables using general linear models depending on distribution of data, lack of many extreme, for example, 0 or 1 proportional data, and independency of variables As only two or three time periods were compared (January/February, 2009, November/December, 2009 and July/August 2010), parametric independent samples Welch T tests were used to compare the means of variables in cases of normal distribution of data or sample sizes of more than 40, which was the most common scenario. In only a few cases, the non-parametric independent samples Mann-Whitney U test was used. The same comparison tests were applied when comparing IPM-trained farmers producing according to a technical guideline with IPM-trained farmers with no guideline to follow and non-IPM farmers. Only when comparing many different IPM practices or different classes of pesticides used, PostHoc multiple comparison tests were applied after having clarified the equality or inequality of variance using analysis (ANOVA), this was, the Tukey test in cases of equal variances, the Dunnett test in cases of equal variances but with extreme data points, or the Games Howell test in case of unequal variances.

RESULTS

Reported tomato varieties and their pests and diseases

Among the 274 interviewed farmers, a large number of tomato varieties are grown. The most preferred varieties are Onyx (31%), Tengeru 97 (19%), Marglobe (12.3%), Cal J (11.9%), and Tanya (6.5%). The most important arthropod pests were considered to be *B. tabasi* (21%), *H. armigera* (11 %), red *Tetranychus* spp. (10), and *Bactrocera* spp. (8%). About 3% of farmers reported no major problems with arthropod pests.

Phytophthora late blight was considered the most important disease according to 19% of the 274 farmers interviewed, *L. taurica* mildew fungus by 12% of the farmers, bacterial or fungal wilts by 9% and TYLCV by 4%. Approximately, 13% of the farmers claimed not to have major problems with diseases.

Adoption of non-hazardous preventive measures against pests

IPM farmers used non-hazardous preventive measures for arthropod, disease and weed control more frequently than non-IPM farmers (Figure 1) (GLM: df = 213;9, F= 1412, $p < 0.001$).

Mulching was used up to 3 times more extensively for weed control, moisture retention in the soil, and predator enhancement by IPM

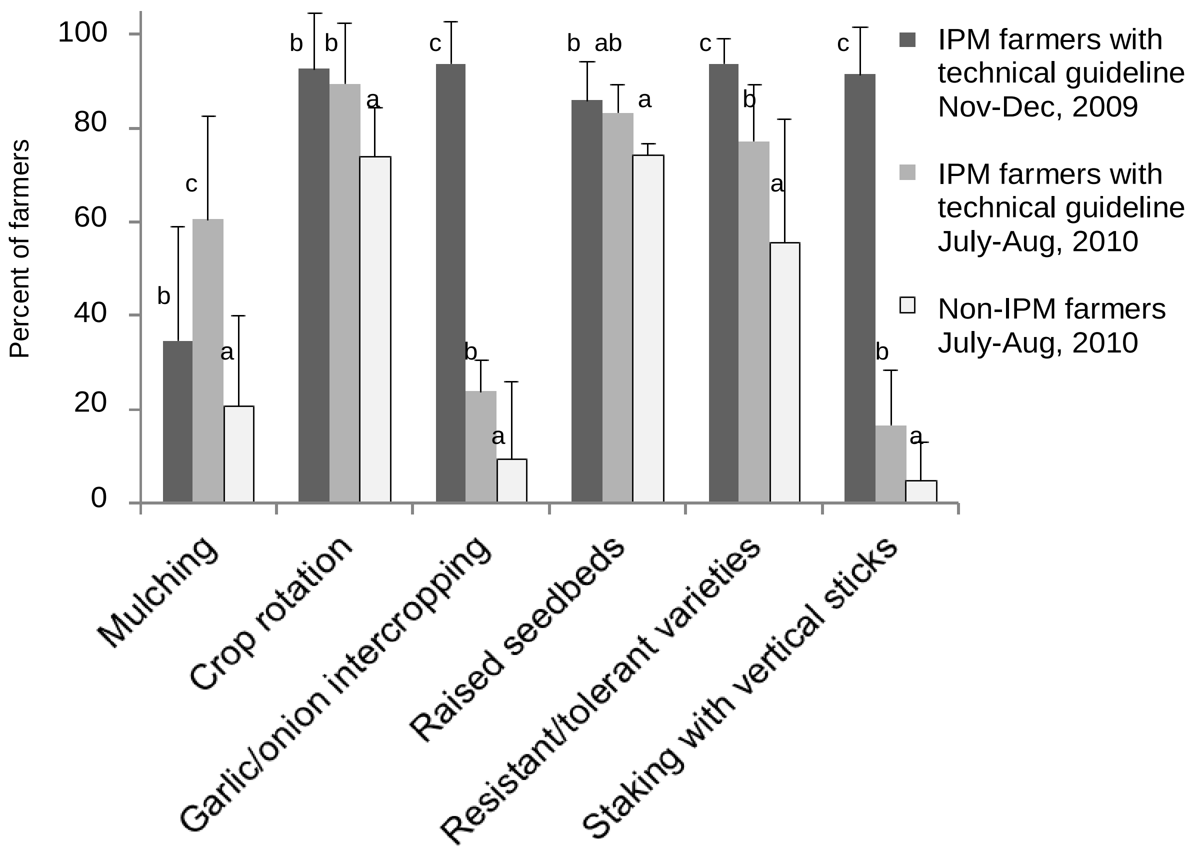

Figure 1. Percent of farmers using non-hazardous *Green* preventive strategies against arthropods, diseases and weeds in outdoor tomatoes in Northern Tanzania. Letters on bars indicate significant differences between farmer groups/years according to the parametric independent samples Welch T-tests at $p < 0.05$.

farmers than non-IPM farmers (July/August, 2010: 60 versus 20%, Figure 1). The use of mulching increased among IPM farmers from 45% in 2009 to 60% in 2010.

Mixed cropping of garlic or onions between tomatoes was frequently used by IPM farmers to repel pests, such as *Agrotis* sp., but less so by non-IPM farmers (Figure 1). IPM farmers used this method intensively in November/December, 2009 (94 ± 9 SD%), but to a less extent in July/August, 2010 (24 ± 7%). This is due to particularly high pest pressure in November and December when weather conditions are optimal, that is, relatively wet, compared to August. The same trends can be observed for the use of raised seed beds to avoid standing water and subsequent problems with soil borne diseases, which was used by 83 to 86% of the IPM farmers, and 74% of non-IPM farmers.

Disease tolerant varieties, such as Tengeru 97, Rio Grande, or Kentom were used more frequently by IPM farmers than non-IPM farmers (77 to 94% versus 56%, Figure 1).

The staking of tomato plants for improved aeration and prevention of disease transfers was used to a higher extent by IPM farmers (17 to 91%) than by non-IPM farmers (about 5%). The use of staking decreased among IPM farmers from 91% in November/December, 2009 to 17% in July/August, 2010. In the latter period, however, it is common practice to grow varieties that are traditionally not staked, for example, the common oval shaped tomato varieties, such as Tanya, Onyx, CAL- J or Rio Grande. In November/December, however, other varieties such as disease tolerant ones are grown; but they often require staking, such as the variety Tengeru 97.

Support of plant health using balanced fertilization

Most farmers applied fertilizers, regardless of whether they practiced IPM or not. In November and December 2009, however, IPM farmers applied less fertiliser than IPM or non-IPM farmers in other cropping seasons, which was likely to be due to prolonged drought (Figure 2).

A larger proportion of IPM farmers with technical guidelines used animal manure than IPM farmers without technical guidelines (Figure 2). In 2010, twice as many IPM farmers used animal manure than non-IPM farmers (86 ± 12% versus 42 ± 11%).

A larger proportion of IPM farmers produced and used

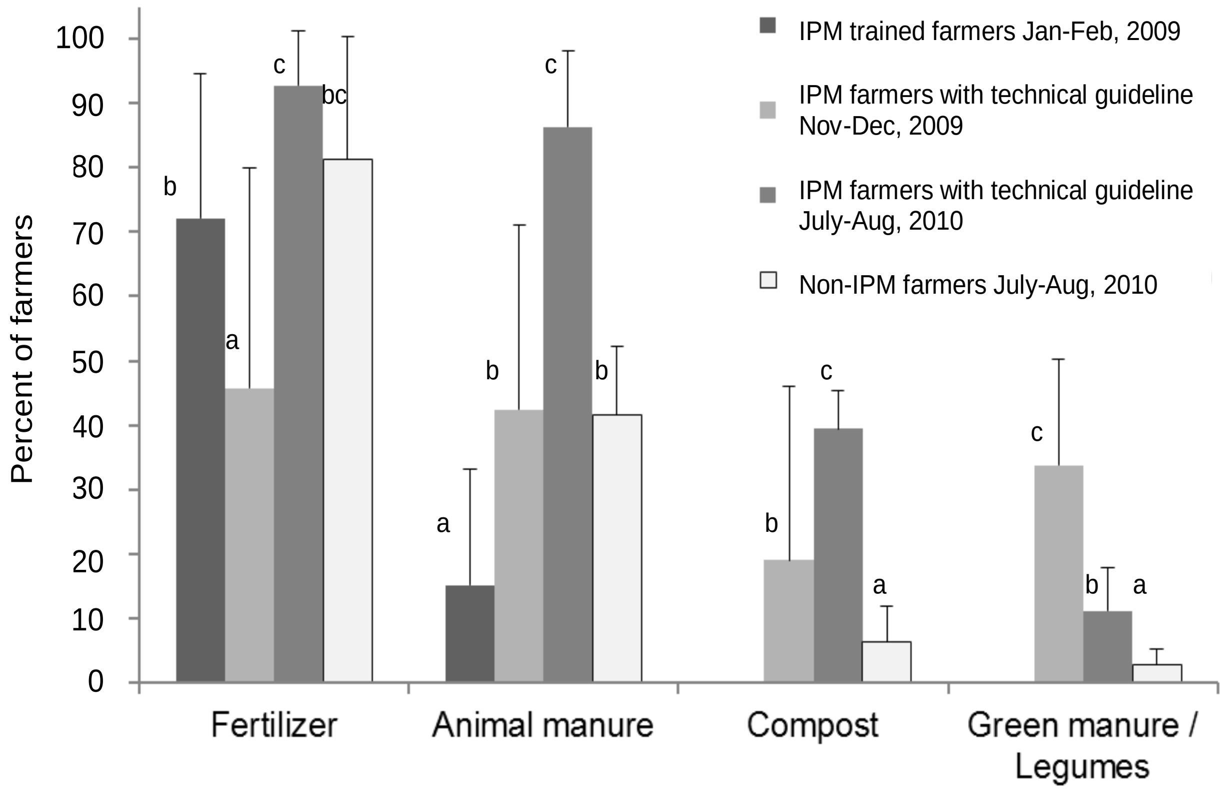

Figure 2. Percent of farmers using different types of fertilizers for balanced nutrition of outdoor tomatoes in Northern Tanzania, through animal manure, composting and/or green manure. Letters on bars indicate significant differences between farmer groups/years according to the parametric independent samples Welch T-tests at $p < 0.05$.

compost for fertilization than non-IPM farmers (19 to 39% versus 6%). A larger proportion of IPM farmers used green manure, such as *Crotolaria* spp. (Sunhemp) or legumes, between tomato cycles to improve soil quality than non-IPM farmers (11 to 34% versus 3%).

Use of monitoring of pests and diseases for decision making

Nearly all farmers, regardless of whether they produced according to IPM standards or not, checked, at least occasionally, for the presence of arthropod or disease pests in their tomato fields (100 ± 0% IPM farmers with technical guideline versus 98 ± 4% non-IPM farmers in July/August 2010, M.-Whitney U test`s $p > 0.05$). A larger proportion of IPM farmers regularly monitored (= scouted) infestation levels over time for better decision-making than non-IPM farmers (92 ± 8% and 79 ± 6% for IPM versus 44 ± 3% for non-IPM farmers, M.-Whitney U test`s $p < 0.05$). Slightly more IPM farmers conducted regular monitoring in November/December, 2009 (92 ± 8%) than in July/August 2010 (79 ± 6%), likely due to the higher pest pressure in November and December.

Nearly all IPM farmers (99 ± 2%) conducted Agro-Ecosystem Analyses (AESA) in their tomato fields, in contrast to only one fourth of the non-IPM farmers (23 ± 5%). Where AESA was applied, IPM farmers conducted it about twice as often as non-IPM famers (2.1 ± 0.3 AESA/week versus 0.9 ± 0.3 per week over the approximately 12 week cropping season).

Nearly all IPM farmers kept records (mostly on the template record sheets provided to them), that is, significantly more than non-IPM farmers (97 ± 6% versus 58 ± 4%, M.-Whitney U test`s $p < 0.05$). The latter, however, had not been provided with template record sheets.

Phase-out of hazardous pesticides and adoption of less hazardous, direct control measures

IPM farmers used hazardous pesticides (WHO toxicity Classes I and II, here synonym '*Red* products') 27 to 84% less frequently than non-IPM farmers (Figure 3); but in general farmers rarely used products from the most hazardous class I, regardless of whether they were an IPM or a non-IPM farmer.

By 2010, IPM farmers used 84% less often hazardous products than non-IPM farmers, 42% more often Y*ellow* pesticides than non-IPM farmers, and 84% more *Green* products than non-IPM farmers. Moreover, from early

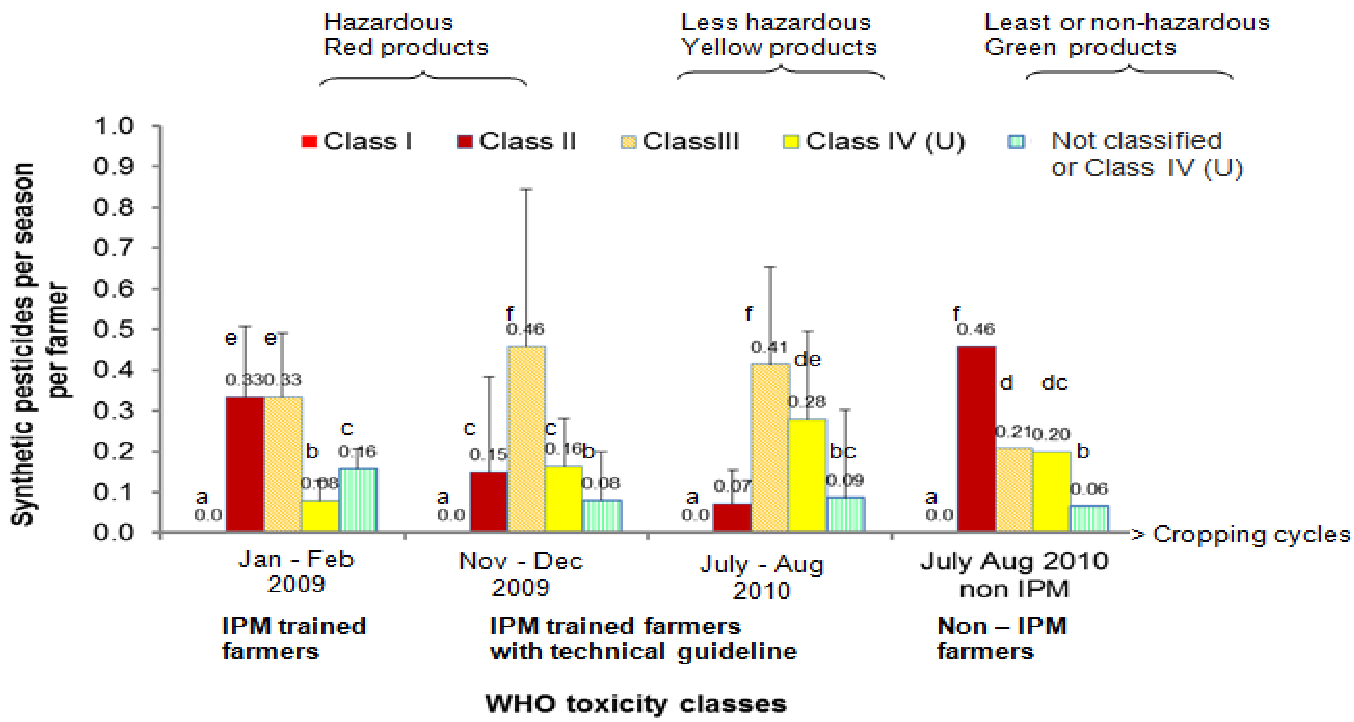

Figure 3. Pesticide sprays per farmer per outdoor tomato season in northern Tanzania according to different toxicity levels. Red = products of WHO toxicity classes I and II not permitted in IPM in Tanzania. Yellow = synthetic products of toxicity class III or U (=IV) allowed when no green product available or feasible. Green = natural source products or biological products classified as U (=IV) or not classified. Letters on bars indicate significant differences according to the PostHoc multiple comparisons Tukey test at $p < 0.05$.

2009 to late 2010, the use of hazardous pesticides among IPM farmers decreased by more than 60%. The use of hazardous products was almost phased out by 2010 (Figure 3).

When considering synthetic pesticides, IPM farmers mainly used products of WHO toxicity classes III and U (=IV) (52 to 70% more than non-IPM farmers). In contrast, non-IPM farmers mainly used the more hazardous class II products (26 to 73 % more than IPM farmers).

Among IPM farmers, the use of hazardous synthetic pesticides of Class II decreased by approximately 21% with time. The use of class III products remained largely stable, but the use of class U (=IV) products increased by 29%. This might be due to the fact that Class II products are sometimes more effective at controlling arthropod and disease pests than Class III or U (=IV) products, and so more frequent sprays of the latter may be required.

The application of a number of hazardous pesticides was phased out over the duration of the study. For example, the Class 1b insecticide dichlorvos, and the Class II insecticides dimethoate, alpha-cypermethrin or other cypermethrins. The phase out of all remaining Class II insecticides was on-going and expected to be achieved by early 2011. These included various products based on deltamethrin, lambda-cyhalothrin, endosulfan, profenofos or chlorpyrifos.

The following eight *Green* or Y*ellow* products were made locally-available during the project period: the Neem-based botanical insecticides (Nimbecidine; Neem oil extracts, Neem seed cakes, Neem seed powders), some mancozeb-based fungicides and liquid copper.

The following 12 *Green* or Y*ellow* products were locally available prior the project, but most farmers were either unaware about their existence or unclear as to how to apply them. Their knowledge in this respect was improved during the project with regard to the following insecticides/acaricides: horticultural oil (for example, sunflower oil), liquid soap, and sprays made from garlic bulbs, onion, mentha, papaya leaf, ground marigold, and maize flour. Knowledge about various fungicides was also enhanced, for example, chlorothalonil + carbendazim-based products, hexaconezole-based products, lemongrass spray and baking soda – horticultural oil sprays (Figure 4).

Reduction of pesticide use

Almost every farmer indicated that they use synthetic pesticides to control arthropods and diseases (96.1% of IPM farmers in January/February 2009, 97.6% of IPM farmers in November/December 2009, 95.7% of IPM farmers in July/August 2010, 100% of non-IPM farmers in

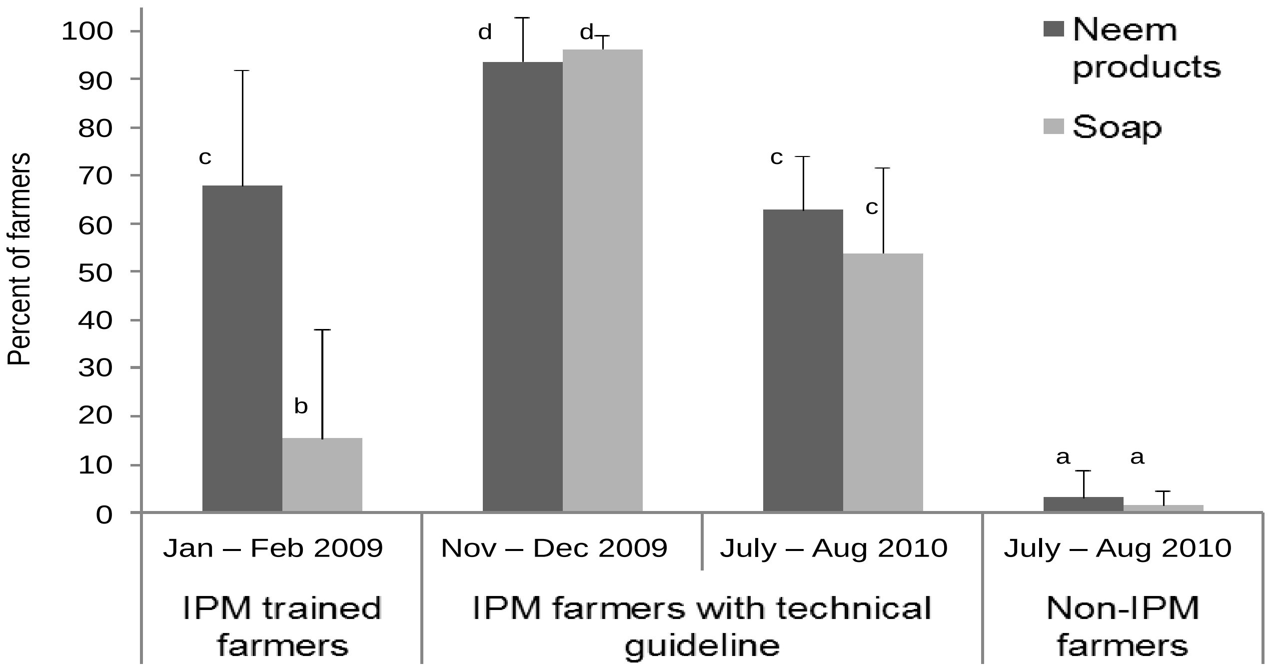

Figure 4. Percentage of farmers using non-hazardous Green direct control measures (natural source products or biological products) against pests in outdoor tomato production in northern Tanzania interviewed per date. Letters on bars indicate significant differences according to the parametric independent samples Welch T tests at p < 0.05.

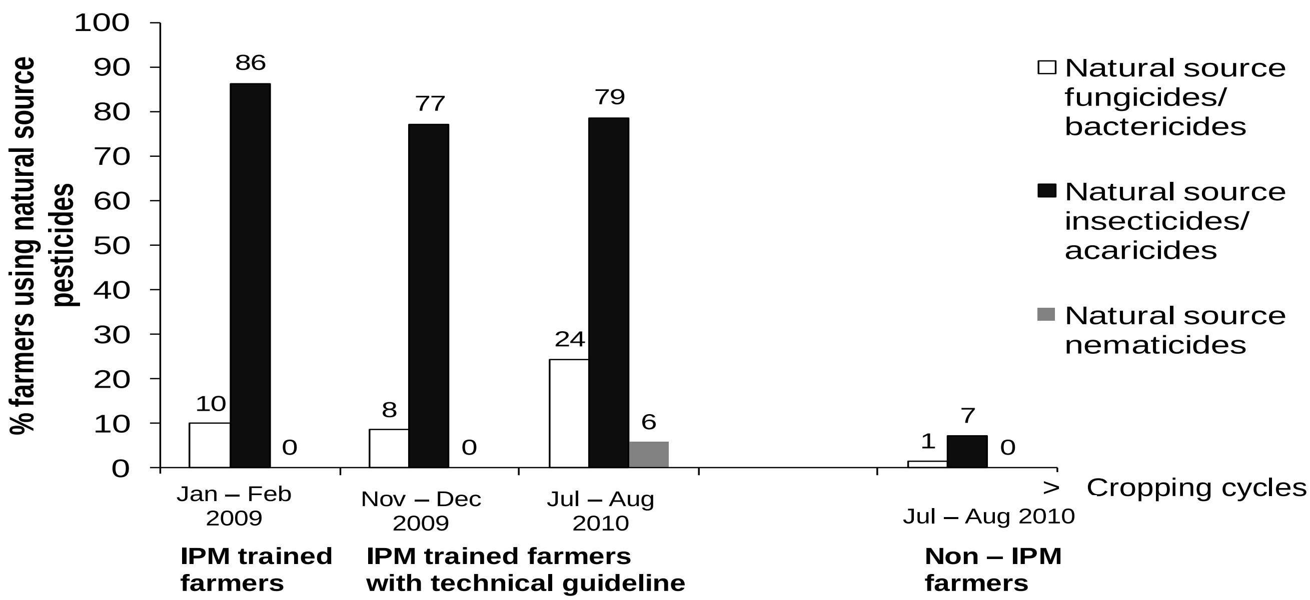

Figure 5. Percent of farmers using synthetic or natural fungicides/bactericides, insecticides/acaricides or nematicides in outdoor tomato production in Northern Tanzania interviewed per date. Letters on bars indicate significant differences according to the PostHoc multiple comparisons Games Howell test at p < 0.05 following ANOVA.

July/August 2010 (more details shown in Figure 5). Between 79.5 and 94.3% of IPM farmers also use natural source pesticides. This is a significantly higher proportion than the 8.6% of non-IPM farmers. The most frequently used natural source insecticides/acaricides included Neem products and soaps.

A larger proportion of famers applied insecticides/acaricides than fungicides/bactericides. This

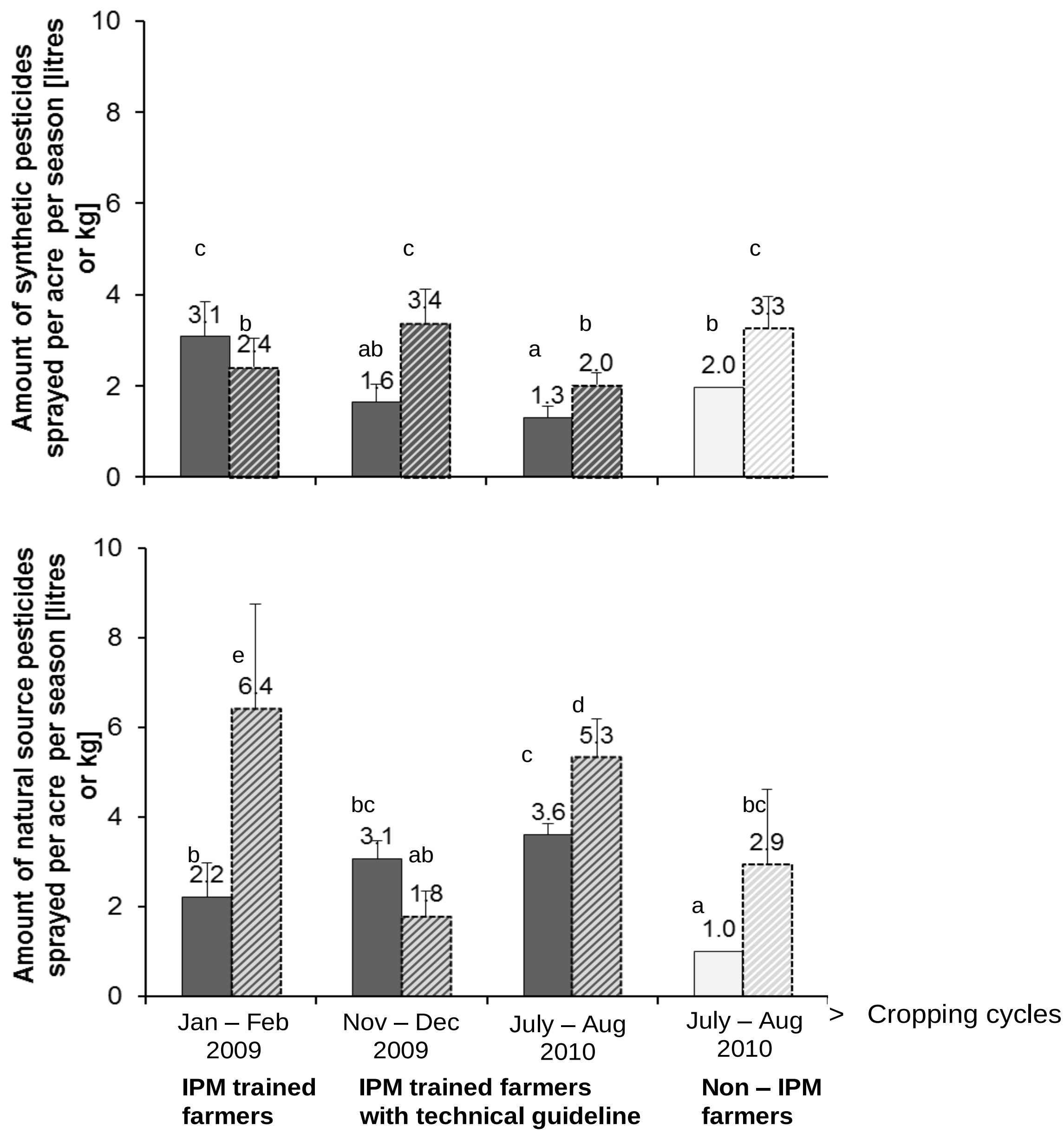

Figure ~~7~~6. Quantity of synthetic and natural source pesticides sprayed per acre in outdoor tomato production northern Tanzania. Sprays of fermented cow urine and slurry not included. Solid bars = litres; patterned bars = kg. Letters on bars indicate significant differences between farmer groups/years according to the parametric independent samples Welch T tests at $p < 0.05$.

was particularly true for natural source products, but can also be seen for synthetic products (Figure 5). Among IPM farmers, the proportion using synthetic or natural source insecticides/acaricides decreased slightly over time (by 19 and 9%, respectively). In contrast, the proportion of IPM farmers using synthetic or natural source fungicides/bactericides increased over time, and by 2010 was higher than the proportion of non-IPM famers using such products (71 versus 60%, and 24 versus 1%, Figure 5). The latter was due to the fact that non-IPM farmers did generally not use natural products for disease control. Hardly, any farmer used nematicides, regardless of being and IPM or non-IPM farmer.

When considering the quantity of synthetic pesticides sprayed per acre, per farmer, per season, the volume was shown to have decreased from early 2009 to late 2010 (Figure 6). In 2010, IPM farmers were spraying a lower quantity of synthetic pesticides than non-IPM farmers and then newly trained IPM farmers in 2009 (1.3 L versus 2 L versus 3.1 L/acre per season). However, the amount of natural source pesticides sprayed by IPM farmers increased over the same period (Figure 6). By

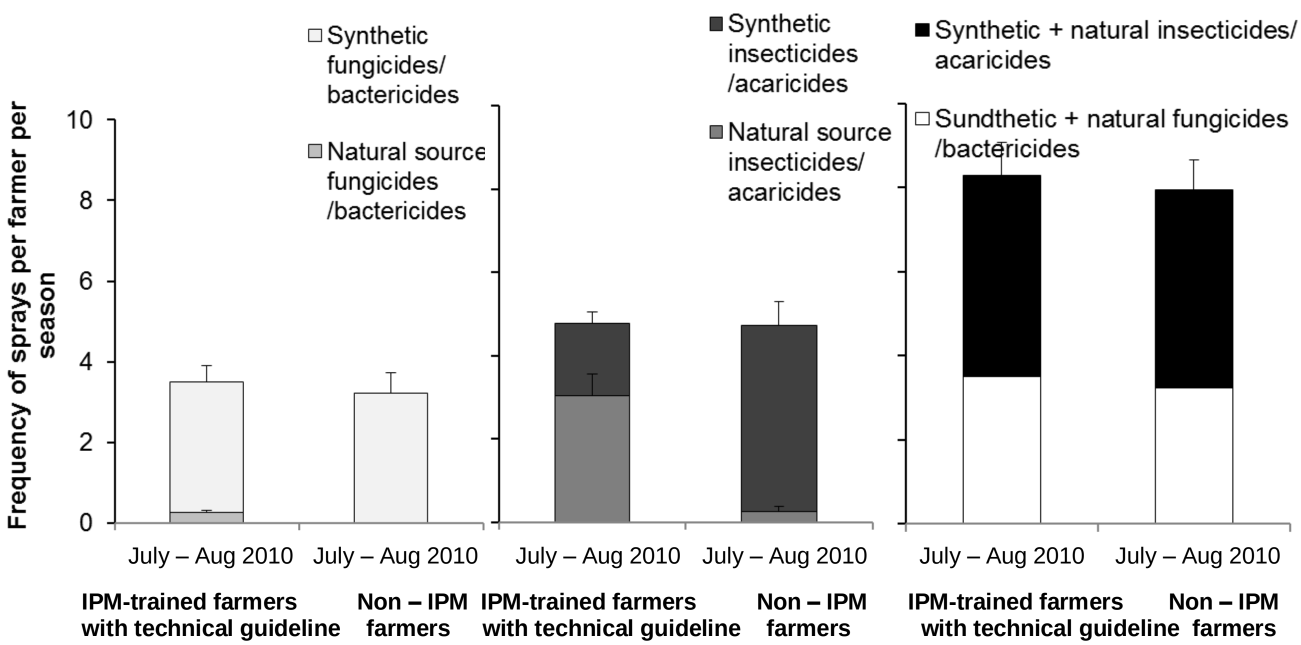

Figure 7. Frequency of application of synthetic and natural source fungicides/bactericides and insecticides/acaricides per season of outdoor tomato production in northern Tanzania. Letters on bars indicate significant differences between farmer groups/years according to the parametric independent samples Welch T tests at $p < 0.05$.

2010, IPM farmers were spraying a larger quantity of such products than non-IPM farmers (3.6 L/ acre/season versus 1 L). When considering the total amount of synthetic or natural source pesticides sprayed per farmer in kilograms, observed patterns were inconsistent (Figure 6). When considering the frequency of synthetic pesticide sprays, fungicides/bactericides were applied 3 to 3.5 times per tomato season by both IPM or non-IPM farmers and insecticides/acaricides were applied 4.5 to 5 times per season (Figure 7). This resulted in an overall spray frequency for pesticides of about 8 times per season. However, the relative frequency of natural source product applications, particularly soap sprays, increased among IPM farmers whereas the frequency of synthetic product applications decreased (Figure 7). Moreover, the actual products used by IPM farmers changed in favour of less toxic ones (see above).

Misuse of pesticides

Regardless of whether the farmers were IPM or non-IPM, only a small proportion used a certain pesticide group against the wrong target, for example an insecticide/acaricide against plant diseases (<3% of farmers), a fungicide /bactericide against an arthropod pest (<3%) or a non-plant protection pesticide (< 1%).

Socio-economic situation

IPM farmers produced 262 ± 234 crates of tomatoes per acre (= 0.4 ha) per season, and non-IPM farmers produced 201 ± 125 crates, respectively. IPM farmers sold 192 ± 165 crates per acre per season, and non-IPM farmers sold 194 ± 149 crates, respectively. IPM farmers sold 79 ± 13% of their tomatoes on local markets, 2.3 ± 1.1% to super markets, 1.6 ± 1.0% to hotels, 2.3 ± 2.1% to central markets and 15 ± 10% in other ways. Non-IPM farmers did usually not sell their tomatoes to super markets or hotels; but sold 71 ± 4% on local markets, 3 ± 4.4% to central markets and 26 ±7.1% in other ways.

The price obtained per tomato crate in target markets (that is, markets identified and targeted by a producer club prior to starting the production of tomatoes) was 12,031 ± 25,867 Tanzanian Shilling (TSH) or 73 ± 160 US Dollar USD for IPM farmers between 2009 and 2010. The price obtained per tomato crate in ordinary markets (that is, markets not specifically identified by a producer prior to staring the production of tomatoes) was 9,825 ± 23,971 TSH or 61 ± 149 USD for IPM farmers, and 9,500 ± 26,924 TSH or 59 ± 167 USD for non-IPM farmers. The income from tomatoes (that is, the tomatoes sold versus tomatoes produced versus production costs without labour) was 946,830 ± 2,215,042 TSH or 5,870 ± 13,733 USD for IPM /farm/season, and 774,803 ± 851,349 TSH or 5,593 ± 12,116 USD for non-IPM farmers. It appeared that IPM farmers profited due to reduced production costs resulting from decreased synthetic pesticide use. 70 ± 46% of interviewed farmers were males. However, IPM farmers were proportionally less males than non-IPM farmers (65 versus 84%) (Table 1). IPM farmers had a proportionally lower school education than non-IPM farmers.

DISCUSSION

It appeared that smallholder farmers who were trained in IPM, provided with a technical guideline and organised in producer clubs more frequently adopted and used non-hazardous preventive or direct measures for arthropod, disease and weed control than conventional farmers during the study time period. The implementation of season-long farmer field schools in east Africa had already been reported as an effective method of training farmers in IPM by others studies (Laurence, 2000), and seemed to have also supported the results in the here-presented case. The same is true for the positive effects of building up producer clubs that can develop small holder farming towards a joined business (James et al, 2010). Solely the combination of farmer training and producer clubs with a joint development of binding technical guidelines for integrated production of vegetables (Boller et al., 2004; Malavolta et al., 2005) was a new aspect in our study.For example, preventive practices that were introduced and/or adopted by IPM farmers included mulching for water retention and predator enhancement, mixed cropping of garlic or onions between tomatoes to repel pests, use of disease tolerant varieties, use of raised seed beds to avoid soil-borne diseases, or staking of tomato plants for improved aeration and prevention of disease transmission. The longer the farmer had been practicing IPM, the more common it was for them to be using preventive measures, thus indicating that the implementation of a technical guideline requires time and experience.

The raising of seed beds and staking of plants are important measures in the rainy seasons (March to May and November to December in Northern Tanzania), and could be even more widely implemented than currently done. In certain periods, surprisingly, the staking of plants was shown to decrease among IPM farmers, for example when varieties that are preferred by consumers and are traditionally not staked are grown to compete within the market during the rainy season (Djurfeldt et al., 2010). However, even traditional varieties would profit from staking and improved aeration. The opposite pattern was found for the use of mulching, a measure used in the dry season to retain water in the soil (Page et al., 2010). An increasing numbers of farmers appeared to have understood that mulching also prevents weed growth and helps to enhance predators.

In terms of direct control measures, IPM farmers used more IPM-compatible control measures than non-IPM farmers. For example, *Green* products used 84% more frequently than by non-IPM farmers. This was likely to have been a result of enhanced knowledge about these practices through farmer training as well the provision of a *Green* and *Yellow list* as part of the technical guideline. In addition, farmers belonging to the vegetable producer clubs were required to adhere to the technical guideline so that they could jointly market their tomatoes as IPM produce. The formation of producer clubs is known to be effective for ensuring the implementation of IPM or other sustainable agricultural practices (Fleurt, 1984; Agwanda et al., 2010; Mithoefer and Waibel, 2011). Another factor might have been that there were about 20% more female IPM farmers than female non-IPM-farmers (Table 1), although reasons are unknown. However, females tend to be more prone to use plant protection methods that are less hazardous for the environment and human health than males. Another factor was that certain non-hazardous or less hazardous products were made available during the study time period through regular contacts between farmers, extension officers and agro-input suppliers. This was part of on-going support of the here-reported project. For example, several Neem–based insecticides and mancozeb- or liquid copper-based fungicides were made locally-available. Several *Green* or Y*ellow* products were already available prior to the project, most likely due to the presence of large scale organic vegetable producing and exporting companies in the region (Mwasha and Leijdens, 2003; Rosinger, 2013). However, many of the surveyed farmers were unaware of their existence and/or how to use them; an issue that was addressed during the project. Nowadays, non-hazardous insecticides/acaricides, such as horticultural oil, liquid soaps, and sprays made from garlic bulbs, onions, mentha, papaya leaf, marigold and flour are used by IPM farmers. This is also the case for the fungicides chlorothalonil + carbendazim, hexaconezole, lemongrass spray and baking soda - horticultural oil sprays. In contrast to the increased use of non-hazardous and *Green* measures, the use of hazardous pesticides (WHO toxicity Classes I and II) by IPM and non-IPM farmers decreased by over 80% over the study period. This is a significant improvement compared to general common agricultural practices in East Africa (Kaoneka et al., 2000; Ngovi et al., 2007). Several hazardous pesticides, such as the Class 1b insecticide dichlorvos, and the Class II insecticides dimethoate/dimethionate, alpha-cypermethrin and other cypermethrins, were totally phased out. With the continued implementation of the technical guideline within the producer clubs, the remaining toxic Class II products were expected to be phased out over the following year (for example, the insecticides deltamethrin, lambda-cyhalothrin, endosulfan, profenofos and chlorpyrifos). This is a big step forward towards the production of tomatoes that are both safer and healthier for the consumer and environment. It will also contribute towards improved safety for the farmers who often do not wear the recommended full personal protective equipment (Ngovi, 2002; Ngovi et al., 2007). Finally, this is in line with the Tanzanian plant protection regulation that does not allow farmers to buy and use Classes I and II products without special training (Jubilant Mwangi MAFC and Joseph Bukalasa TPRI, 2012, pers. comm.).

Surprisingly, most farmers regardless of whether they were trained in IPM or not, did not misuse pesticides; for example, applying an insecticide/acaricide against a plant disease. Such misuse of pesticides is known to occur across East Africa (Ngovi et al., 2007). This demonstrates a relatively high understanding about arthropod and disease pests and their control options by farmers within the surveyed region of Northern Tanzania. This is particularly encouraging as about 27% of IPM farmers and 4% of non-IPM farmers had no or at least no formal education (Table 1). Such successes are likely a result of the support provided by the extensive system of over 7,000 frontline village extensionists of the Ministry of Agriculture, Food Security and Cooperatives (MAFC) of Tanzania (Dr. Kajigili, Section Extension Services of the Crop Department of MAFC, 2011, pers. comm.), and farmer trainings in IPM through the German agency for technical cooperation (GTZ), and other organisations in the region from the late 1970s to early 2000s (Bohlen, 1978; Kilimo, 2005; ASDP, 2009).

One of the main aims of enhancing and expanding IPM implementation in the project area was to reduce the overall use and reliance on pesticides. However, arthropod pest and disease pressure appeared to be so high that nearly every farmer resorted to the use of synthetic pesticides, regardless of whether they were a practicing IPM farmer or not. Vegetable producers in the African tropics and subtropics are known to face an enormous amount of arthropod and disease pest problems (Dobson et al., 2002; Pesticide Action Network, 2005; ICIPE, 2006). Of these, white flies and mango fruit flies are particularly difficult to control. However, in our survey, between 79 and 94% of IPM farmers used natural source pesticides in addition to synthetic pesticides, as opposed to 9% of non-IPM farmers. In terms of quantity, IPM farmers sprayed a lower volume of synthetic pesticides than non-IPM farmers. The frequency with which IPM farmers sprayed synthetic products also decreased, whereas the frequency with which natural source products, particularly soap sprays, were applied increased. It is worth noting that certain *Green* products, such as soaps and oils, need to be sprayed more frequently and at higher quantities than synthetic products in order to achieve similar control effects. The intense spraying by IPM farmers could therefore be misinterpreted when assessing rational use of pesticides. Furthermore, soaps, as well as most biological products, are safe to farmers and consumers (Kaoneka et al., 2000; WHO, 2009).

The survey data demonstrated that the longer the farmer had been practicing IPM and producing tomatoes according to a technical guideline, the lower the use of synthetic pesticides (quantity and frequency). Although this study did not aim to investigate the socio-economic situation of farmers in detail, the costs and income data suggest that IPM farmers are not making a loss compared to non-IPM farmers. Our hope was somewhat fulfilled that farmers would profit due to reduced production costs resulting from decreased pesticide use. Consequently, the IPM approach could be sustainable for Tanzania vegetable production, and could become a business as known from other Africa regions (James, et al., 2010).

Conclusion

Training of farmers in IPM, the implementation of a technical guideline and the establishment of producer clubs has led to the production of tomatoes that are likely to be safe for producers, consumers and the environment due to reduced use of hazardous pesticides. Although the survey did unfortunately not address qualitative achievements during the learning processes of farmers, it is anticipated that the here-reported outputs are a result of learning and changing behaviours. Overall, the above also means that the international development projects behind the activities that have generated the here-reported results have been effective and the donor investment has been worthwhile.

Therefore, we can promote, despite some uncertainties in such approaches (Tripp et al., 2005; Erbaugh et al., 2010; Gilbert, 2013), the implementation of season-long tomato farmer field schools in East Africa as an effective method of training farmers in IPM. We can also highlight the effectiveness of establishing vegetable producer clubs (James et al, 2010) as a way of encouraging farmers to produce tomatoes according to internationally recognised standards and empowering them through the joint marketing of their produce.

Conflict of Interest

The author(s) have not declared any conflict of interest.

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Abbreviations: IPM, Integrated Pest Management; **WHO toxicity class,** toxicity classes of pesticides of the World Health Organisation; **MAFC,** Ministry of Agriculture, Food Security and Cooperatives of the United Republic of Tanzania.

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Farmer perceptions of aflatoxin management strategies in lower Eastern Kenya

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Aflatoxins pose a serious problem to maize grains, rendering them unsuitable for human and livestock consumption. This study assessed farmers' attitude toward, and knowledge and perceptions of, the nature, causes and use of biological technologies in aflatoxin control in Embu, Machakos, Makueni and Kitui Counties of Kenya. A total of 480 households were randomly selected from two districts per county using a GPS system. The tools used in the survey included pre-tested semi-structured questionnaires, focused group discussions, key informant interviews and secondary data exploration. The information collected included crop production constraints, existing aflatoxin management strategies, farmers' experiences with use of atoxigenic strains of *Aspergillus* and other household farm production activities. The study found that farmers were largely aware of the aflatoxin problem and its negative effects, factors that contribute to its occurrence, and available options to address it. The main pre-harvest aflatoxin control technologies used were crop rotation, irrigation, use of resistant crop varieties and pest control. The main post-harvest aflatoxin control technologies used were proper storage, drying, sorting, and use of pesticides to manage pests. Modern aflatoxin control technologies such as ammoniation and use of hydrogels were not in use mainly due to unavailability, high cost and safety concerns (especially regarding grains meant for human consumption). Effective management of aflatoxin contamination requires that farmers are aware of the problem and use a combination of strategies targeting the crop before and after harvesting, and understanding farmers' perceptions and knowledge is a vital step to finding a local solution for aflatoxin management. The study recommends the strengthening of existing public extension service system to enable it deliver up-to-date information, through a variety of channels, on aflatoxin and its management to farmers in a more effective and timely manner.

Key words: Aflatoxin, Aflasafe, farmers, perceptions, Kenya.

INTRODUCTION

Aflatoxins are naturally occurring fungal toxins produced by two types of moulds, *Aspergillus flavus* and *Aspergillus parasiticus* (Daniel et al., 2011). These moulds are known to infect cereals, pulses and a range of other crops. In Kenya, the presence of aflatoxins in maize poses a major food security challenge as maize is the major staple food in the country (Okoth and Kolla, 2012). Over the past decade, various incidents of

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aflatoxin contamination have occurred in lower eastern Kenya, leading to huge losses of human life and destruction of infected maize (Atser, 2010). For instance, during the 2004 outbreak, 317 cases of aflatoxin poisoning were recorded in Kitui, Makueni, Machakos and Thika districts with 127 resulting in fatalities (Probst et al., 2007; Okoth and Kolla, 2012). In 2010, 2.3 million bags of maize grown in the eastern and coastal regions of Kenya were declared unfit for human consumption by the Ministry of Public Health and Sanitation due to high levels of aflatoxin contamination (FAO/UON, 2011).

Globally, up to 36 million Disability-Adjusted Life Years (DALYs) are lost annually due to aflatoxin contamination (IITA, 2010). DALY is used to quantify the health impact or measure overall disease burden and is expressed as the number of years lost due to ill-health, disability or early death. In addition, aflatoxins cause huge losses in harvested grains globally – with sub-Saharan Africa (SSA) accounting for 14.8% of the losses. In Eastern and Southern Africa, post-harvest grain losses range from 10 to 20% (World Bank, 2011). These losses not only aggravate hunger, food insecurity and poverty in SSA but infected grain containing aflatoxins also pose a serious health risk to consumers. The consumption of contaminated produce results in high morbidity and mortality in SSA depending on the quantity of aflatoxins consumed (CAST, 2003; Lewis et al., 2005). Aflatoxin contamination costs farmers and countries millions of dollars annually, not only due to loss of the produce and poisoning of livestock and humans but also due to their inability to access markets since presence of the toxin is a global food safety and quality issue (Bandyopadhyay, 2010). It is estimated that $1.2 billion of trade is foregone globally due to aflatoxin contamination, with African economies losing about $450 million (IITA, 2010). Reduction of aflatoxin presence in crops can therefore improve access to markets and, in turn, raise incomes of poor households and improve health by reducing human exposure to the natural poison (Stack and Carlson, 2006).

Aflatoxin contamination of produce such as maize can occur at any stage, from production, harvesting, postharvest handling, processing, storage and distributio). Erratic rainfall, high temperatures, high humidity and certain characteristics of smallholder production practices are considered to be predisposing factors to aflatoxin contamination in natural settings. Such practices include the nature of certain food-production systems like subsistence farming; a decline in available farm land, making rotations impossible; and a lack of resources, technology, and infrastructure for optimal drying and storage practices. Because aflatoxins are tasteless and colorless, they easily permeate farmers' fields and storage without detection. They are extremely poisonous and have been associated with various diseases, such as aflatoxicosis, hepatotoxicity or, in severe cases, fulminant liver failure in both humans and livestock (Lewis et al., 2005). Chronic dietary exposure to low doses of aflatoxins is a known risk factor for liver cancer and may also affect protein metabolism and immunity to diseases, thus exacerbating the effects of malnutrition and infectious diseases (Williams et al., 2004). Aflatoxins have also been shown to slow the growth and development of children – the result of which is stunting, which affects their life-long potential (CAST, 2003; Wild, 2007).

Presence of aflatoxins can be reduced through various strategies including breeding crops for resistance; improved agronomic, cultural, harvesting and post-harvest handling practices; and the use of biological control agents. Some of these control practices are known to farmers who undertake them routinely within their crop production protocols. However, some of the important production- and post-harvest practices, in addition to stringent food-safety monitoring and standards, are not undertaken due to various factors including cost, culture and/or lack of awareness of the practice (Novack, 2009). Modern aflatoxin control technologies such as ammoniation and hydrogels were not widely used by the survey farmers mainly due to unavailability and high cost of procurement. In some cases, farmers were not are aware of methods of prevention other than those stemming from traditional practices – which include crop rotation, irrigation, use of resistant varieties, pest control and traditional smearing of maize cobs with soil. The use of biological control agents such as Aflasafe is relatively new, especially among smallholder farmers in Africa. Aflasafe is based on the use of atoxigenic strains of *Aspergillus* spp. that work through competitive exclusion of toxigenic strains from the substrate (Abbas et al., 2006). Several studies have been undertaken in West Africa to assess the potential of native atoxigenic isolates of the fungus to reduce aflatoxin contamination in maize (Atehnkeng et al., 2008). For instance, a mixture of four atoxigenic strains of *A. flavus* of Nigerian origin has been granted a provisional registration as Aflasafe in Nigeria (IITA, 2010). Because of the promising results of using native atoxigenic isolates in biological aflatoxin control, on-farm trials with Aflasafe are currently on-going in Kenya, Burkina Faso and Senegal to determine its efficacy and potential use for aflatoxin control in those countries (Hell et al., 2010).

Although many studies have been undertaken on Aflasafe, most have concentrated on its biological potential for use in aflatoxin control under experimental conditions (Atehnkeng et al., 2008; Wu and Khlangwiset, 2010; Hell et al., 2010; IITA, 2010; Probst et al., 2011; Muthomi et al., 2012; Mutegi et al., 2012). None of these studies has focused on farmers' knowledge and attitudes on the nature and causes of aflatoxin contamination in their area, or on their perception of the performance and cost of adopting Aflasafe as a biological aflatoxin-control option, probably due to their not knowing of the product.

Table 1. Number of respondents in each of the eight districts selected in lower eastern Kenya.

County	District	Total number of trial farmers	Number of trial farmers surveyed	Number of non-trial farmers surveyed
Embu	Mbeere North	80	30	30
	Embu East	40	30	30
Kitui	Ikutha	14	14	46
	Nzambani	20	20	40
Machakos	Kangundo	23	23	37
	Kathiani	20	20	40
Makueni	Mbooni East	20	20	40
	Makueni	49	30	30
Total		266	187	293

Farmers' knowledge of the cause of a problem and potential solutions thereof is often the first step towards identifying and designing appropriate strategies for its control. In addition, their perception of how well a new technology performs is, understandably, one of the key factors influencing their decision to adopt new technologies (Kilvin, 1966; Adesina and Baidu-Forson, 1995). It is widely recognized that many potentially beneficial technologies are not adopted by the intended end users (in this case, farmers) because their views and perceptions were not taken into account in the design or development of the technology. This study aims to fill this gap and shed light on such perceptions. The information generated by this study will be useful in guiding the design of programmes to introduce and disseminate Aflasafe and information on its use to farmers. Additionally, these findings will inform implementers on the kind of information and incentives needed to motivate farmers to adopt the new technology once it is proven and commercialized.

MATERIALS AND METHODS

Study area

This study was undertaken in four counties of Kenya (Embu, Kitui, Machakos and Makueni). Table 1 shows the study districts with the corresponding sample sizes. Sixty farmers were randomly selected in each of the eight districts using a Geographical Positing System (GPS) system, which resulted in a total of 480 farmers surveyed. The GPS system was pre-loaded with the waypoints, and the enumerators were taught how to locate a household using the pre-loaded waypoints during the training we provided (on using the GPS) prior to undertaking the survey. The 60 farmers in each district comprised 30 trial and 30 non-trial farmers. Trial farmers were those involved in the Aflasafe trials conducted by the Kenya Agricultural Research Institute (KARI) while non-trial framers were those outside the trial. Where the number of trial farmers in a district fell below 30, all of the trial farmers in that district were surveyed and the balance topped up with non-trial farmers. Figure 1 shows a map of the study households from the study area.

The list of trial farmers were obtained from the frontline extension staff of the Ministry of Agriculture in each district. To ensure representation of non-trial farmers in each district, one non-trial division in the district was randomly selected. All the households in that division were mapped by a Geographical Information System (GIS) expert and the appropriate number of households randomly selected from the map. The sample households were then identified by trained enumerators using a GPS which had been pre-loaded with the waypoints.

Primary data were collected using a pre-tested semi-structured questionnaire. The target respondent was the household head. In his/her absence, his/her spouse or a close member of the household familiar with farm operations was interviewed. The questionnaire contained sections on the farmer's socio-demographic characteristics, knowledge on causes, effects and signs of aflatoxin contamination, and his/her willingness to adopt Aflasafe once it comes to the market. Face-to-face interviews were conducted with farmers by well-trained enumerators using the local dialect.

Data analysis

All the questionnaire data were captured in Microsoft Access relational database by a data clerk. The data were thoroughly checked to correct or remove all erroneous data caused by contradictions, disparities, keying mistakes, and missing bits before they were analyzed. The questionnaire data were analyzed using the statistics programme SAS. Descriptive statistics (principally means and frequencies) were computed to characterize farmers' socio-economic attributes as well as to gauge perceptions of the effects of aflatoxin contamination at the farm level.

RESULTS

Farmers' socio-economic characteristics

Among the 480 survey respondents, 255 (or 53.1%) were male (Table 2). There were more females (54.5%) than males (45.5%) among the trial farmers and more males (58.0%) than females (42.0%) among the non-trial farmers. The higher proportion of females among the

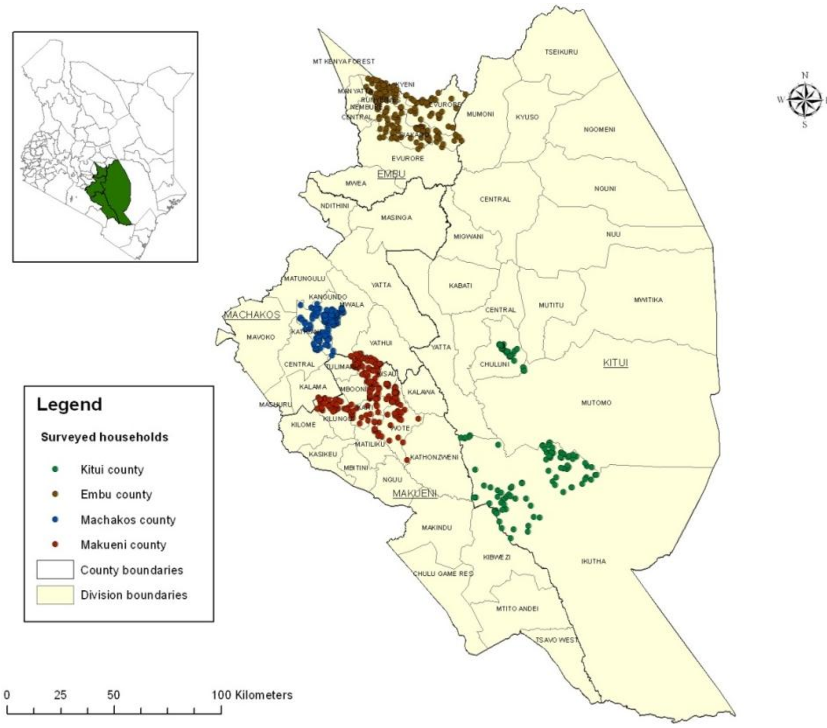


Figure 1. Map of the study households in lower eastern Kenya.

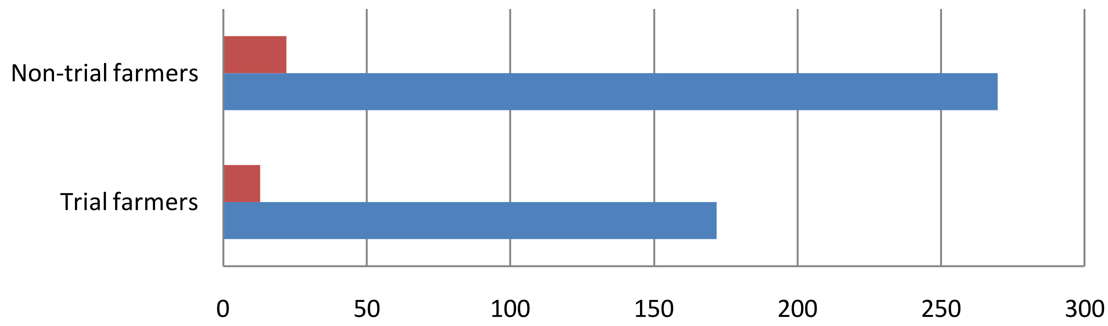
Table 2. Level of formal education and farm labor supply of heads of households among trial and non-trial farmers in eastern Kenya.

Characteristic	Trial farmers		Non-trial farmers	
	Frequency	Percentage	Frequency	Percentage
Level of formal education				
None	21	12.0	35	13.2
Primary	72	40.9	106	39.9
Secondary	52	29.6	86	32.3
Tertiary	31	17.6	39	14.7
Labor supply on-farm				
Full-time	112	64.0	143	54.4
Part-time	52	29.7	104	39.5
Not applicable	11	6.3	16	6.1

trial farmers reflects the underlying importance of women's contribution to agricultural labour in developing countries, including Kenya.

The average age of heads of household among trial and non-trial farmers was 55.8 years (s.e. = 1.1; range = 25-90) and 51.6 years (s.e. = 0.8; range= 25-95) respectively and was significantly different between the two groups (p=0.0025). Age is an important factor to consider as adoption studies show that older farmers are more likely to try new innovations, especially those associated with eliminating a persistent problem such as aflatoxin (Feder et al., 1985; Adesina and Zinnah, 1993; Adesina and Baidu-Forson, 1995).

Education is also an important determinant of technology adoption because it tends to reduce farmers' risk aversion, thus enabling them to try out new innovations. Our data show that the majority of the household heads had attained a primary level of education (40.9% of 176 trial farmers and 39.9% of 266 non-trial farmers) (Table 2). Among the trial farmers, approximately 40% had attained secondary and tertiary education, which was slightly higher than the 36% of the



	Trial farmers	Non-trial farmers
Have not heard	13	22
Have heard	172	270

Figure 2. Knowledge of aflatoxin contamination among farmers in lower eastern Kenya.

non-trial farmers. Additionally, among the two groups, most of the household heads worked full time on the farm (64% of 175 trial vs 54.4% of 263 of non-trial farmers).

About half of the trial and two-thirds of non-trial households were in the “poor” category. Very few households were in the “rich” category, that is, 21 vs 36 households among trial and non-trial groups respectively. In general, 282 farmers (or 58.8%) were in the “poor” category. Another 141 farmers (or 29.4%) were in the medium income category while 57 farmers (or 11.9%) were in the “rich” category. Poverty is both a result as well as a cause of low technology adoption. Additionally, poverty amplifies risk aversion particularly among the poorer households which may forego more profitable but risky technologies in order to avoid a loss (Dercon and Christiaensen, 2011).

Farmers’knowledge of aflatoxin and aflatoxin control strategies

A high percentage of trial (93%, or 172 out of 185 trial farmers) and non-trial (92.5%, or 270 out of 292 non-trial farmers) farmers had heard about aflatoxins in their area (Figure 2). This is an indication of the extent of the knowledge of the aflatoxin problem and an indicator of its severity in the study districts where aflatoxin contamination is endemic and where many outbreaks have been previously reported (Korir and Bii, 2012; Okoth and Kolla, 2012). The fact that a number of respondents in the study area had not heard about aflatoxins is surprising and such a finding underlines the need for continuous education through agricultural extension services.

When asked to indicate when aflatoxin contamination last occurred in their locality, the responses differed widely within the eight study districts. In Nzambani district, for example, the problem of aflatoxin was said to be fairly frequent. In Ikutha district, the problem had not occurred since the 2005 outbreak. In Kathiani and Makueni districts the problem of aflatoxin was said to occur every time there is high rainfall, and in correspondence to seasons when farmers have a bumper harvest. In Mbooni East district, aflatoxin outbreaks were said to be uncommon.

The three main causes of aflatoxin contamination cited by the survey respondents were improper storage (42.6% of trial farmers vs 47.2% of non-trial farmers); improper drying (12.2% of trial farmers vs 16.6% of non-trial farmers), and harvesting crops when they were not properly dry (8.4% of trial farmers vs 11.3% of non-trial farmers) (Table 3). This indicates that farmers had adequate knowledge of the causes of aflatoxin in their area. It is generally understood that, knowledge of the cause of a problem is often the first step towards identifying and designing appropriate strategies for its control.

Of the 180 trial farmers who answered the question, 81.7% could identify the fungal growth or symptoms associated with aflatoxin contamination when shown pictures of infected material by the researchers. Another 101 (or 66.9%) of the 151 who answered the question further indicated that they could differentiate other types of mold growth that are not associated with aflatoxin production. With regard to non-trial farmers, 220 (or 78.6%) of the 280 respondents indicated that they knew how to identify fungal growth or symptoms associated with aflatoxin contamination. This finding underscores the level of knowledge among farmers in lower eastern Kenya, of the nature, form and causes of aflatoxin contamination in their locality. As indicated earlier, such knowledge is important in prompting farmers to design appropriate strategies for the management of aflatoxin contamination.

Table 3. Farmers' knowledge on the causes of aflatoxin contamination in lower eastern of Kenya.

Cause	Trial farmers		Non-trial farmers	
	Frequency	Percentage	Frequency	Percentage
Improper storage	101	42.6	176	47.2
Improper drying	29	12.2	62	16.6
Harvesting crops when not properly dry	20	8.4	42	11.3
A lot of rain during harvesting	16	6.8	19	5.1
Dampness in store	15	6.3	21	5.6
High moisture content	15	6.3	22	5.9
Premature harvesting	10	4.2	4	1.1
Infection from the soil	9	3.8	7	1.9
Many chemicals used on crops	3	1.3	4	1.1
Damage from pests	2	0.8	1	0.3
Rotting of maize	2	0.8		-
Bad seeds	1	0.4	3	0.8
Can be genetic	1	0.4		-
Due to shifting cultivation/ mixing crops in a farm	1	0.4	1	0.3
Maize has poison whose source is unknown	1	0.4		-
Applying pesticide on wet cereals	1	0.4	1	0.3
Delayed harvesting		-	2	0.5
Untreated cereals		-	1	0.3
Do not know	10	4.2	7	1.9
Total	**237**	**100**	**373**	**100**

Table 4. Proportion of farmers' responses on crops most affected by aflatoxin in lower eastern Kenya.

Crop	Pooled		Trial farmers		Non-trial farmers	
	Frequency	Percent	Frequency	Percent	Frequency	Percent
Maize	470	69.4	183	70.4	287	68.8
Sorghum	107	15.8	45	17.3	62	14.9
Millet	34	5.0	8	3.1	26	6.2
Groundnuts	2	0.3	1	0.4	1	0.2
Cassava	51	7.5	18	6.9	33	7.9
Beans	5	0.7	1	0.4	4	0.96
Don't know	4	0.6	1	0.4	3	0.7
All grains	3	0.4	2	0.8	1	0.2
Mushrooms	1	0.1	1	0.4	0	0
Total	**677**	**100**	**260**	**100**	**417**	**100**

Table 4 shows farmers' responses regarding their knowledge about the crops most affected by aflatoxin in their area. The four most frequently mentioned crops were maize (accounting for 69.4% of all responses), sorghum (15.8%), cassava (7.5%) and millet (5%).

Farmers' awareness and use of pre-harvest aflatoxin control technologies

Figure 3 shows the level of awareness of trial and non-trial farmers of different aflatoxin control technologies used in maize in lower eastern Kenya. Generally, the level of awareness was rather low given that none of the six alternative technologies comprised even 40% of the responses. Nonetheless, trial farmers were aware of crop rotation, pest control and use of resistance varieties as the main pre-harvest aflatoxin control technologies. Non-trial farmers were mainly aware of crop rotation and pest control as the main pre-harvest aflatoxin control technologies. More trial (21.7%) than non-trial farmers (0.8%) were aware of the utility of bio-control as an

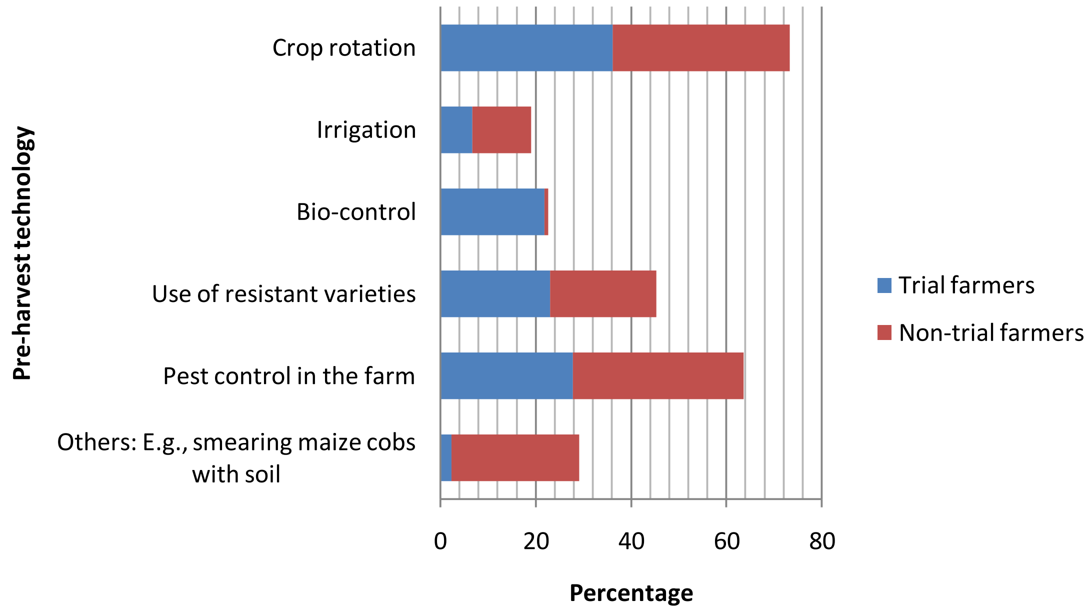


Figure 3. Proportion of trial and non-trial farmers who indicated their level of awareness of different pre-harvest aflatoxin control technologies used in maize in lower eastern Kenya.

aflatoxin control method for use in maize-perhaps because they had seen Aflasafe being administered in their farms by KARI researchers.

With regard to the actual use of pre-harvest aflatoxin control technologies, it was noted that those farmers who were not involved in the trials reported rates of use, abandonment and non-adoption [of the pre-harvest technologies] that were similar to those expected (Table 5). However, the proportion of trial farmers who had never adopted any aflatoxin control technology was higher than that of non-trial farmers. The three main reasons given by trial farmers for not adopting pre-harvest aflatoxin control technologies were: Lack of adequate information about the technology, high cost of technology, and fear of technology. Such perceptions may lead to technology failure hence efforts are needed to alleviate them especially when introducing a new technology in the study area.

Farmers' awareness and use of post-harvest aflatoxin control technologies

Figure 4 shows the proportion of farmers' awareness of different post-harvest aflatoxin control technologies. In general, proper storage, proper drying, sorting and use of post-harvest pesticides recorded high levels of awareness amongst both trial and non-trial farmers.

The use by farmers of the above-mentioned technologies is shown in Table 6. Proper storage, drying, sorting and post-harvest pesticides were the most widely used post-harvest aflatoxin control technologies. Very few farmers used food processing and ammoniation as post-harvest aflatoxin control technologies. The three main reasons for non-adoption of post-harvest aflatoxin control technologies included lack of information about the technology, high cost of the technology and fear of the technology. A number of farmers had abandoned the use of various post-harvest aflatoxin control technologies.

DISCUSSION

Farmers' perceptions of the utility of a new technology in addressing identified production constraints is one of the main factors that influence their willingness to purchase the technology and therefore their adoption decision (Kilvin, 1966; Adesina and Baidu-Forson, 1995). This study sought to assess farmers' perceptions about use of biological technologies in aflatoxin control in Kenya. The study found that farmers were largely aware of the aflatoxin problem. For instance, farmers knew that aflatoxin contamination in maize is caused by *Aspergillus* spp. arising from high moisture content either during harvesting or in storage.

Moreover, studies show that cereals (e.g., maize, sorghum and millet), oil crops (e.g., groundnuts) and root crops (e.g., cassava) are the crops most widely affected by aflatoxin contamination in developing countries (William et al., 2004; Wu et al., 2008; Mutegi et al., 2012). Our findings suggest that farmers are also aware of the main crops mostly affected by aflatoxin – namely, maize (accounting for 69.4% of all responses), sorghum (15.8%), cassava (7.5%) and millet (5%) (Table 4).

Table 5. Proportion of trial and non-trial farmers that reported using different pre-harvest aflatoxin control technologies in maize in lower eastern Kenya

Technology	Trial farmers		Non-trial farmers	
	Frequency	Percentage	Frequency	Percentage
Crop rotation				
Currently using	14	42.4	24	49.0
Abandoned	3	9.1	3	6.1
Never adopted	16	48.5	19	38.8
Other			3	6.1
Irrigation				
Currently using	1	5.9	6	19.4
Abandoned	-		1	3.2
Never adopted	16	94.1	24	77.4
Bio-control				
Currently using	5	16.1	1	2.4
Abandoned	11	35.5	23	56.1
Never adopted	15	48.4	17	41.5
Use of resistant varieties				
Currently using	12	44.4	24	57.1
Abandoned	1	3.7	-	
Never adopted	14	51.9	18	42.9
Pest control in the farm				
Currently using	16	55.2	42	73.7
Abandoned	-		2	3.5
Never adopted	12	41.4	13	22.8
No aflatoxin on the farm	1	3.4	-	
Others: E.g. smearing maize cobs with soil				
Currently using	-		16	38.1
Abandoned	-		7	16.7
Never adopted	13	100	19	45.2

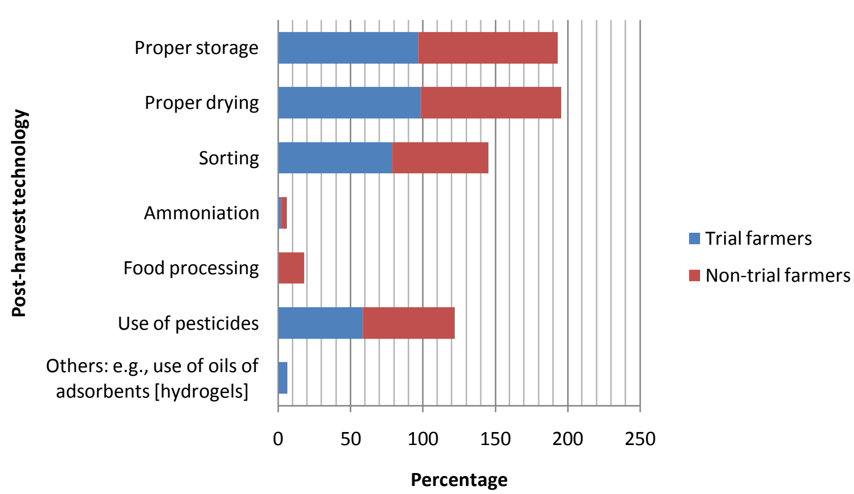


Figure 4. Proportion of trial and non-trial farmers who indicated their level of awareness of different post-harvest aflatoxin control technologies used in maize in lower eastern Kenya.

Table 6. Proportion of trial and non-trial farmers that reported using different post-harvest aflatoxin control technologies in maize in lower eastern Kenya.

Post-harvest technology	Trial farmers		Non-trial farmers	
	Frequency	Percentage	Frequency	Percentage
Proper storage				
Currently using	64	100	118	95.9
Abandoned			1	0.8
Never adopted			4	3.3
Proper drying				
Currently using	64	100	123	99.2
No aflatoxin on the farm			1	0.8
Sorting				
Currently using	43	97.7	77	98.7
Never adopted	1	2.3	1	1.3
Ammoniation				
Currently using	1	8.3	3	13.0
Abandoned			3	13.0
Never adopted	11	91.7	17	73.9
Food processing				
Currently using	3	21.4	17	48.6
Abandoned			2	5.7
Never adopted	11	78.6	16	45.7
Post-harvest pesticides				
Currently using	32	78.0	61	85.9
Abandoned	1	2.4		
Never adopted	8	19.5	10	14.1
Others: E.g., oils or adsorbents (hydrogels)	0			
Abandoned			2	13.3
Never adopted			13	86.7

These findings corroborate those from previous studies and show how well farmers in lower eastern Kenya are aware of the problem of aflatoxin contamination in their area, which is probably due to years of experience with the problem. The earliest record of aflatoxin contamination in lower eastern Kenya was in 1982 in the then Machakos, Kitui and Makueni districts (Muthomi et al., 2012; Korir and Bii, 2012).

However, the survey farmers had a low level of awareness of different aflatoxin control technologies used in maize. In 40% of the responses (Figure 3), none of the six alternative technologies were cited. This low level of awareness of aflatoxin control technologies could be attributed to the fact that so far no effective aflatoxin management strategies exist after contamination has occurred. Before Aflasafe became available, farmers in the study were relying on traditional methods of aflatoxin control such as smearing the maize cobs with soil. Although most farmers knew about crop rotation, irrigation and pesticide use as important crop husbandry practices, these were not clear to them as aflatoxin management technologies. This finding reflects in part the failure of the public extension system to support farmer learning and empowerment by communicating relevant messages aimed at addressing pernicious problems such as aflatoxin contamination.

In particular, the low awareness of aflatoxin control technologies was reflected in the low utilization of modern pre- and post-harvest control methods in the study area. For instance, only five (or 16.1%) and one (or 2.4%) of trial and non-trial farmers, respectively, used pre-harvest bio-control technology (Table 5). With respect to post-harvest aflatoxin control technologies, only one (or 8.3%) trial and three (or 13%) non-trial farmers used ammoniation, and no trial farmers or non-trial farmers used hydrogels (Table 6). Some of the reasons for the low use of modern pre- and post-harvest aflatoxin control technologies included unavailability of specific technologies, lack of information on the technologies and their high cost.

That both groups of farmers were not well versed in ammoniation, food processing or use of hydrogels as post-harvest aflatoxin control technologies in maize could be attributed to the fact that these methods are rather more sophisticated, costly and unavailable compared to traditional methods. The lack of knowledge about these technologies among the survey farmers suggests that, in order for Aflasafe and other technologies to achieve the high level of uptake desired, there is a need for the team that developed Aflasafe to demonstrate how these technologies work and convince farmers of the benefits associated with their use.

Conclusion

Aflatoxins constitute a huge public health problem in Kenya, particularly in the lower eastern province. Understanding farmers' attitudes toward, and their knowledge and perception of, the causes of any constraint is one of the keys to finding a local solution for aflatoxin management. This study assessed farmers' knowledge, attitude and perceptions of the nature, causes and use of biological technologies in aflatoxin control in Kenya. While the study found high levels of knowledge about the causes of aflatoxin contamination and found that farmers could identify the crops most commonly affected by aflatoxin, the level of awareness of different aflatoxin control technologies was rather low. As a result, there was low adoption of aflatoxin control options commonly available in the study area. Even where these options were used, the farmers were generally unaware of the extent to which what they were doing could limit the development of aflatoxin. There was also low adoption of modern aflatoxin control technologies mainly due to lack of information about the technology, high cost of the technology and fear of the technology. The study team therefore recommend the strengthening of the existing public extension service system to enable it to deliver up-to-date information on aflatoxin and its control to farmers in a more effective and timely manner. Such information can be disseminated through radio, existing system of government extension workers and farmer groups that engage in peer learning, which the study found were the main channels of information dissemination in the study area.

Conflicting interests

The authors declare that there are no conflicts of interest

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Perceptions of smallholder farmers on improved box hive technology and its profitability in Northern Ethiopia

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This study was initiated to analyze smallholder beekeepers' perceptions towards the constraints and benefits of using improved box hive and its profitability compared to traditional beehive in Ahferom district of Tigray region, Ethiopia. Both primary and secondary data sources comprising qualitative and quantitative data types were utilized. Primary data were collected by interviewing 130 randomly selected smallholder beekeepers during March to April, 2011. Descriptive statistics and partial budgeting techniques were employed to analyze the data using SPSS-16. The findings revealed that beekeepers perceived that improved box hive is superior in its honey quantity and quality, swarm control, hive durability, avoidance of bee mortality and ease of inspection and management of hive, however, it is constrained by high hive price and unavailability of improved inputs, skilled manpower requirement and low honey market demand compared to traditional beehive. Partial budget and sensitivity analyses implied that adoption of improved box hive technology makes smallholder beekeepers more profitable than traditional beehive and profitable up to 20% variability in inputs cost and output prices. Therefore, the higher profitability and less sensitivity to input cost and output price variability of improved box hive over traditional beehive should be considered by policy-makers and planners of governmental and non-governmental organizations (NGOs) in setting their policies and strategies of institutional services development and honey production improvement interventions.

Key words: Perception, profitability, improved box hive, partial budget, sensitivity analysis, smallholder beekeepers.

INTRODUCTION

Apiculture is a promising off-farm enterprise, which directly and indirectly contributes to smallholder's income in particular and nation's economy in general. It has significant role in generating and diversifying the income of subsistence Ethiopian smallholder farmers mainly the small land holders and landless (EARO, 2000; Gezahegn, 2001). In Ethiopia, traditional, transitional and improved beehives were recognized for honey production

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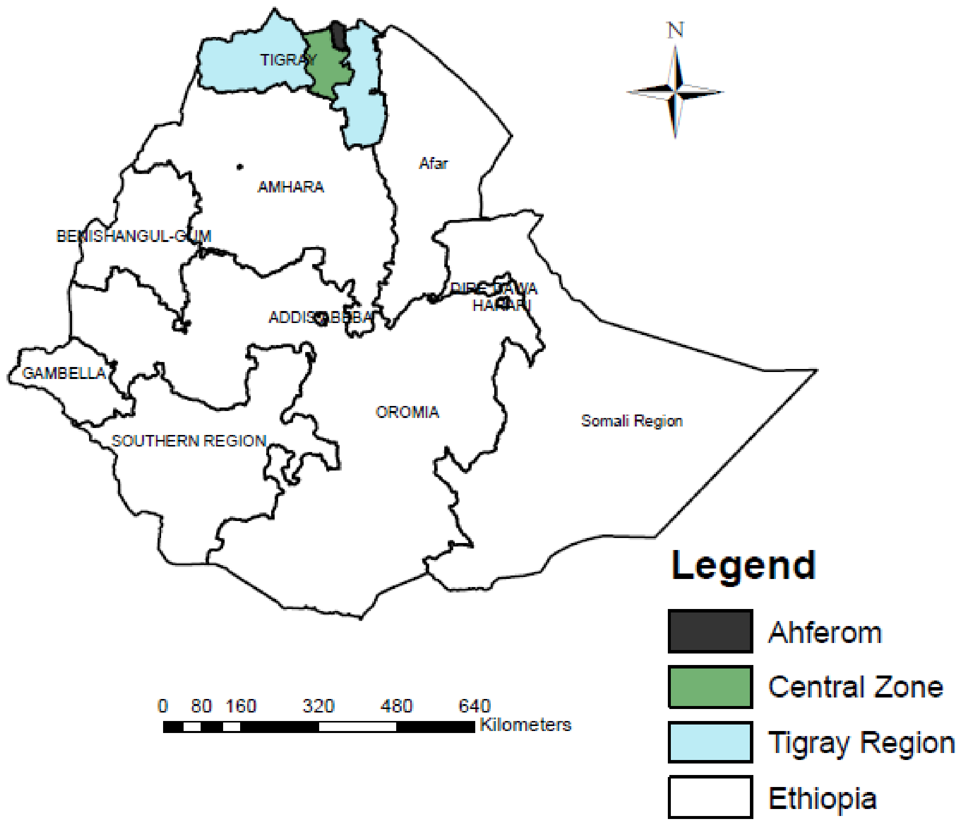

Figure 1. Location map of Ahferom district.

with a total of 5.15 million beehives (of 93% traditional) and the farm households keeping bees were 1.4 million. Endowed with diverse agro-climatic zones, the total honey and beeswax production estimates in Ethiopia is about 39,700 and 3,800 tons per year, respectively. Such an amount puts the country 10th in honey and 4th in beeswax production worldwide. Moreover, Ethiopia has the potential to produce up to 500,000 tons of honey and 50,000 tons of beeswax per year (GDS, 2009).

Thus, the current Ethiopian government has increased its attention to develop the apiculture sub-sector as one of its strategies for poverty reduction and export diversification; and different non-governmental organizations (NGOs) have been intervening to assist the poor smallholder farmers through the introduction and promotion of box hive to obtain higher honey production of good quality that can enable the smallholder farmers in particular and the country in general to be benefited from the sub-sector (GDS, 2009). Similarly, great effort has been made by regional government extension package and Relief Society of Tigray to promote improved box hive technology in the region to increase the quantity quality of honey production and build the capacity of beekeepers for better management of bees and hives for honey and beeswax production (Gidey and Mekonen, 2010).

Even though all the efforts have been made at national and regional level to introduce improved apiculture technology, the perception of smallholder farmers towards the improved box hive technology is different that some perceived positively, but others negatively compared to the traditional beehive. As a result, some smallholders adopt this technology but some of the adopters need not to intensify to a business level, and significant number of smallholders kept with traditional production system.

Therefore, the primary objective of the study was to analyze smallholder beekeepers' perceptions towards the constraints and benefits of using improved box hive and its profitability compared to traditional beehive.

RESEARCH METHODOLOGY

Description of the study area

Ahferom district (Figure 1) is among the major honey producing districts in Tigray region next to Kilte-Awlaello and Atsbi-Wombert districts and also among potentially the most promising areas for the production of honey next to Tselemti and Medebay-Zana districts. However, up to around a decade back all beekeepers of the district were only engaged in traditional production system (OoARD, 2009) though improved box hive has been introduced and promoted in the country since 1970 (HBRC, 1997).

Table 1. Sample distribution in the selected *Tabias*.

Sample *Tabia*	THHH*	Total beekeepers		Non-adopters		Adopters	
		HHH**	Sample	HHH	Sample	HHH	Sample
Sero	2138	427	41	210	20	217	21
L. M. Tsemri	1716	396	38	202	19	194	19
My-Suru	1099	282	27	120	11	162	16
Degose	1065	251	24	94	9	157	15
Total	6018	1356	130	626	59	730	71

Source: *Tabias* recorded, 2011; *THHH, total household heads; **HHH, household heads.

Sampling technique and sample size

Multi-stage sampling procedure was used to select sample smallholder beekeepers for the interview. Ahferom district was selected purposively based on the honeybee production potential, availability of bee flora and improved box hive promotion. Excluding five *Tabias*[1] that were affected by the Ethio-Eritrea conflict, four *Tabias* were selected randomly out of the remaining 22 rural *Tabias*. In the selected *Tabias*, the beekeepers were stratified into non-adopters and adopters of improved box hive sub-groups. Having the list of beekeepers from each *Tabia*, 130 sample beekeepers (59 non-adopters and 71 adopters) were selected randomly based on the probability proportional to size sampling technique from the selected *Tabias* (Table 1).

Method of data collection

Both primary and secondary data sources comprising qualitative and quantitative data types were utilized for this study. Primary data were obtained from sample respondents during March to April, 2011 by using semi-structured questionnaire through interview method. Secondary data were gathered from various sources such as reports of Ministry of Agriculture (MoA) at different levels, Central Statistical Agency (CSA), district Bureau of Agricultural and Rural Development *(*BoARD), NGOs, previous research findings, Internet and other published and unpublished materials.

Method of data analysis

The data were analyzed using descriptive statistics and partial budgeting analysis with the help of SPSS version 16.0 software package.

Partial budgeting technique

Partial budgeting is a method of organizing data and information about the costs and benefits of alternative practices (CIMMYT, 1988). This methodology evaluates the changes from one technology to another by comparing the changes in costs and benefits associated with each practice. In this case, for the profitability analysis, comparison of the net benefits from traditional beehive and improved box hive was made in per hive basis. Finally, if the net benefit is positive, the conclusion drawn will be that the proposed practice (improved beekeeping) has relative advantages, otherwise it would be better-off to stay using the current practice (traditional beekeeping).

Moreover, partial budgeting analysis also suggests marginal analysis. In apiculture enterprise, if the net benefits from improved box hive are higher than those for traditional beehive, it may appear that smallholder farmers would choose to adopt improved box hive, but the choice is not obvious, because smallholder farmers will also want to consider the increase in costs. Although the calculation of net benefits accounts for the costs that vary, it is necessary to compare the extra (or marginal) costs with the extra (or marginal) net benefits. Higher net benefits may not be attractive if they require very much higher costs (CIMMYT, 1988). In changing from their traditional beekeeping practice to an improved beekeeping the smallholder farmers must make an extra investment per hive; in return, they will obtain extra benefits per hive. One way of assessing this change is marginal rate of return. Variability in costs of inputs and prices of outputs that affects marginal benefits and costs was employed using sensitivity analysis.

RESULTS AND DISCUSSION

Descriptive results

Perceptions of smallholder farmers regarding the benefits and constraints of using improved box hive technology compared to traditional beehive

An analysis of farmers' knowledge, particularly their perceptions and attitudes regarding the benefits and constraints of using improved box hive as compared to traditional one is essential for explaining why farmers prefer/not prefer the technology. Farmers differed in their perceptions of the performance of improved box hive and traditional beehive with respect to the benefits and constraints characteristics. Accordingly, three categorizations were specified for each characteristic as inferiority, same and superiority of the improved box hive over traditional beehive and vice-versa. Table 2 shows farmers' perception for benefits that could be obtained from improved honey production as compared to the traditional one. In their observation, the benefits of improved box hive fall into mainly durability of the hive, ease of inspection and management of the hive, swarm control, avoidance of bee killing during harvesting period, marketability of hive products, labor-saving, quality and quantity of honey. Of these benefit characteristics, quantity of honey produced, quality of honey, swarm control, durability of the hive, avoidance of bee killing during harvest time and ease of inspection and

[1]*Tabia* is the smallest administrative unit in Tigray region.

Table 2. Perceptions of farmers regarding the benefits of using improved box hive compared to traditional beehive and their prioritization.

Characteristics		Non-adopters		Adopters		Total sample		Rank
		N	%	N	%	N	%	
Quantity of honey	Inferior	0	0.0	0	0.0	0	0.0	1st
	Same	16	27.1	4	5.6	20	15.4	
	Superior	43	72.9	67	94.4	110	84.6	
Quality of honey	Inferior	0	0.0	0	0.0	0	0.0	2nd
	Same	20	33.9	9	12.7	29	22.3	
	Superior	39	66.1	62	87.3	101	77.7	
Durability of hive	Inferior	4	6.8	3	4.2	7	5.4	4th
	Same	17	28.8	8	11.3	25	19.2	
	Superior	38	64.4	60	84.5	98	75.4	
Management and inspection	Inferior	10	17.0	3	4.2	13	10.0	3rd
	Same	18	30.5	9	12.7	27	20.8	
	Superior	31	52.5	59	83.1	90	69.2	
Marketability of honey	Inferior	26	44.1	44	61.9	70	53.8	7th
	Same	15	25.4	21	29.6	36	27.7	
	Superior	18	30.5	6	8.5	24	18.5	
Swarm control	Inferior	4	6.8	1	1.4	5	3.8	5th
	Same	24	40.7	19	26.8	43	33.1	
	Superior	31	52.5	51	71.8	82	63.1	
Labor-saving	Inferior	8	13.6	6	8.5	14	10.8	8th
	Same	32	54.2	35	49.2	67	51.5	
	Superior	19	32.2	30	42.3	49	37.7	
Avoidance of bee killing	Inferior	4	6.8	4	5.6	8	6.2	6th
	Same	16	27.1	27	38.1	43	33.0	
	Superior	39	66.1	40	56.3	79	60.8	

Source*:* survey output (2012); N, number of observation; %, percentage of observations.

management were remarked by 84.6, 77.7, 63.1, 75.4, 60.8 and 69.2% of the farmers, respectively as superiority of improved box hive over the traditional one. For instance, farmers' perception for the quantity of honey produced from improved box hive can also be confirmed with the quantitative results. This implies that honey produced from improved box hive (26.04 kg) was significantly higher than the honey produced from traditional beehive (12.56 kg) in the study area. On the other hand, even though, the average price of honey produced from improved box hive (89.30 ETB[2]) was a little higher than that of the average price of honey produced from traditional beehive(76.09 ETB) but honey produced from traditional beehive has high market demand (preferred by buyers) than honey produced from improved box hive. This may be due to the problem of adding extra materials such as banana, sugar, white flour and grounded bone to the honey produced from improved box hive by some sellers (traders and/or producers). Thus, 53.8% of the farmers respond that honey produced from traditional beehive has high market demand than honey produced from improved box hive in the study area. Only 51.5% of the farmers perceived that improved box hive and traditional beehive have no difference in labor-saving. Furthermore, not only the farmers observed the comparison of benefits between improved and traditional beehives but particularly farmers also observed the comparison of benefits of using improved box hive and they were ranked as 1st, 2nd, 3rd, 4th, 5th, 6th, 7th and 8th for quantity, quality, ease of inspection and management, hive durability, swarm control, no bee killing during harvest period, marketability

[2] 1.00 USD = 16.858 ETB.

of honey and labor saving, respectively (Appendix A: Table 1).

Farmers reported various constraints that hinder the adoption of improved box hive technology. The main constraints that limits improved box hive technology adoption were suggested by the farmers as price of improved inputs, unavailability of improved inputs, skilled manpower requirement, susceptibility to pests, predators and diseases, absconding due to different natural and man-made factors, credit constraint, lack of extension support, drought (lack of feed and water), marketing problem, and pesticides and herbicides applications. Hence, severe, same and less severe categorizations were used to compare the level of constraints of using improved box hive with traditional one.

Out of the main constraints that limit this technology adoption were the price of improved inputs, unavailability of improved inputs and skilled manpower requirement. All, 83.1 and 68.5% of the farmers in the study area indicated that inputs of improved honey production were very expensive, inadequately available and required skilled manpower, respectively. In line with this the limited extension support, credit constraint, absence of market for outputs, occurrence of absconding as a result of pests, predators, diseases, pesticides and herbicides applications, drought (lack of feed and water) were mentioned as constraints to low rate and level of improved box hive technology adoption (Table 3). According to the respondents' perceptions, constraints of using improved box hive technology also ranked depending on the level of seriousness as 1st, 2nd, 3rd, 4th, 5th, 6th, 7th, 8th, 9th and 10th for price of improved inputs, skilled man-power requirement, lack of improved inputs, marketing problem, credit constraint, lack of extension support, absconding, pesticides and herbicides application, drought and susceptibility to pests and diseases, respectively (Appendix A: Table 2).

Partial budgeting result

Partial budget method was used to evaluate the changes from one technology to another by comparing the changes in costs and benefits associated with each practice. In this case, for the profitability analysis, comparison of the net benefits from traditional beehive and improved box hive was made in per hive basis. This analysis excludes the fixed costs such as land, bee colony, labor (unskilled) requirement other than combs preparation and honey harvesting, and bee shed because they are unchanging across practices. The costs that vary across the two practices include labor (skilled) cost during preparation of combs and harvesting, cost of beeswax used for preparing combs, cost charged to accessories, depreciation on fixed inputs, feed cost, transport cost, interest on fixed and variable costs. Moreover, in this case, both hives were assumed to be used for production rather than for multiplication of bee colony. All benefits and costs should be calculated using the nearest market prices and input costs. That is, the actual price which the farmer pays for the inputs or receives for the products in 2010/2011 at the nearby market place. Opportunity cost was considered for activities undertaken by the farmers. Farmers obtained different honey yield and beeswax; and they sold at different selling prices throughout 2010/2011. Hence, the average honey yield and beeswax, and average selling prices were taken for the partial budget in this study. The same was done for inputs costs and requirements. Besides, there are other things to be considered in this analysis:

(1) Scientific studies implied that 8 to 10% of the honey produced from traditional beehive and 0.5 to 2% of the honey produced from improved box hive is beeswax. Accordingly, 9% of the honey produced from traditional beehive and 1.25% of the honey produced from improved box hive were considered for the average beeswax produced from traditional and improved box hive, respectively.
(2) Depreciation for the fixed inputs was estimated using the straight-line method as purchase price minus salvage value divided by life time of the input.
(3) Depreciation for bee colony and bee shed was excluded from the analysis due to similarity in both practices.
(4) Development bank of Ethiopia was providing loan for those who participated in agricultural investments. Therefore, an interest rate of 7.5% was assumed to be used for all variable and fixed costs.
(5) Traditional beehive assumed to be constructed in 1 man-day (MD); hence, the opportunity cost of 1 man-day was considered as the price of traditional beehive.
(6) Depreciation of traditional beehive was calculated by considering the salvage value which is 10% of its original price at 5 years service life.
(7) The price of improved box hive was 795 at 15 year service life and its salvage value would be 10% of its purchase price.

Input requirements and their costs that vary for both improved and traditional hives were shown in Table 4. Beeswax was purchased to prepare combs using foundation sheet for improved box hive which requires skilled labor, but bees themselves prepared combs for traditional beehive. Improved box hive required improved accessories and skilled labor during honey harvesting, whereas homemade equipments was used by anybody who have endogenous knowledge on honey harvesting from traditional beehive. Bee colonies kept in improved box hive required more supplement feed than bee colonies kept in traditional bee hive. This high feed requirement by the bee colonies helps them to accomplish the mechanically prepared specified number

Table 3. Perceptions of farmers regarding the constraints of using improved box hive compared to traditional beehive and their prioritization.

Attributes		Non-adopters		Adopters		Total sample		Rank
		N	%	N	%	N	%	
Expensive improved inputs	Severe	59	100.0	71	100.0	130	100.0	1st
	Same	0	0.0	0	0.0	0	0.0	
	Less	0	0.0	0	0.0	0	0.0	
Unavailability of improved inputs	Severe	51	86.4	57	80.3	108	83.1	3rd
	Same	8	13.6	14	19.7	22	16.9	
	Less	0	0.0	0	0.0	0	0.0	
Required skilled manpower	Severe	49	83.0	40	56.3	89	68.5	2nd
	Same	7	11.9	27	38.1	34	26.2	
	Less	3	5.1	4	5.6	7	5.4	
Credit constraint	Severe	23	38.9	12	17.0	35	26.9	5th
	Same	16	27.1	30	42.2	46	35.4	
	Less	20	34.0	29	40.8	49	37.7	
Lack of extension support	Severe	5	8.5	1	1.4	6	4.6	6th
	Same	28	47.5	29	40.8	57	43.8	
	Less	26	44.0	41	57.8	67	51.5	
Marketing problem	Severe	41	69.5	32	45.1	73	56.2	4th
	Same	15	25.4	25	35.2	40	30.8	
	Less	3	5.1	14	19.7	17	13.1	
Absconding	Severe	11	18.6	15	21.1	26	20.0	7th
	Same	28	47.5	29	40.9	57	43.8	
	Less	20	33.9	27	38.0	47	36.2	
Drought	Severe	7	11.8	5	7.0	12	9.2	9th
	Same	48	81.4	63	88.8	111	85.4	
	Less	4	6.8	3	4.2	7	5.4	
Pesticides and herbicides applications	Severe	6	10.2	2	2.8	8	6.2	8th
	Same	46	78.0	59	83.1	105	80.8	
	Less	7	11.8	10	14.1	17	13.1	
Susceptibility to pest and diseases	Severe	8	13.6	2	2.8	10	7.7	10th
	Same	21	35.6	30	42.3	51	39.2	
	Less	30	50.8	39	54.9	69	53.1	

Source: Survey output (2012); N, number of observation; %, percentage of observations.

of combs in the improved box hive. Improved box hive required additional inputs relative to traditional beehive. Such difference in input requirements of the two hives resulted in cost difference between the two hives.

Table 5 shows a partial budget for both improved and traditional honey production practices. The result shows that the traditional beehive yields on average 12.56 kg/hive/year at its average selling price of 76.09 ETB/kg, while improved box hive yields on average 26.04 kg/hive/year at its average selling price of 89.30 ETB/kg. Hence, average yield and average price of improved box hive is higher than traditional hive.

Table 4. Average input requirements and costs of both practices.

Activity	Traditional beehive	Improved box hive
Labor for combs preparation (MD hive^{-1})	-	1
Wage rate for comb preparation (ETB)	-	58.00
Labor cost for combs preparation (ETB) (A)	-	58.00
Labor for harvesting (MD hive^{-1})	1.50	2
Wage rate for harvesting (ETB)	35.00	58.00
Labor cost for harvesting (ETB) (B)	52.50	116.00
Labor cost (ETB) (A+B)	52.50	174.00
Beeswax for comb making (kg hive^{-1})	-	1
Beeswax price (ETB)	-	50.00
Beeswax cost (ETB)	-	50.00
Feed (kg hive^{-1})	1.3	2
Feed price (ETB)	18.00	18.00
Feed cost (ETB)	23.40	36.00

Source: survey output (2012).

Table 5. Summary of partial budget for improved and traditional beehives.

Activity	Traditional beehive	Improved box hive
Average honey yield (kg hive^{-1})	12.56	26.04
Average honey selling price (ETBkg^{-1})	76.09	89.30
Average beeswax yield (kg hive^{-1})	1.13	0.33
Average beeswax price (ETBkg^{-1})	50	50
Gross benefit (ETBhive^{-1}) (C)	1012.19	2341.87
Labor cost (ETBhive^{-1})	52.50	174.00
Beeswax cost (ETBhive^{-1})	-	50.00
Feed cost (ETBhive^{-1})	23.40	36.00
Accessories charged (ETBhive^{-1})	-	15.00
Transport cost (ETBhive^{-1})	-	7.50
Interest on variable costs (ETBhive^{-1})	5.69	21.19
Interest on fixed costs (ETBhive^{-1})	2.63	59.63
Depreciation of beehive	6.30	47.70
Total costs that vary (ETBhive^{-1}) (D)	90.52	411.02
Net benefit (ETBhive^{-1}) (C-D)	921.67	1930.85
Marginal benefit (ETB) (E) as compare to traditional	1009.18	
Marginal cost (ETB) (F) as compare to traditional	320.50	
Marginal rate of return (MRR = E/F) (%) as compare to traditional	3.15 or 314.87%	

Source: survey output (2012).

The total costs that vary for both improved and traditional honey production were estimated to be 411.02 and 90.52 ETB/hive, respectively. The net benefits were 1930.85 and 921.67 ETB/hive for improved and traditional honey production, respectively. That is, the net benefit of improved box hive is more than twice higher than the net benefit of traditional beehive. Workneh (2007) conducted similar analysis in Atsbi-Wemberta district Eastern zone of Tigray region. He found that the net benefit of improved box hive was around three times higher than that of traditional beehives, even though some cost categories were not included in the partial budget analysis such as depreciation cost of beehives, which makes significant difference in the net benefit of the two hives. However, net benefits are not the same thing as profit, because the partial budget does not include the

Table 6. Sensitivity analysis of net benefits to 20% increases in inputs cost.

Activity	Traditional beehive	Improved box hive
Gross benefit (ETBhive^{-1})	1012.19	2341.87
Total costs that vary (ETBhive^{-1})	108.60	493.20
Net benefit (ETBhive^{-1})	903.59	1848.67
Marginal benefit (ETB) compared to traditional	945.08	
Marginal cost (ETB) compared to traditional	384.60	
Marginal rate of return (MRR) (%) compared to traditional	2.46 or 245.73%	

Source: survey output (2012).

other costs of production which are not significant to this particular decision. It may come into view that smallholder farmers would choose to adopt improved box hive, but the choice is not obvious, because smallholder farmers will also want to consider the increase in costs. Hence, in this case, smallholder farmers will obtain extra (marginal) benefit of 1009.18 ETB/hive by investing extra (marginal) cost of 320.50 ETB/hive to adopt improved box hive. Furthermore, the marginal analysis for the alternative practices is calculated using the marginal rates of return as marginal benefit divided by marginal cost to decide which practice is acceptable to smallholder farmers. Accordingly, the marginal rate of return is 3.15 ETB (314.87%). Therefore, for each 1 ETB/hive on average invested in improved box hive, smallholder farmers recover their 1 ETB, plus an extra 3.15 ETB in net benefits. This implies that adoption of improved box hive makes higher marginal benefit than traditional beehive.

In addition to being concerned about the net benefits of alternative technologies and the marginal rates of return in changing from one to another, smallholder farmers also take into account the possible variability in results (CIMMYT, 1988). Yield, input and output prices in partial budget are subject to vary in the future. However, only input and output prices variability in the future was considered in this analysis. A method used for estimating input and output prices variability is called sensitivity analysis. Sensitivity analysis simply implies redoing a marginal analysis with alternative prices. Hence, in this study, the sensitivity analysis was undertaken by moving the prevailing average inputs cost upwards by 20% and the output prices downwards by 20% relative to the average market price.

Table 6 shows the effect of increasing inputs cost by 20% on net benefits and marginal benefits of beekeeping practices. Assuming a 20% increase in inputs cost of beekeeping practices, the net benefits of both improved and traditional beehives has been firmly declined but the net benefit of improved box hive (1848.67 ETB/hive) was found still higher as compared to the traditional hive (903.59 ETB/hive). Marginal benefit also decreased from 1009.19 ETB to 945.08 ETB but marginal cost increased from 320.50 ETB to 384.60 Birr. Thus, the sensitivity analysis shows that increase in inputs costs of beekeeping activity by 20% declined the farmers' MRR from 314.87 to 245.73%. This implies that low sensitivity for inputs costs variability didn't frustrate beekeeper farmers' adoption and adopters' intensification of improved box hive technology; because for each 1 ETB/hive on average invested in improved box hive, farmers recover their 1 ETB, plus an extra 2.46 ETB in net benefits.

A decrease in the honey and beeswax prices of the improved and traditional beehives by 20% resulted in severe decline of the net benefits of both improved and traditional beehives. Even though the net benefits of the both hives declined, the net benefit of the improved box hive (1462.48 ETB/hive) was found to be higher as compared to the net benefit of traditional beehive (719.21 ETB/hive) and the marginal benefits obtained from improved box hive as compared to traditional beehive was decreased from 1009.18 to 743.27 ETB with constant marginal cost of 320.50 ETB. Therefore, the decrease in honey and beeswax prices of both practices by 20% decreased the MRR of smallholder farmers from 314.87 to 232% (Table 7). This implies that modest sensitivity for output prices variability did not discourage beekeeper farmers' adoption and adopters' intensification of improved box hive technology. Because for each 1 ETB/hive on average invested in improved box hive, smallholder farmers recover their 1 ETB, plus an extra 2.23 ETB in net benefits. In general, the sensitivity analysis reveals that adoption of improved box hive still makes higher marginal benefit than traditional beehive.

CONCLUSION AND RECOMMENDATIONS

Based on the findings of the study, the following recommendations are suggested to be considered by Governmental and NGOs in their future intervention strategies aimed at introducing of improved box hive technology to improve honey production in the study area in particular and other areas with similar settings.

According to the smallholder beekeepers' perceptions,

Table 7. Sensitivity analysis of net benefits to 20% decrease in output prices.

Activity	Traditional beehive	Improved box hive
Gross benefit ($ETBhive^{-1}$)	809.73	1873.50
Total costs that vary ($ETBhive^{-1}$)	90.52	411.02
Net benefit ($ETBhive^{-1}$)	719.21	1462.48
Marginal benefit (ETB) compared to traditional	743.27	
Marginal cost (ETB) compared to traditional	320.50	
Marginal rate of return (MRR) (%) compared to traditional	2.32 or 232%	

Source: survey output (2012).

adoption of improved box hive has relative benefits over traditional beehive in its honey quantity and quality, swarm control, hive durability, avoidance of bee mortality and ease of inspection and management of hive; however, still it is highly constrained by expensive and lack of inputs technology and skilled manpower requirement and low honey market demand compared to traditional beehive. Therefore, great effort need to be made by government organizations and different development partners in supplying improved beekeeping inputs on the basis of farmers' purchasing power and develop technical skills of beekeepers on improved box hive technology for apiculture improvement. Moreover, the government has to be formalized the producers to have honey market linkage with domestic honey processing private limited companies.

As improved box hive is profitable over traditional beehive, substantial attention need to be given for every smallholder farmer to adopt and intensify improved box hive technology, and thereby improve their livelihood.

Conflict of Interest

The author(s) have not declared any conflict of interest.

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APPENDIX

Appendix A. Respondents' perceptions regarding the benefits and constraints of using improved box hive prioritizations

Table 1. Respondents' perception regarding the benefits of using improved box hive prioritization.

Characteristics	Ranking of benefits according to respondents perception (%)							
	1st	2nd	3rd	4th	5th	6th	7th	8th
Quantity of honey	83.1	15.4	1.5	0.0	0.0	0.0	0.0	0.0
Quality of honey	14.6	48.5	26.2	9.2	0.0	0.8	0.8	0.0
Durability	1.5	6.9	18.5	39.2	10.0	6.2	6.9	10.8
Management of hive	0.8	24.6	43.8	22.3	2.3	0.8	0.0	5.4
Marketability	0.8	0.0	0.0	1.5	10.8	13.1	53.8	20.8
Swarm control	0.0	0.0	1.5	5.4	50.0	19.2	10.8	13.1
Labor saving	0.8	4.6	9.2	13.8	13.8	10.0	13.8	33.8
Avoid bee killing	0.0	0.0	0.0	6.9	13.8	49.2	13.8	16.2

Source: Survey output (2012).

Table 2. Respondents' perception regarding the constraints of using improved box hive prioritization.

Characteristics	Ranking of constraints according to respondents perception (%)									
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
Expensive improved inputs	76.9	4.6	12.3	4.6	1.5	0.0	0.0	0.0	0.0	0.0
Lack of improved inputs	13.8	23.8	34.6	14.6	9.2	3.8	0.0	0.0	0.0	0.0
Required skill man power	9.2	41.5	35.4	6.2	6.2	1.5	0.0	0.0	0.0	0.0
Lack of credit	0.0	8.5	2.3	10.8	46.9	6.2	15.4	7.7	1.5	0.8
Lack of extension	0.0	0.0	0.0	0.0	3.1	41.5	11.5	21.5	16.9	5.4
Marketing problem	0.0	8.5	7.7	48.5	11.5	12.3	5.4	3.1	0.0	3.1
Absconding	0.0	4.6	0.8	1.5	1.5	7.7	43.8	10.8	23.8	5.4
Drought	0.0	0.0	0.0	3.1	4.6	11.5	13.1	11.5	39.2	16.9
Pesticides application	0.0	7.7	6.9	8.5	7.7	10.0	6.9	40.0	3.1	9.2
Susceptibility to pest, disease and predators	0.0	0.0	0.0	2.3	8.5	5.4	3.8	5.4	15.4	59.2

Source: Survey output (2012).


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