The buzz about bees and poverty alleviation: Identifying drivers and barriers of beekeeping in sub-Saharan Africa

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Abstract

The potential of beekeeping to mitigate the exposure of rural sub-Saharan African farmers to economic stochasticity has been widely promoted by an array of development agencies. Robust outcome indicators of the success of beekeeping to improve household well-being are unfortunately lacking. This study aimed to identify the key drivers and barriers of beekeeping adoption at the household level, and quantified the associated income contribution in three agro-ecological zones in Uganda. Beekeepers were generally the most economically disadvantaged people in the study areas and tended to adopt beekeeping following contact with non-government organisations and access to training. Whilst incomes were not statistically lower than their non-beekeeping counterparts; their mean household well-being scores were significantly lower than non-beekeeping households. The inability of beekeeping to significantly improve well-being status can in part be attributed to a lack of both training in bee husbandry and protective equipment provision such as suits, gloves and smokers. These are critical tools for beekeepers as they provide the necessary confidence to manage honey bees. Rather than focusing solely on the socio-economic conditions of farmers to effectively adopt beekeeping, future research should also attempt to evaluate the effectiveness of development agencies’ provision to the beekeeping sector.

Introduction

The impact of environmental and economic shocks on the rural poor, who depend upon their own local food system to survive, can have profound implications for their livelihood and welfare security [1]. A diversified livelihoods portfolio is considered by many as a more resilient system to manage risk [2,3]. A household’s ability to diversify into more resilient income streams is contingent upon ownership, control and access to key livelihood assets such as
Beekeeping offers multiple potential benefits to the rural poor such as increased household income streams [7,8], nutritional and medicinal products for sale or home use [9] as well as improving pollination services essential for increased crop yields [10,11]. Whilst beekeeping appears to have a contribution to make to rural livelihoods, its purported production potential in sub-Saharan Africa remains relatively untapped. For example, Kenya’s production potential is estimated to be 100,000 tonnes of honey per year, but only 14.6% of this is realized [12–14]. Similarly, Uganda harvests only 1% of its estimated production potential of 500,000 tonnes of honey per year [15]. Furthermore, Africa’s share of the world honey trade also remains low [16]. However, it is nonetheless thought to hold a competitive advantage in the organic and fair trade sectors [17], suggesting that substantial opportunities exist for rural households to improve their economic resilience.

Uganda is among the five countries in sub-Saharan Africa licensed to export honeybee products to the European Union [18]. In spite of this opportunity to develop the export market, Uganda has failed to meet both its export quota to the EU as well as home grown demand for honey [18], due to low domestic productivity and weak beekeeping adoption rates [15].

Adoption of new agricultural technologies in sub-Saharan Africa is typically contingent upon access to appropriate technical information and provision of reliable costs and benefits associated with the activity [19,20]. Several studies suggest beekeeping adoption is contingent upon multiple factors all of which may interact: on-farm income; level of savings and access to credit; cash generation; household food and medicine provision; availability of agricultural extension services and membership of farmers’ groups [12,15,21,22].

This study sought to identify the key drivers of beekeeping adoption, and aimed to quantify the degree to which beekeepers’ household well-being differed from non-beekeepers. The study objectives were thus to: 1) quantify beekeeper household status using a well-being index, 2) identify key factors drivers and barriers of beekeeping adoption, and 3) quantify the relative contribution of beekeeping to household income.

Materials and methods

Study area and data collection

The study was carried out in the primary honey producing areas of Uganda [23] which included the West Nile (Arua district), the Eastern (Soroti district) and the mid-Northern (Kitgum district) agro-ecological zones as clustered by [24,25]. Before commencing the study, ethical approval was obtained from the ethics review committee of the College of Veterinary Medicine, Animal Resources and Biosecurity, Makerere University (No. SBLS.ADR.2016). Consent forms were signed prior to each respondent being interviewed and they were advised that they were free to participate or withdraw at any point during the interview.

Sampling procedure

Multi-stage sampling, using purposive and random-stratified techniques, was used to identify beekeeping and non-beekeeping households. The three agro-ecological zones were purposively selected based on mean annual honey yields. The West Nile–Arua district (84,320 kg) was classified as a relatively high producer, the mid-Northern–Kitgum district (27,500 kg) as moderate, and the Eastern–Soroti district (<16,310 kg) as a low producer [26]. Beekeeper respondents were randomly selected from a list obtained from the Uganda National Apiculture
Development Organization (TUNADO), and stratified by agro-ecological zone. Non-beekeepers were randomly selected from a list of farmers provided by each district agricultural office.

The beekeepers’ list comprised 630 beekeeping households of which 166 were selected for interview (Table 1). A semi-structured questionnaire was administered to any adult beekeeper and non-beekeeper in each household.

A set of 34 variables was analysed to identify any significant factors influencing choice of farm enterprise, beekeeping adoption and attitudes towards beekeeping (S1 Table). Descriptive and inferential statistical tools such as the Pearson chi-square likelihood ratios and Levene’s test of equal variances were used to show which t-statistic to consider during comparison of beekeepers with non-beekeepers. Household well-being variables (S2 Table) selected from a list adapted from [27] were validated during focus group discussions and the subsequent data was aggregated to generate a household well-being index using a categorical principal component analysis (CATPCA) [28]. Factor scores were generated using spline ordinal transformation and dimension one was used to calculate the household well-being index, whereby a value of 3 indicated a relatively wealthy attribute score and 1 indicated the least wealthy score. The above analyses were performed in Statistical Package for the Social Sciences (SPSS) version 22 [29].

To explore predictors of beekeeping adoption and intensity of beekeeping, a two-stage Heckman model was applied [30]. It was chosen for its ability to correct sample selection biases [31,32]. Our study tried to avoid biases resulting from correlation of error terms and simultaneously omitted variables. The first model predicted the probability of a farmer adopting beekeeping using a probit maximum likelihood function for both beekeepers and non-beekeepers. The second model used an ordinary least squares estimation equation for the intensity of beekeeping (number of beehives owned) as determined by the farm household asset endowments and characteristics with the inverse Mill’s ratio term as an added variable to reveal the probability of an observation belonging to the selected sample group. A significant Mill’s lambda ratio indicates the presence of sample selection biases and that they were corrected [31,32]. The above analyses were performed in Stata 13 statistical software [32]. Furthermore, beekeepers were classified into small scale and large scale producers based on mean number of beehives owned. Those beekeepers who had beehives less than the mean were classified as small scale while large scale beekeepers were above the mean.

Results

Socio demographic characteristics of respondents

There was no significant difference in age and household size between beekeepers and non-beekeepers (t = 1.02) (Table 2). Beekeepers’ mean annual income was significantly lower than non-beekeepers (t<0.05). The proportion of farmers owning land and the average farm size were not significantly different between beekeeping and non-beekeeping households (t = -0.14). The reported mean land acreage per household (9.22 for beekeepers and 9.44 for non-
beekeepers) was higher in the study area compared to the national average of 2.8 acres per household [33]. Few beekeepers (4.2%) had attained secondary or tertiary education compared to 48.5% of non-beekeepers (Table 2).

Eleven of the 16 well-being indicators explained variation in household well-being across the three agro-ecological zones (Table 3). These were as follows in order of descending proportional variance: 1) ownership of new clothes and shoes, 2) food shortage, 3) ability of a household to send children to school, 4) household member hired as casual labourer, 5) number of meals per day, 6) type of house owned, 7) sleeping on a mattress, 8) ownership of animals, 9) household's ability to hire labour, 10) member of household in off-farm employment and 11) use of rare items like sugar and cooking oil. The mean well-being index (calculated based on the CATPCA) of beekeeping households was significantly lower than that of non-beekeepers, suggesting that beekeeping households were relatively less wealthy compared to non-beekeepers (Fig 1).

Table 2. Socio-demographic characteristics of households as measured with continuous and categorical variables.

| Characteristics                      | Beekeeper (mean±s.e.) | Non-beekeeper (mean±s.e.) | t-statistic |
|--------------------------------------|-----------------------|---------------------------|-------------|
| Age                                  | 44.62±1.21            | 42.84±1.24                | 1.02        |
| Number of household members          | 10.37±0.38            | 10.30±0.39                | 0.13        |
| Number of land acres                 | 9.22±1.29             | 9.44±0.88                 | -0.14       |
| Number of cattle                     | 4.72±0.46             | 4.68±0.46                 | 0.06        |
| Number of sheep                      | 1.59±0.37             | 0.55±0.16                 | 2.42**      |
| Number of goats                      | 4.97±0.41             | 3.93±0.40                 | 1.80*       |
| Number of pigs                       | 1.17±0.26             | 0.36±0.10                 | 2.67***     |
| Number of poultry                    | 23.82±2.43            | 12.33±0.86                | 4.17***     |
| Land allocated to crops              | 5.48±0.43             | 5.21±0.37                 | 0.45        |
| Land allocated to livestock          | 2.34±0.34             | 1.53±0.14                 | 1.96**      |
| Annual crop income                   | 382.97±72.67          | 245.07±19.54              | 1.70**      |
| Annual livestock income              | 89.36±9.90            | 325.42±50.41              | -4.96***    |
| Annual non-farm income               | 90.45±16.42           | 320.50±62.50              | -3.82***    |
| Total household income               | 605.82±74.19          | 870.47±81.82              | -2.40**     |
| Gender (comparison of gender         | Females               | Males                     | 9.373***    |
| distribution between beekeepers      | 21.7                  | 62.3                      |             |
|                                     | (yes = 1 & non-beekeepers no = 0) | (n = 163) & (n = 138) |             |
| Education (comparison of education   | No formal education   | 59.6                      | 90.479***   |
| level between beekeeper              | Primary education     | 36.1                      |             |
|                                     | Secondary education   | 3.6                       |             |
|                                     | Tertiary education    | 0.6                       |             |
| Main income sources (comparison of   | On-farm income sources| 85.5                      | 9.604***    |
| main income sources between          | Off-farm income       | 7.2                       |             |
| beekeeper yes = 1 & non-beekers      | Non-farm income       | 7.2                       |             |
| number of beekeepers no = 0)         | Land ownership        | 83.7                      | 1.926       |
|                                     | (comparison of land    | 88.4                      |             |
| ownership between beekeeper yes = 1  | ownership between     |                           |             |
| & non-beekers no = 0)                | beekeepers yes = 1    |                           |             |
|                                     | (n = 163) & (n = 138) |                           |             |

*** denotes the mean or percentage difference between beekeepers and non-beekeepers is significant at 1%,
** the mean or percentage difference between beekeepers and non-beekeepers is significant at 5%,
* the mean or percentage difference between beekeepers and non-beekeepers is significant at 10%

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Table 3. Factor loadings for well-being indicators based on varimax rotation.

| Variable                                      | Centroid Coordinates | Mean variance |
|-----------------------------------------------|----------------------|---------------|
| Ownership of new clothes and shoes           | 0.71                 | 0.37          |
| Experienced food shortage and how long it lasted | 0.69                 | 0.35          |
| Children in the household in school          | 0.68                 | 0.34          |
| Any member of household hired as casual labourer | 0.63                 | 0.32          |
| Meals per day                                 | 0.59                 | 0.30          |
| Type of house owned                           | 0.57                 | 0.28          |
| Sleep on mattress                             | 0.53                 | 0.27          |
| Which animals were owned                      | 0.50                 | 0.27          |
| Household hires labour                        | 0.49                 | 0.25          |
| Any member of household in off-farm employment | 0.48                 | 0.25          |
| Use of rare items like sugar, cooking oil     | 0.44                 | 0.22          |
| Marital status of household head              | 0.08                 | 0.07          |
| Ownership of any scarce assets                | 0.00                 | 0.31          |
| Age                                           | 0.01                 | 0.29          |
| Land ownership of the household               | 0.01                 | 0.06          |
| Membership in any groups                      | 0.01                 | 0.04          |
| Active total                                  | 6.40                 | 3.98          |
| % of variance                                 | 40.00                | 24.87         |

In this model the Cronbach’s Alpha for dimension 1 is 0.90, dimension 2 is 0.337, and the total is 0.931.

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(S3 Table). For instance, a majority of beekeeping households (53%) slept hungry compared to 12% among non-beekepers. A high number of beekeeping households (42%) also reported having faced a food shortage in their households that lasted more than two months compared to 17% of the non-beekeeping households. Non-beekepers had a higher proportion of cattle ownership compared to beekeers, and a majority (54%) of beekeepers had no off-farm employment compared to 12% of the non-beekeers. Other well-being indicators revealed that provision of everyday casual labour was high among beekeers. A majority of beekeers (88%) owned grass-thatched houses compared to 37% among non-beekeers, with 72% of

Fig 1. Comparing the mean well-being score for beekeepers and non-beekeepers A) indicates a low mean score which according to the study measurements signify less wealthy households, while B) shows a higher mean score implying non-beekeeping households were slightly wealthier than the beekeers. All measurements based on dimension one scores.

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the beekeepers sleeping on polythene or mats as opposed to mattresses compared to only 23% of non-beekeepers.

Most beekeepers (93%) were affiliated to a farmer group compared to non-beekeepers (65%). Significantly fewer beekeepers (48%) were members of savings groups compared to non-beekeepers (67%). Beekeepers were more likely to have adopted beekeeping (97%) if access to beekeeping extension services (access to relevant information) was available compared to the non-beekeepers’ likelihood (70%) to start other on-farm enterprises. Neither access to routine extension officer visits nor market information varied significantly between beekeepers and non-beekeepers (Table 4). Beekeeping extension services were mainly provided by NGOs and government agricultural extension departments, whilst agricultural extension services for other farm enterprises to non-beekeepers were mainly provided by government agricultural extension services and private consultants (Table 4).

### Drivers and barriers to beekeeping adoption

The farmers’ decision to diversify their on-farm enterprises was mainly driven by the need to fulfil their household nutritional needs (yes = 1, no = 0, n = 280/296, 92%) and income (yes = 1, no = 0, n = 269/296, 91%). Other drivers of on-farm enterprise diversification included availability of market for products (yes = 1, no = 0, n = 210/296, 71%), on-farm labour demands (yes = 1, no = 0, n = 91/296, 31%) and presence of local knowledge and traditional uses for the particular on-farm enterprise (yes = 1, no = 0, n = 60/296, 20%). The farmers’ diversification into beekeeping was mainly driven by the perceived higher income earning potential from hive products (59%), after seeing other farmers keeping bees (51%), as well as information and support received from government departments (50%) and non-government organizations.

The non-beekeepers were disinclined to adopt beekeeping due to limited beekeeping knowledge (62%), fear of defensive honey bees (59%), insufficient capital to purchase inputs (31%) and limited land availability (24%). Several non-beekeepers were unsure whether beekeeping could be profitable (16%) and cited poor market access for hive products (15%) as

| Table 4. Accessibility of agricultural extension services. |
|------------------------------------------------------------|
| **Type of agricultural extension services** | **Non-beekeepers n = 138 (%,** | **Beekeepers n = 163 (%,** | **Chi-square value (df = 1)** |
| | yes = 1) | yes = 1) | |
| Agricultural extension services | 69.57 | 96.99 | 43.36*** |
| Training on agricultural enterprise & beekeeping management | 31.1 | 87.95 | 103.30*** |
| Training on agricultural & beekeeping product processing | 37.68 | 58.43 | 12.99*** |
| Routine extension agent visits | 36.96 | 46.39 | 2.75 |
| Agricultural input & beekeeping equipment support | 46.38 | 87.35 | 58.88*** |
| Agricultural and beekeeping products market information | 63.04 | 59.04 | 0.51 |

*** The mean difference between beekeepers and non-beekeepers is significant at 1%.

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The mean difference between beekeepers and non-beekeepers is significant at 1%,
deterrents to beekeeping adoption. Interestingly, in response to a Likert scale set of questions, the majority of non-beekeeping respondents was either ‘very interested’, ‘interested’ or ‘somewhat interested’ in adopting beekeeping, suggesting an untapped source of new beekeepers (n = 92/130, 71%).

Predictors of beekeeping technology adoption

Probit modelling allowed the identification of significant associations between farmers’ socio-economic characteristics and likelihood to adopt beekeeping (Table 5). Several probit models with different specifications were estimated in order to test the robustness and significance of the coefficients. Male farmers and those who had none or only primary education were more likely to be beekeepers. Households with comparatively lower well-being index scores were more likely to be beekeepers. Membership to a farmer’s group increased a farmer’s likelihood of becoming a beekeeper. Contact with NGOs also significantly increased the likelihood to adopt beekeeping (Table 5).

The intensity of beekeeping adoption

The mean number of hives per beekeeper was 22.87 (s.d. = 22.73; min 2; max 192). A substantial proportion of beekeepers had only one to three years beekeeping experience (43.4%, n = 72/166), followed by 31.3% (n = 52/166) with four to seven years, and only 25.3% (n = 42/166) with eight years or more. Using three ordinary least square models, the robustness and significance of coefficients measuring intensity of beekeeping adoption was estimated. The intensity of beekeeping adoption (i.e. the number of hives owned) was primarily dependent upon the beekeeper’s years of experience and membership to a savings or credit group (Table 6).

Beekeepers acquired most of their top bar and frame hives (KTB and Langstroth, respectively) through donations. Traditional beehives tended to be locally made by the beekeepers (Table 7).
Honey was the main product harvested, followed by beeswax and propolis. Beekeeping contributed about 7% to annual household incomes (Table 8). So, this may indicate that if beekeeper households did not have beekeeping to supplement their income, they would be 7% financially worse-off than they are currently.

### Discussion

For the first time to the authors’ knowledge, this study has attempted to categorise and quantify the impact of beekeeping on household well-being. However, disaggregating the influence of beekeeping on well-being without knowledge of the pre-existing socio-economic conditions of the household renders causality difficult. Nonetheless, this study has identified key drivers and barriers of beekeeping adoption and their relative impact on household well-being.

### Table 6. Step 2: Estimation of beekeeping adoption intensity.

| Explanatory variable                                      | Model 1 Coefficients (s.e.) | Model 2 Coefficients (s.e.) | Model 3 Coefficients (s.e.) |
|-----------------------------------------------------------|------------------------------|------------------------------|------------------------------|
| Years of experience in beekeeping                        | 4.974 (1.656) ***            | 4.966 (1.677) ***            | 4.897 (1.166) ***            |
| Land acreage (acres)                                     | -0.095 (0.105)               | -0.092 (0.106)               | -0.093 (0.105)               |
| Dummy farmer interested in beekeeping (1: yes)            |                             | 8.182 (12.063)               | 8.034 (12.061)               |
| Membership to farmer group (1: yes)                      | 4.441 (6.381)                | 5.077 (6.236)                | 4.772 (6.311)                |
| Membership to savings and credit group (1: yes)           | 6.906 (3.462) **             | 6.608 (3.463) **             | 6.670 (3.462) **             |
| Access to beehives donations through NGO and government (1: yes) | 0.210 (5.074)               | 0.616 (5.014)                | 0.443 (5.043)                |
| Distance to market (kilometres)                           | 0.5197 (0.234) *             | 0.495 (0.236) *              | 0.498 (0.236)                |
| Dummy West Nile ecological zone                           | 8.677 (4.851)                | 8.663 (4.846)                | 8.852 (4.869)                |
| Dummy Eastern ecological zone                             | -2.524 (4.830)               | -2.907 (4.799)               | -2.765 (4.821)               |
| Mills Lambda ratio                                        | -1.742 (4.130)               | -1.043 (4.084)               | -1.754 (4.379)               |
| Constant                                                  | 0.930 (0.487)                | -15.584 (15.704)             | 17.228 (10.318)              |
| rho                                                       | -0.086                       | -0.052                       | -0.087                       |
| Sigma                                                     | 20.237                       | 20.203                       | 20.209                       |

Model 1: Wald chi2 (8) = 26.47 prob (chi2) <0.001, Model 2: Wald chi2 (9) = 40.55 prob (chi2) <0.001, Model 3: Wald chi2 (9) = 41.23 prob (chi2) <0.001

Note:
* refers to a significance at 10%,
** at 5%, and
*** at 1%. Number of observations = 301, censored = 138, uncensored = 163.

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### Table 7. Provision of beehives.

| Type of beehive     | Number of beekeepers | Proportion bought (%) | Proportion donated (%) | Proportion locally made (%) | Proportion co-funded (%) |
|---------------------|----------------------|-----------------------|------------------------|----------------------------|----------------------------|
| Traditional beehives|                      |                       |                        |                            |                            |
| Log hives           | 150                  | 25                    | 4                      | 70                         | 1                          |
| Pot hives           | 35                   | 41                    | 19                     | 0                          | 40                         |
| Top bar hives       |                      |                       |                        |                            |                            |
| Kenya top bar (KTB) | 109                  | 10                    | 84                     | 2                          | 4                          |
| Frame hives         |                      |                       |                        |                            |                            |
| Langstroth          | 34                   | 12                    | 88                     | 0                          | 0                          |

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Honey was the main product harvested, followed by beeswax and propolis. Beekeeping contributed about 7% to annual household incomes (Table 8). So, this may indicate that if beekeeper households did not have beekeeping to supplement their income, they would be 7% financially worse-off than they are currently.
Before further discussing the implications of this study, it is worthwhile considering the following caveat. Whilst the use of all livelihood asset capitals in this study facilitated the contextualization of beekeeping adoption drivers, other important factors that may have influenced farmers’ livelihood choices such as the influence of institutional, economic, social and political processes were not included. Such processes and their interactions are complex and consequently beyond the scope of this current study.

In this study, all beekeepers were farmers but not all farmers were beekeepers and yet beekeepers were significantly less educated and had a well-being index score lower than their non-beekeeping counterparts. Low educational attainment in sub-Saharan Africa has previously been used as a proxy measure of poverty [34] and there are obvious correlates between education and the well-being outcome in our study. Given that beekeeping farmers were comparatively more disadvantaged in terms of their overall well-being, it is somewhat surprising that they went to the additional cost of acquiring hives in the first place. It is widely agreed in the agricultural technology adoption literature that farmers who are relatively wealthier than their counterparts tend to more readily accept the associated risks of new technology adoption [4].

One possible partial explanation of such risk-taking resides in the development agencies’ programme prioritisation of key recipients, who identify and target the economically most disadvantaged in society as a means of maximising programme impact on poverty alleviation [35–37]. Consequently, most of the top bar and frame hives owned by respondent beekeepers were acquired through either NGO or Ugandan Government donations. Whilst contact with development organisations was associated with hive type ownership and was a key factor in farmer adoption of beekeeping, the hive management skills of beekeepers were independent of any previous contact with NGOs or Government departments, suggesting that skills remained undeveloped.

Sufficient access to knowledge transfer outlets such as extension service officers and/or NGO programmes was critical in the adoption and continuation of beekeeping. Many extension services have been sub-contracted by the Ugandan Government to private service providers as a means to offset the staffing costs of frontline agricultural extension provision, particularly in remote areas such as Northern Uganda [38]. Possibly as a consequence of cost-

| Table 8. Products harvested, current income benefits and unit product prices from beekeeping. |
|---------------------------------|---------------------------------|
| Variable                        | Annual yield per beekeeper Mean ± s.e. (n = 163) |
| Products (annual yields, kg)    |                                 |
| Honey                           | 13.42±1.39                      |
| Beeswax                         | 3.51±1.26                       |
| Propolis                        | 0.19±0.80                       |
| Current income benefit (annual income, USD) |                     |
| Total household income          | 615.48±74.18                    |
| Honey                           | 32.10±3.43                      |
| Beeswax                         | 10.33±4.50                      |
| Propolis                        | 0.58±0.34                       |
| Total beekeeping income         | 43.01±6.92                      |
| Proportion of beekeeping income | 0.69                            |
| Unit prices of product (USD/kg) |                                 |
| Honey                           | 2.61±0.14                       |
| Beeswax                         | 3.01±0.36                       |
| Propolis                        | 4.00±1.19                       |

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saving initiatives, the provision of adequate training in beekeeping was generally absent. The importance of training in driving technology adoption in this study is commensurate with the findings of several other studies [20,39–41]. Farmer group membership was found to be an important factor in beekeeping adoption. This is probably due to the demands frequently made by extension service providers (NGOs and Government extension departments), who tend to prefer training and equipment provision to be directed towards farmer groups rather than individual farmers in order to maximise economies of scale [20,42].

Factors that inhibited beekeeping adoption rates included insufficient knowledge, fear of defensive bee behaviour and limited financial capital. The role of knowledge acquisition on technology adoption rates, especially as a free-flowing exchange of information within and between communities, has been previously identified [43]. Appropriate and repeated training of beekeepers in honeybee behaviour management would help to address this challenge [44].

Whilst beekeeping adoption has generally been understood to entail the presence of at least one hive on the farm, this is not necessarily a sufficiently robust indicator of successful adoption. For instance, the adoption intensity (the relative number of hives per beekeeper) is also critical in determining the impact of a government or NGO-driven beekeeping programme. The majority of beekeepers in this study, as in previous studies [12–14], were small-scale beekeepers (<22 hives) primarily using traditional hives and generating low honey yields. In this study we found that the income contribution of beekeeping to households was not significantly high. Girma & Gardebroek [42] found the beekeeper income contribution to rural households to be high in Ethiopia, whilst Leisher et al [45] found it to be lower, suggesting that income contribution of beekeeping to rural livelihoods varies regionally and beekeeping alone may not be sufficient to alleviate relative impoverishment (as defined by the above authors) among the rural poor in Uganda.

A key component of the success or failure of the beekeeping adoption rate in this study was the lack of relevant training regarding effective hive management. Whilst the donation of beehives from NGOs increased the likelihood of farmers to adopt beekeeping, the ultimate success and continuation of beekeeping was contingent upon access to appropriate training, frequency of delivery and provision of protective equipment. Most beekeepers had been given only one day’s training, and this was delivered in a classroom context without any practical exposure. The quality and quantity of such training were not quantified in this study, but many beekeepers reported that they were unable to effectively use the top bar hive and preferred to use the fixed-comb style hive. This has important implications for NGOs who continue to supply hives throughout sub-Saharan Africa, as it would appear that the donation of hives to the exclusion of protective equipment and training is likely to fail to improve beekeeping households’ well-being. Furthermore, a lack of appropriate training and supply of protective equipment may lead to the undermining of farmer confidence in both the honey product sector and NGOs as a positive vector of livelihood change.

Concluding remarks

Whilst ‘beekeeping as a poverty alleviating activity’ has been widely promoted by international development agencies, national and local governments and an array of NGOs as a panacea to poverty alleviation, this study suggests that beekeeping has not significantly improved the farmers’ well-being. Critical requirements of successful beekeeping adoption by farmers (as identified by the farmers) are bee husbandry knowledge and protective equipment. However, what they are typically provided with, is an inexhaustible supply of modern hives and insufficient training in hive management. Rather than focussing solely on the plight of farmers to
effectively adopt beekeeping, future research should attempt to evaluate the effectiveness of development agencies’ provision to the beekeeping sector.

**Supporting information**

S1 Table. Determinant factors of beekeeping adoption.

S2 Table. Household well-being score card used.

S3 Table. Summary statistics of household wellbeing indicators.

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**References**

1. Davies M, Guenther B, Leavy J, Mitchell T, Tanner T. Climate change adaptation, disaster risk reduction and social protection: complementary roles in agriculture and rural growth? [Internet]. Sussex; 2009. Report No.: 320. www.ids.ac.uk/ids/bookshop

2. Headey D. Diversification and development in pastoralist Ethiopia. J world Dev [Internet]. 2014; 56:200–13. https://www.infona.pl/resource/bwmeta1.element.elsevier-327f1864-009c-3f06-a646-259b62bdb9bb

3. Barbieri C, Mahoney E. Why is diversification an attractive farm adjustment strategy? Insights from Texas farmers and ranchers. J Rural Stud. 2009; 25:58–66.

4. Bigsten A, Tengstam S. Smallholder diversification and income growth in Zambia. J Afr Econ [Internet]. 2011; 20(5):781–822. Available from: http://jae.oxfordjournals.org/content/20/5/781.full.pdf+html
5. Hilmi M, Bradbear N, Mejia D. Beekeeping and Sustainable Livelihoods [Internet]. Food and Agriculture organisation of the United Nations; 2011. http://www.fao.org/3/a-i2462e.pdf

6. Paumgartner F, Kassa H, Zida M, Moeliono M. Benefits, challenges, and enabling conditions of collective action to promote sustainable production and marketing of products from Africa’s dry forests. J Rev policy Res [Internet]. 2012; 29(2):229–50. Available from: http://onlinelibrary.wiley.com/doi/10.1111/j.1541-1338.2011.00549.x/epdf

7. Girma J, Gardebroek C. The impact of contracts on organic honey producers’ incomes in southwestern Ethiopia. For Policy Econ. 2015;

8. Pokhrel S. Comparative benefits of beekeeping enterprise in Chitwan, Nepal. J Agric Environ [Internet]. 2009; 10. http://www.nepjol.info/index.php/AEJ/article/view/2129/1960

9. Gebreychaness Berhane M. Socio-economic analysis of market oriented beekeeping in Atsbi Wemberta district of Eastern zone, Tigray region. [Internet]. Masters thesis Mekelle University; 2010. https://cgspace.cgiar.org/handle/10568/2553

10. Gallai N, Salles J-M, Settele J, VaissièRE BE. Economic valuation of the vulnerability of world agriculture confronted with pollinator decline. Ecol Econ [Internet], 2009 Jan [cited 2014 Jul 10]; 68(3):810–21. Available from: http://www.sciencedirect.com/science/article/pii/S0921800908002942

11. Klein A-M, VaissièRE BE, Cane JH, Steffan-Dewenter I, Cunningham SA, Kremen C, et al. Importance of pollinators in changing landscapes for world crops. In: proceedings of the royal society [Internet]. 2007. p. 303–13. http://rsbp.royalsocietypublishing.org/content/274/1608/303.short

12. Carroll T, Kinsella J. Livelihood improvement and smallholder beekeeping in Kenya: the unrealised potential. Dev Pract [Internet]. 2013; 233:332–45. http://www.tandfonline.com/action/journalInformation?journalCode=cdip20

13. Government of Kenya. National beekeeping policy [Internet]. Nairobi; 2009. http://vetvac.org/galvmed/law/docs/187_national_beekeeping_policy_draft9-6-2009-final_-_apiculture.pdf

14. Kimitel R. K., Korir B. K. Indigenous beekeeping for sustainable beekeeping development: a case of Kibwezi district, Kenya. In: Proceedings of the 1 st National Science, Technology and Innovation Week, (NCST) [Internet]. Nairobi, Kenya; 2012. http://www.utm.ac.ke/assets/research/sec_sti/conference_proceedings first ST&I week.pdf

15. Kalanzi F, Nansereko S, Buyinza J, Kiwuso P, Turinayo Y, Mwanja C, et al. Socio-economic analysis of beekeeping enterprise in communities adjacent to Kalinzu forest, Western Uganda. Int J Res land-use Sustain [Internet]. 2015; 2:81–90. Available from: http://www.landusesustainabilityjournal.org/socio-economic-analysis-of-beekeeping-enterprise-in-communities-adjacent-to-kalinzu-forest-western-uganda.html

16. CBI Market Intelligence. Trade statistics of honey in Europe [Internet]. The Hague; 2015. https://www.cbi.eu/market-information/honey-sweeteners/trade-statistics/

17. van Loon M, Koekkoek JF. Export opportunities for African organic honey and besswax. [Internet]. Bennekom; 2006. http://www.grolink.se/epopa/publications/market-studies/EPOPA_marketsurveyhoney-Jan06-web.pdf

18. TUNADO. The Uganda National Apiculture Development Organisation TUNADO Strategic Plan-2012 [Internet]. Kampa; 2012. https://www.google.be/search?q=uganda+apiculture+export+strategy&oq=apiculture+export-strategy&gs_l=serp.1.0.0i22i302.2213.7429.0.9214.24.19.3.2.2.0.287.2807.7j7j1.16.0....0...1c.1.64.serpi.3...16.1618.7ooHhHMH-Mh_k

19. Asfaw A, Admassie A. The role of education on the adoption of chemical fertiliser under different socio-economic environments in Ethiopia. J Agric Econ [Internet]. 2004; 30:215–28. Available from: www.elsevier.com/locate/agecon

20. Ramirez A. The Influence of social networks on agricultural technology adoption. In: procedia—social and behavioral sciences [Internet]. 2013. p. 101–16. http://www.sciencedirect.com/science/article/pii/S1877042813010288

21. Mijumi A, Natukunda K, Kugonza DR. Factors affecting the adoption of beekeeping and associated technologies in Bushenyi district, Western Uganda. J Livest Res Rural Dev [Internet]. 2012; 24(8). Available from: http://www.lrrd.org/lrrd24/8/muju24133.htm

22. Bhusal SJ, Thapa RB. Comparative study on the adoption of improved beekeeping technology for poverty alleviation. J Agric Anim Sci [Internet]. 2005; 26:117–25. http://www.nepjol.info/index.php/JAAS/article/view/664/629

23. Hope Aldo. Using multiple partners to strengthen the honey value chain in West Nile. [Internet]. Arua, Uganda; 2011. https://www.yumpu.com/en/document/view/6541968/using-multiple-partners-to-strengthen-the-honey-value-chain-snv
24. Wasige Ejet John. Assessment of the impact of climate change and climate variability on crop production in Uganda [Internet]. Kampala: 2009. http://start.org/download/gec08/wasige-final.pdf
25. Wortmann CS, Eledu CS. Uganda’s agroecological zones: a guide for planners and policy makers [online]. 1999 [cited 2016 Mar 30]; http://ciat-library.ciat.cgiar.org:8080/xmlui/handle/123456789/1017
26. UBOS, MAAIF. National Livestock Census Report [Internet]. Kampala, Uganda; 2009. http://www. livestock.go.ug/userfiles/National Livestock Census Report 2009.pdf
27. Friis-Hansen Esbern. Agricultural development among poor farmers in Soroti district, Uganda: Impact assessment of agricultural technology, farmer empowerment and changes in opportunity structures. In: Impact assessment workshop. Mexico: Danish institute for international studies; 2005.
28. Linting M, van Der Kooij A. Nonlinear principal components analysis with CATPCA: a tutorial. J Pers Assess [Internet]. 2012; 94(1):12–25. Available from: http://www.tandfonline.com/loi/hjpa20
29. Meulman JJ, Van Der Kooij AJ, Heiser WJ. Principal Components Analysis With Nonlinear Optimal Scaling Transformations for Ordinal and Nominal Data.
30. Heckman JJ. Sample selection bias as a specification error. sourceeconometrica, J Econ Soc [Internet]. 1979; 47(1):153–61. Available from: http://www.jstor.org
31. Heckman JJ. Sample Selection Bias as a Specification Error. Source Econom [Internet]. 1979; 47(1):153–61. Available from: http://www.jstor.org
32. Kouamé EB-H. Adoption and levels of demand of fertilizer in cocoa farming in Cote D'Ivoire: does risk aversion matters?? In: The CSAE Conference- “Economic Development in Africa” [Internet]; St Catherine's College,Oxford; 2011. http://www.csae.ox.ac.uk/conferences/2011-edia/papers/769-kouame. pdf
33. FAO. The smallholder farmers’ dataportrait is a comprehensive, systematic and standardized data set on the profile of smallholder farmers across the world. [Internet]. 2012 [cited 2016 Jan 6]. http://www. fao.org/economic/esa/esa-activities/esa-smallholders/dataportrait/country-details/en/?cnt=84211
34. Échevin D. Measuring Vulnerability to Asset-Poverty in Sub-Saharan Africa. World Dev. 2013; 46:211–22.
35. Trust Kilimo. Making markets work to reduce poverty making markets work to reduce poverty six years of Kilimo Trust in East Africa [Internet]. Arusha; 2011. http://www.kilimotrust.org/documents/Kilimotrust 6 Year Report.pdf
36. Røling N. Sustainability pathways for impact: scientists’ different perspectives on agricultural innovation. Int J Agric Innov [Internet]. 2015; 7(2):83–94. Available from: http://www.tandfonline.com/action/journalInformation?journalCode=tags20
37. Haggblade S, Hazell P, Reardon T. Strategies for stimulating poverty-alleviating growth in the rural non-farm economy in developing countries [Internet]. 2002 [cited 2015 Dec 14]. Report No.: 92. http://x.ptr. ynggy.com/resource/data/0703/U04137/OcwWeb/Oturban-Studies-And-Planning/11-471Fall-2004/pdf/ eptp92.pdf
38. Benin S, Nkonya E, Oketch G, Pender JL, Nahdy S, Mugarura S, et al. Assessing the impact of the national agricultural advisory services (NAADs) in the Uganda rural livelihoods [Internet]. Washington DC; 2007. Report No.: 724.: http://www.ifpri.org/publication/assessing-impact-national-agricultural-advisory-services-naads-uganda-rural-livelihoods
39. Knowler D, Bradshaw B. Farmers’ adoption of conservation agriculture: a review and synthesis of recent research. Food Policy [Internet]. 2007; 32(1):25–48. Available from: http://www.sciencedirect.com/science/article/pii/S0306919206000224
40. Simtowe F, Kassie M, Diagne A, Asfaw S, Shiferaw B, Sillim S, et al. Determinants of agricultural technology adoption: The case of improved pigeonpea varieties in tanzania. J Int Agric [Internet]. 2011; 50(4):325–45. Available from: http://repository.cimmyt.org/xmlui/handle/10883/22167?show=full
41. Tumbo SD, Mutabazi KD, Masuki KFG, Rwemumbiza FB, Mahoo HF, Nindt SJ, et al. Social capital and diffusion of water system innovations in the Makanya watershed, Tanzania. J Socio Econ [Internet]. 2013; 43:24–36. Available from: https://www.researchgate.net/publication/257472121_Social_capital_and_diffusion_of_water_system_innovations_in_the_Makanya_watershed_Tanzania
42. Girma J, Garderbrook C. The impact of contracts on organic honey producers’ incomes in southwestern Ethiopia. For Policy Econ [Internet]. 2015 Jan [cited 2015 Dec 21]: 50:259–68. Available from: http://www.sciencedirect.com/science/article/pii/S1389934114001476
43. Abebe GK, Bijnam J, Pascucci S, Omota O. Adoption of improved potato varieties in Ethiopia: The role of agricultural knowledge and innovation system and smallholder farmers’ quality assessment. J Agric Syst [Internet]. 2013; 122:22–32. Available from: https://www.researchgate.net/publication/ 259126586_Adoption_of_improved_potato_varieties_in_Ethiopia_The_role_of_agricultural_ knowledge_and_innovation_system_and_smallholder_farmers’_quality_assessment

Beekeeping adoption and socio economic drivers
44. Breed MD, Guzman-Novoa E, Hunt GJ. Defensive behavior of honey bees: organization, genetics, and comparisons with other bees. Annu Rev Entomol [Internet]. 2004 [cited 2015 Dec 14]; 49:271–98. Available from: http://www.annualreviews.org/doi/abs/10.1146/annurev.ento.49.061802.123155

45. Leisher C, Sanjayan M, Blockhus J. Does Conserving Biodiversity Work to Reduce Poverty? A State of Knowledge Review, in Biodiversity Conservation and Poverty Alleviation. In: Exploring the Evidence for a Link (eds Roe D, Elliott J, Sandbrook C and Walpole M) [Internet]. John Wiley & Sons; 2012 [cited 2016 Jul 25]. http://onlinelibrary.wiley.com/doi/10.1002/9781118428351.ch9/summary