Efficiency of some common treatments on infestation level with wax moths, colony strength and honey yield in Northeast Ethiopia: Participatory and comparative analysis

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Efficiency of some common treatments on infestation level with wax moths, colony strength and honey yield in Northeast Ethiopia: Participatory and comparative analysis

Ademe Mihiretu* and Agazhe Tsegaye

Abstract: Beekeeping is an integral part of livestock-based livelihood system in tropical and subtropical regions of Ethiopia. Despite its importance, the sub-sector is challenged by humble colony strength and honey yield due to pests including wax moths. To avert these challenges different treatments were suggested by researchers regardless of economic, social and technical efficiency analysis. This participatory study is thus intended to evaluate the efficiency of treatments on infestation level with wax moths, colony strength and honey yield in Northeast Ethiopia. Un-replicated on-farm experiment was conducted on six beekeepers comprising supplementary feeding, tobacco leaf smoking, the combination and control treatments. Economic, biological and preference data were collected periodically. Profitability was estimated in partial budget, while biological and preference data were analysed using ANOVA and weighted ranking matrix, respectively. Results revealed that tobacco smoking had the lowest infected combs (0.7 ± 0.2) followed by the combination, supplementary feeding and control groups in ascending order. Supplementary feeding provided highest mean honey yield

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PUBLIC INTEREST STATEMENT
Even though beekeeping is an integral part of livestock-based livelihood system in subtropical regions of Ethiopia, the sub-sector is challenged by different problems. Destruction of beeswax combs in particular and apiary farming in general led researchers and beekeepers to apply different treatments. Supplementary feeding, tobacco leaf smoking and a combination of both were most commonly advised treatments. In fact, these treatments cannot prevent infestation with wax moths absolutely, rather may reduce the infestation levels. Besides, the treatments were recommended without beekeepers’ active participation, profitability analysis, compatibility and applicability evaluation. These factors are of course the building blocks for extensive and demand driven technology diffusion and adoption. Therefore, this participatory and comparative study was intended to evaluate the efficiencies of some common treatments on infestation levels with wax moths, colony strength and honey yield in Northeastern Ethiopia.
| (14.7 ± 1.2) (p < 0.05). Add to the honey yield improvement, ensuring active and strong colony with supplementary feeding is playing significant role in regulating wax moth infestation. Moreover, supplementary feeding was efficient with net benefit of ETB2811.2 (USD98.5) and 4396.9% marginal rate of return. It was also beekeepers’ primary choice by the overall preference parameters. Spearman’s correlation indicated that beekeepers’ preference rank was coincided by 80% with actual measured rank. Therefore, supplementary feeding is suggested for further promotion in similar agro-ecologies to regulate infestation level with wax moths, colony strength and honey yield enhancement.

Subjects: General Science; Nutrition; Biology; Food Additives & Ingredients

Keywords: bees; beekeepers; preferences; partial budget; Spearman’s correlation

1. Introduction

Beekeeping is an art of keeping bee colonies for economic benefit and has been practiced for a long time. Initially, honey bees (*Apis mellifera monticola*) are discovered in Spain and Africa in the cave drawings around 7000BC (Meikle et al., 2012). It is one of the important agricultural activities that provides many job opportunities besides the valuable honey products (Kwadha et al., 2017). Ethiopia is the leading among honey and beeswax producers worldwide for centuries (Alemu et al., 2014). The country produces about 98% of honey and beeswax yield from traditional hives due to its tremendous agro climatic conditions and biodiversity, which favored the existence of diversified honeybee flora and huge number of bee colonies (Fenet & Alemayehu, 2016). Recently, the loss of honey bee colonies has been recorded in different parts of the world. The specific reasons behind the colony collapse disorder are not fully known, but it mostly happens due to a number of harmful factors (Maini et al., 2010). Particularly, includes many pests such as varroa mites, wax moths, small hive beetles, vespa hornets and parasitic flies attack honey bee colonies causing serious damages (Ellis et al., 2013).

As part of sub-tropical region, Ethiopia is not only favorable to bees but also for diverse bee pests and predators, interacting with the life of honeybees (Malede et al., 2015). Ants, honey badgers, birds, wax moth, spiders, termites and snakes cause devastating damage to bee colonies and products (Chala et al., 2012). Wax moths are a very destructive insect pest in the beehive. The moths attack wax combs to feed on cast larval skins and stored food (Kwadha et al., 2017). The common wax moth pest that occupies and damage bee colonies has four stages of development (egg, larva, pupa, and adult) (Abou-Shaara & Staron, 2019). Although wax moths are considered as micro pest, it can cause greater damage to beekeeping equipment and stored combs particular on the weak or diseased colonies (Ellis et al., 2013). The conflicting interest between crop and honey producers increased the use of pesticides and herbicides that severely threatened bee colonies (Food and Agriculture Organization [FAO], 2012). Application of chemicals (fungicides, pesticides and herbicides) hinder the productivity of honey bee colonies. Hence, the use of chemicals to control these pests is not recommended as it can contaminate bee products and negatively affect the health of honey bees (Abou-Shaara, 2017a).

Organic beekeeping does not accept the application of chemicals (Iancu et al., 2012). Searching for safe and sustainable alternatives to control honey bee pests is a very important approach. The use of biological control agents; predators, parasitoids, or pathogens to control the pests can be considered as suitable choices (Ellis et al., 2013). There are different mechanical methods to control wax moths, outside the hives, but inside the hives, the control options are limited and mainly depend on boosting the colony strength, or using specific traps (Abou-Shaara, 2017b). In Ethiopia, wax moths are found almost anywhere honey bees are kept, but they can be a major problem for beekeepers in warmer climates, particularly in the northeast tropics and subtropics.
Dessalegn, 2015; Tolera & Dejene, 2014). The significant impact on economic importance of wax moths has led to a number of investigations on its life history, biology, behavior, ecology, physiology and control (Fenet & Alemayehu, 2016). Beekeeping is an integral part of animal husbandry led livelihood system in the study area. Sekota woreda has about 82,684 colonies that cover 9.86% of the honeybee population in Northeast Ethiopia (Central Statistics Authority [CSA], 2017). Woreda is an administrative boundary (equivalent to district) in Ethiopia (Mihiret et al., 2019a). However, despite its huge potential, the sub sector is not well exploited due to influences from pests and predators, mainly wax moths (Abeje et al., 2017).

The complete destruction risk of stored beeswax combs in particular and apiary farming in general led researchers in Sekota Dryland Agricultural Research Center to evaluate potential wax moth control methods in Northeast Ethiopia. Accordingly, supplementary feeding, colony fumigation with tobacco leaf smoke and the combination of both were suggested to ensure colony population, in turn to cope up with wax moths as well as to reduce the infestation levels (Alemu et al., 2014). However, the recommendations were provided simply on the bases of biological stances, without giving due attention to beekeepers’ participation, economic profitability, societal acceptability and technical applicability. These factors are of course, the building blocks for the wider technology diffusion in general and demand driven knowledge tracking in particular. Therefore, this participatory study was aimed to evaluate the efficiency of some common treatments on infestation level with wax moths, colony strength and honey yield improvement in Sekota woreda of Northeast Ethiopia.

2. Materials and methods

2.1. Study area

The study was carried out in Sekota woreda, one of the potential areas of beekeeping in sub-tropical zones of Northeast Ethiopia (Figure 1). In Sekota, beekeeping is an integral part of livestock-based livelihood system (Mihiretu & Abebow, 2020). Sekota woreda is found at 12°68’35” N and 39.01’41” E latitude and longitude with an altitude range of 2000–2300 m above sea level (Mihiretu et al., 2019b). The annual minimum and maximum temperature of the area is 26.6°C and...
31.6°C, respectively (Mihiretu & Assefa, 2019). The annual rainfall is 774.3 mm and its distribution is mostly characterized by an erratic nature (Abeje et al., 2016). Agro-ecologically, most parts of the woreda is classified as mid altitude and categorized by rugged topography of mountains, hills and gorges (Mihiretu et al., 2019c). The vegetation cover mainly consists of scattered bushes, shrubs and acacia species, which in turn provides good opportunity for beekeeping (Alemu et al., 2014).

2.2. Beehive and beekeepers
Sekota woreda was selected purposively to represent the high spot areas of wax moth infestation according to the expertise suggestion and report, on top of the huge bee colony population. It has about 82,684 honeybee colonies, which comprises 9.86% of the honeybee population in northeast Ethiopia (CSA, 2017). Strong linkage with extension personnel followed by thorough discussion was created to have a common understanding on the experimental objectives. Participant beekeeping farmers were thus selected in collaboration with subject matter specialists (SMSs) (Mihiretu et al., 2019c). Accordingly, 20 beekeepers who have previous experience about honey bees were identified and organized in to farmers’ research and extension group (FREG). The nominees were purposive to represent the different social segments in order to have diverse spectrum of age, sex and wealth (Mihiretu et al., 2019c). The FREG had chairman and secretary to facilitate tasks jointly with researchers and SMSs throughout the experiment.

The honeybee (*Apis mellifera monticola*) race under framed top bar hives with the colony queens aged nearly five years were selected for the experiment. This is because it was the dominant race in Northeastern Ethiopia where the study is undertaken (Amssolu et al., 2004). Beehives with zero infestation of wax moths and have similar colony strength were purposively identified for the experiment. Colony strength indicators (viz., the number of combs and frames covered by bees) were normalized to make the trial colonies comparable. In fact, normalization reduces the effects of human triggered errors in the experiment (Alemu et al., 2014). Among FREG members, six arbitrary beekeepers having beehives that fulfill the required criteria were selected to host the trial. Therefore, a total of 24 beehives were picked for the trial (six beehives per treatment and four treatments per beekeeping farmer). Theoretical as well as on job trainings were provided on experimental treatments as well as seasonal colony managements. Memorandum of understanding (MoU) was signed between beekeepers, SMSs and researchers to ensure participation and share responsibilities amongst them (Table 1).

| Duties/responsibilities                        | Responsible stakeholders |
|-----------------------------------------------|--------------------------|
|                                               | Bee-keepers | Researchers | SMSs   |
| Experimental site and farmer selection        | x           | x           | x      |
| Action plan preparation                       | x           | x           | x      |
| Input preparation and supply                  | x           | x           |        |
| Offering technical training                   | x           | x           |        |
| Trial beehive layout arrangement              | x           | x           | x      |
| Beginning the trial or work                   | x           | x           |        |
| Beehive management                            | x           | x           |        |
| Joint monitoring and evaluation               | x           | x           | x      |
| Data recording and collection                 | x           | x           | x      |
| Field days and experiences sharing            | x           | x           |        |
| Yield collection (harvesting)                 | x           |             |        |
| Analysis and reporting                        | x           |             |        |
| Preparation of extension materials and        |             |             | x      |
| communicating research outputs                |             |             |        |

Table 1. Division of duties and/or activities among responsible stakeholders in the FREG
2.3. Treatments
The experiment was conducted in 2017–2018 production years, for five consecutive dearth months (December–April) through participatory approach. The on-farm trial was directed comprising four treatments: supplementary feeding, tobacco leaf smoking, supplementary feeding + tobacco leaf smoking and the control group, arranged as treatment 1, 2, 3 and 4, respectively (Table 2). These methods are of course cannot be considered as effective prevention techniques to wax moths, rather can be considered as the potential control means. The treatments were arranged in un-replicated simple block, considering the host beekeepers as replication. They were arranged in such a way that one treatment group not to affect the other treatment group. Each treatment (1, 2, 3 and 4), thus had six replications and they were assigned to each beekeeper. The treatments were provided for five dearth months and stopped at the end of April 2018 (before the local honey season). Because, the sugar syrup feeding mixed with the nectar from plants may be causing higher honey yield.

2.4. Measured parameters
Both quantitative and qualitative data were collected. The number of frames covered by bees infected combs with wax moths and colonies absconding rate were measured parameters from each treatment in 15 days interval. Wax moth infestation level was measured through calculating the comb areas infested with wax moth eggs, larvae, pupae and adult moths in the study periods. However, the honey yields of each hive were collected after the trial during the honey season (October 2018). Perception and preference data were collected via checklists and focus group discussions (FGDs) at the end of the experiment. Secondary data were also gathered from different published and unpublished sources to triangulate and support results of the study. Except the experimental colonies, beehives and management, all other costs/expenses were covered by the research center while the yield goes to beekeepers. All production costs and benefits were collected to compare the cost-effectiveness of treatments. The variable costs were taken from used input (i.e. sugar, tobacco leaf, feeding kit, smoker, sweeper and labor) for treatments, keeping the colony and hive costs constant. Honey yield was adjusted by 10% and the selling price per kg was taken at the farm gate. The average labor cost for collecting tobacco leaf was expressed in person day, where one person day was assumed to be 8 h of work. All monetary values are expressed in Ethiopian Birr (ETB), averagely 1USD = 28.55ETB in the study periods.

Farmers’ preference to each treatment was evaluated and apprehended as a group through assigning literate farmers to lead the discussion. The farmers hence brainstormed to identify parameters to be considered in treatment selection. Therefore, honey yield, effectiveness in controlling wax moths infestation, ease technical applicability and social acceptability as well as minimum cost were identified as preference parameters.

2.5. Statistical analysis
The measured parameters were analysed in descriptive statistics and ANOVA using SAS software. The later was to test the statistical differences at 5% significance level, followed by post hoc (LSD) analysis to compare the mean separations. Hence, significant differences between treatments were assigned with different letters (a, b, and c). The net benefit, gross return, total variable cost, marginal cost and marginal net benefits were calculated accordingly from the collected economic data (Mihiretu et al., 2019b). The marginal rate of return (MRR) of one treatment to the other was also calculated using the following formula:

\[
MRR = \frac{\Delta NB}{\Delta TVC} \times 100
\]  

(1)

where: MRR = marginal rate of return, \( \Delta NB \) = change in net benefits and \( \Delta TVC \) = change in total variable input costs.
Table 2. Pictorial description and arrangement of the experimental treatments

| Treatment −1 | Treatment −2 | Treatment −3 | Treatment −4 |
|--------------|--------------|--------------|--------------|
| **Supplementary feeding:** | **Tobacco leaf smoking:** | **Supplementary feeding + tobacco smoking:** | **Local management:** |
| Supplying 0.5 liter of sugar syrup at 7 days interval in dearth period on top of flowering plants around the beehives would strengthen colonies without any additional management. | Freshly dried tobacco leaves were used to produce smoke then to fumigate the colony for 2-3 minutes per 7 days via the hive entrance. | The combination of sugar syrup and tobacco leaf smoking in 7 days interval. | The control (beekeepers’ existing intensive management) was included as comparison with suggested treatments. |
Parameters identified by farmers were compared each other pair-wise to provide rank to be considered as a weight (Ferdous et al., 2016). Weighted ranking matrix table was constructed and the farmers compare and contrast treatments each other using the identified parameters then the values counted to provide scores (Mihiretu et al., 2019c). The scores of each treatment were summed and ranked. The rank was multiplied by the respective weight, the products aggregated for final selection (least sum was ranked first) (Russell, 1997). Spearman’s rank correlation was also used to see the degree of coincidence between farmers’ preference rank and the actual measured attributes rank (Mihiretu & Assefa, 2019). The correlation coefficient is defined as:

\[ r_s = 1 - \frac{6 \sum d^2}{n(n^2 - 1)} \]  

(2)

where \( d \) = difference in the ranks assigned to the same phenomenon and \( n \) = number of phenomena ranked.

3. Results

3.1. Performance of measured parameters

Among treatments, tobacco leaf smoking had the lowermost infected combs (0.7 ± 0.2), followed by the combination treatment and supplementary feeding in ascending order. However, the control group had the highest mean of infected combs (1.7 ± 0.2). The ANOVA result in Table 3, thus revealed that, statistically significant difference between treatments in number of infected combs with wax moth (\( p < 0.05 \)). The higher number of frames covered by bees were recorded from supplementary feeding (8.4 ± 1.2), followed by the combination treatment (6.6 ± 0.6), tobacco leaf smoking (5.7 ± 0.3) and the control group (5.9 ± 0.5) in descending order. In terms of honey yield, supplementary feeding was provided the highest mean yield in kg hive\(^{-1}\) (14.7 ± 1.2). The combination and tobacco leaf smoking treatments were second and third in their honey yield productivity, respectively (Table 3). The lowest mean honey yield was recorded from the control group in kg hive\(^{-1}\) (3.7 ± 0.9). The ANOVA result therefore shows that statistically significant difference between treatments in honey yield (\( p < 0.05 \)).

3.2. Partial budget comparison

As illustrated below (Table 4), the highest total variable cost was recorded from the combination treatment group with a mean of ETB 728.8 (USD 25.5) while the lowest was from supplementary feeding having a mean of ETB 128.8 (USD 4.5). However, the highest net benefit of ETB 2,811.2 (USD 98.5) is recorded from supplementary feeding followed by the combination group, tobacco leaf smoking and the control group with net benefits of ETB 731.2 (USD 25.6), 585 (USD 20.5) and 560 (USD 19.6) per beehive, respectively.

| Treatments | Number of frames covered by bees | Number of infected combs | Honey yield in kg hive\(^{-1}\) |
|-----------|---------------------------------|--------------------------|-----------------------------|
| Supplementary feeding | 8.4 ± 1.2 \(^a\) | 1.3 ± 0.1 \(^b\) | 14.7 ± 1.2 \(^ab\) |
| Tobacco leaf smoking | 5.7 ± 0.3 \(^b\) | 0.7 ± 0.2 \(^c\) | 6.3 ± 1.5 \(^bc\) |
| Supplementary feeding + tobacco smoking | 6.6 ± 0.6 \(^b\) | 0.9 ± 0.1 \(^bc\) | 7.3 ± 1.5 \(^b\) |
| Control group | 5.9 ± 0.5 \(^b\) | 1.7 ± 0.2 \(^a\) | 3.7 ± 0.9 \(^c\) |
| Coefficient of Variation (%) | 17.7 | 21.9 | 18.2 |
| Mean | 6.6 | 1.1 | 8 |
| Sig (\( p \leq 0.05 \)) | ** | ** | *** |

**, *** implies significance levels at 5 and 1%, respectively; values with the same superscript letter(s) in the same column are not significantly different (\( p \leq 0.05 \))
Table 4. Partial budget comparison of different treatments

| Economic factors | Control group | Treatments (ETB hive\(^{-1}\)) |
|------------------|---------------|--------------------------------|
|                  |               | Supplementary feeding | Tobacco smoking | Combination group |
| Costs: Sugar syrup (kg) | - | 121.8 | - | 121.8 |
| Tobacco leaf gathering (man/day) | - | - | 600.0 | 600.0 |
| Labor for management (man/day) | 155.0 | - | - | - |
| Kits (smoker, sweeper, plate) | 25.0 | 7.0 | 75.0 | 7.0 |
| Total variable costs | 180.0 | 128.8 | 675.0 | 728.8 |
| Gross benefits | 740.0 | 2940.0 | 1260.0 | 1460.0 |
| Net benefits | 560.0 | 2811.2 | 585.0 | 731.2 |
| Marginal net benefits | - | 2251.2 | 25.0 | 171.2 |
| Marginal costs | - | - | 497.0 | 551.2 |
| MRR (%) | - | 4396.9 | 5.0 | 31.1 |

Average cost of inputs used in the experiment:

- Sugar = 24.35ETB/kg
- Labor cost = 60 ETB/Man day
- Average price of honey = 200 ETB/kg

Average equipment price:

- Smoker = 75 ETB
- Sweeper = 25 ETB
- Feeding plate = 7 ETB
- 1USD = 28.55ETB (Ethiopian birr)

3.3. Beekeepers' preference to different treatments

The weighted ranking matrix table result shows that the treatment which has least sum of score was ranked first and preferred as the best choice. Based on the overall weighted preference criteria, thus beekeeping farmers preferred the control group as the primary choice followed by supplementary feeding, tobacco leaf smoking and the combination group (Table 5). Spearman’s rank correlation on the degree of coincidence between beekeeping farmers’ preference rank and the actual measured parameters rank for honey yield and number of infected combs was assessed across treatments. Therefore, beekeeping farmers’ preference ranks on honey yield and number of infected combs were coincided by 80% with the actual measured parameters rank (Table 6).

4. Discussion

It is true that an increasing trend of different bee pests and predators interacting with the life of honeybees and caused a devastating damage to the sub-sector (Amssalu et al., 2004). The effects from wax moth particularly were very sensitive and destructive to national apiary farming in general and the study area in particular. Meanwhile, beekeeping farmers in the study area are not readily accessible to different treatments which are efficient, applicable and acceptable to their local context. This comparative study was therefore, conducted to evaluate performances of some common treatments on infestation level with wax moths, colony strength and honey yield under farmer’s condition using their beehives and active participation in Northeast Ethiopia. The result thus revealed that statistically significant difference among treatments in terms of honey yield, colony strength or bee population and infected combs with wax moths (p ≤ 0.05). Among treatments, supplementary feeding was provided the highest mean honey yield followed by the combination group, tobacco leaf smoking and the control group in descending order. Therefore, supplying colonies with 0.5 L sugar syrups in 15 days interval at the dearth period would provide a 297.3% yield advantage over the unsupplied control colonies. The combination group had fewer yield than the supplementary feeding alone. This result was in agreement with the finding by
Table 5. Comparison of beekeeping farmers’ preference to different treatments

| Preference parameters                        | Score*weight | Treatments                  |          |          |          |          |
|---------------------------------------------|--------------|-----------------------------|----------|----------|----------|----------|
|                                             | Score        | Supplementary feeding | Tobacco leaf smoking | Combination group | Control group |
|                                             | weight       |                          |                      |                     |             |
|                                             | score * weight |                          |                      |                     |             |
| Productivity (honey yield)                  | score        | 1.00                       | 4.00                | 2.00                | 3.00        |
|                                             | weight       | 1.00                       | 1.00                | 1.00                | 1.00        |
|                                             | score * weight | 1.00                       | 4.00                | 2.00                | 3.00        |
| Effectiveness in controlling wax moths infestation | score        | 3.00                       | 2.00                | 1.00                | 4.00        |
|                                             | weight       | 3.00                       | 3.00                | 3.00                | 3.00        |
|                                             | score * weight | 9.00                       | 6.00                | 3.00                | 12.0        |
| Ease applicability and societal acceptability | score        | 2.00                       | 3.00                | 4.00                | 1.00        |
|                                             | weight       | 4.00                       | 4.00                | 4.00                | 4.00        |
|                                             | score * weight | 8.00                       | 12.0               | 16.0                | 4.00        |
| Minimum cost (efficiency)                   | score        | 3.00                       | 2.00                | 4.00                | 1.00        |
|                                             | weight       | 2.00                       | 2.00                | 2.00                | 2.00        |
|                                             | score * weight | 6.00                       | 4.00                | 8.00                | 2.00        |
|                                            | \(\sum (score \times weight)\) | 24.0                       | 26.0                | 29.0                | 21.0        |
| Ranks                                       | 2            | 3                          | 4                    | 1                    |             |

Rank numbers 1, 2, 3 and 4 stands for best, fair, worst and not selected treatments, respectively.
Table 6. Spearman’s correlation of actual measured parameters’ rank and preference rank of treatments

| Treatments                  | Honey yield | Actual rank | Preference rank | d²   | Infected combs | Actual rank | Preference rank | d²   |
|-----------------------------|-------------|-------------|-----------------|------|----------------|-------------|-----------------|------|
| Supplementary feeding        | 14.7        | 1           | 1               | (1-1)² | 1.3            | 3           | 3               | (3-3)² |
| Tobacco leaf smoking        | 6.3         | 3           | 4               | (3-4)² | 0.7            | 1           | 2               | (1-2)² |
| Feeding + tobacco smoking   | 7.3         | 2           | 2               | (2-2)² | 0.9            | 2           | 1               | (2-1)² |
| Control group               | 3.7         | 4           | 3               | (4-3)² | 1.7            | 4           | 4               | (4-4)² |

$r_s = 0.8$ (80%)

where $r_s =$ correlation coefficient $d =$ difference in ranks assigned to the same phenomenon and $n =$ number of phenomena ranked
Alelu et al. (2014). It would be due to the negative effects of tobacco smoke on the younger honey bees to make sicker and even die, which in turn reduces the population of worker honey bees that directly contributing to the honey production.

The average honey yield of the trial colonies was 8.0 kg hive⁻¹ in the season, which is lower than the 10.56 kg hive⁻¹ yield reported by Amssalu et al. (2004). This might be attributed to variables related to environment; i.e. the flowering potential of the trial sites and extra management that beekeepers applied. However, lesser honey productivity across the entire treatments was mainly due to the fact that the trial was placed closer to homestead backyards, where access to flora is scanty considering the higher colony density in the area. The number of frames covered by bees was significantly higher for colonies assigned to supplementary feeding, followed by the combination and control group. The treatment under tobacco leaf smoke however, had the lowest number of frames covered by bees and weaker colonies. This may be attributed to its toxic nature and would harm younger bees mainly in the dry and dearth periods. The finding is in harmony with the result reported by Alelu et al. (2014).

The number of infected combs with wax moth is significantly lower for colonies treated with tobacco leaf smoke, followed by the combination group and supplementary feeding. The higher number of infected combs in the combination group over tobacco leaf smoke is mainly attributed to the attractive nature of sugar syrup for bee pests including the wax moth. This in turn, upsurge the infestation level as the number of moths increase. The current result is in agreement with Abou-Shaara (2017b), who studied the biology of moths and described as they can complete their development using different types of food in the hive. However, among treatments the higher infected combs with wax moth was recorded from the control treatment. As a result, out of 33.33% of the absconded colonies in the experiment, about 16.7% were from the control group due to wax moth infestation. Because lower and weaker bee colonies couldn’t attend the combs in the hive thus gave an opportunity of entrance for the wax moths. This study repeated the finding by Alemayehu et al. (2017), studied in the other region of the country. On the other hand, 16.7% of the absconded were from colonies treated with tobacco leaf smoke, as it would result in greater aggravation of honey bees that already set to swarm. The overall mean of infected combs with wax moth per colony was 1.1, which is higher than the mean of 0.9 reported by Amssalu et al. (2004) in other parts of the country. The difference would be due to the ecological differences that the trial sites entitled with, which has in turn an effect on the rate and gravity of wax moth occurrence.

Moreover, the total variable cost of supplementary feeding was lower, but its net benefit is by far higher than other treatments. The MRR for supplementary feeding, tobacco leaf smoking and the combination group was thus 4396.9%, 5.0% and 31.1%, respectively. This implies that for each ETB 1.00 investment for the respective treatments, an additional ETB of 43.97, 0.05 and 0.31 can be obtained after paying the costs incurred. The weighted ranking matrix result also indicated that among treatments, the control and supplementary feeding was preferred as the first and second choices, respectively, by beekeepers. But, tobacco leaf smoking was not preferred by beekeepers due to the religious taboo associated with tobacco leaf in the society. Similarly, the combination group was condemned by its higher input cost requirement on top of the tobacco leaf taboo.

5. Conclusion
Even though tobacco leaf smoking was relatively effective in wax moth control with lowermost infected combs, its honey yield productivity was very low. The highest honey yield was obtained from supplementary feeding. Despite supplementary feeding has higher infected combs compared to tobacco leaf smoking and combination group, it was by far better than the control treatment. The economic return from tobacco leaf smoking and combination group was not promising compared to supplementary feeding. These lower economic returns are mainly associated with minimum honey yield production. Moreover, beekeepers favored supplementary feeding for better honey yield, ease technical applicability, societal acceptability and minimum in put cost. Add to the honey yield production improvement, ensuring active and strong colonies with additional feeding is thus playing a significant role in regulating
the wax moth infestation. In fact, supplementary feeding should not be used during honey seasons in order to prevent honey contamination with artificial feeding, but should be provided during the dearth periods of the year. Therefore, considering all the efficiency parameters, supplementary feeding to the honey bee colonies is recommended to improve production and productivity in the sub-sector. Finally, the FREG approach has shown some positive effects on the extension process through providing room for active stakeholder participation in experiment. Therefore, this approach should be considered as an important instrument for future research output dissemination.

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