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Optimising beekeeping development programs for improved productivity, income and welfare: A case study of Papua New Guinea

Cooper Nat Schouten [a,*], David Lloyd [a], Reuben W. Sengere [b], Jonah Aranka [b]

[a] *School of Environment, Science and Engineering, Southern Cross University, Lismore, Australia*
[b] *Coffee Industry Corporation Ltd, Aiyura, Eastern Highlands Province, Papua New Guinea*

Abstract

Beekeeping can provide important sources of cash income for farmers in developing countries where land is unconducive to crop and livestock production systems. In many low-income countries however, attrition among beekeeping adopters remains a chronic problem, colony losses are high, support for and coordination of the sector is low, and practices, production and income from beekeeping is often inefficient. This study investigated the key drivers and practices influencing incomes from beekeeping, honey production and numbers of hives owned by beekeepers in the Eastern Highlands Province of Papua New Guinea. Survey data from 117 beekeepers revealed that beekeeping contributes to improving farmers resilience and security in times of financial hardship with 85 % of beekeepers reporting using their honey as a form of a bank and beekeepers earning average annual net incomes of US$715.50. Specifically, our results highlight the importance of supplementary feeding, multiplying colonies by making splits, reinvestment into beekeeping enterprises and access to more than a single apiary site as key factors influencing productivity and income. This study provides guidelines for optimising beekeeping outcomes in low-income countries and provides recommendations to inform policy options for strengthening beekeeping for sustainable community development programs and partnerships.

Keywords: International assistance, rural development, sustainable livelihoods, honey, *Apis mellifera*

1 Introduction

The determinants underpinning the success of international agricultural research for development programs are not always clear, and their effectiveness is varied (Anderson *et al*., 2012; Wagner, 2019). Beekeeping represents an example of this phenomenon and has become an increasingly targeted strategy of aid programs in low and middle-income countries (Schouten, 2020a; Schouten 2020b). Apiculture has been considered an exemplary intervention for sustainable rural development (Bradbear, 2009), which can be attributed to its extensive prevalence in rural communities globally (Crane, 1999), its low environmental impact (Mogni *et al*., 2009) and its significant contributions to diversification and cash incomes among rural economies (Girma & Gardebroek, 2015; Pokhrel, 2009; Bradbear, 2009; Cortopassi-Laurino *et al*., 2006; Gupta *et al*., 2014; Schouten & Lloyd, 2019). Keeping bees can offer many livelihood benefits in addition to income generation from honey (Lowore, 2020; Schouten & Lloyd, 2019), and pollination by bees can increase crop yields and contribute to maintaining biodiversity in natural ecosystems (Abrol, 2012; Allsopp *et al*., 2008; Partap, 2002).

Despite the enthusiasm of funding agencies, the determinants underpinning the success of beekeepers and livelihood outcomes of such programs has received little attention (Chambers, 1993; King *et al*., 2010; Otis & Bradbear, 2003; Schouten, 2020). Further, attrition among adopters remains a chronic problem, colony losses are high, technical skills are low, and practices, production and income from beekeeping is often inefficient (Schouten & Lloyd, 2019; Roberts *et al*., 2020; Wagner *et al*., 2019). Commercialisation of bee products, including honey, beeswax, nucleus colonies and queen bees, are generally unregulated, and demand often exceeds supply (de Figueiredo *et al*., 2017; Legesse, 2014). Apiculture thus remains an under-exploited income generat-

* Corresponding author – Cooper.Schouten@scu.edu.au

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ing livelihood activity with significant potential for improving incomes and welfare among beekeeping communities without exacerbating environmental degradation.

Success in beekeeping is usually defined by numbers of hives, honey production and profit. However, research (Bradbear, *et al*., 2002; Bradbear, 2009) highlights the importance of deviating from commonly used variables, such as honey yields or increased numbers of bee hives, as sole measurable indicators of beekeeping program success. Ideally, social development impact methodologies should also seek to measure indicators of wellbeing, for example, increased resilience to shocks and seasonality and improved agency, relations and empowerment (Austin *et al*., 2020). While research emphasises the need for participatory approaches to pre- and post-program evaluation of the change that is brought about to the lives of beneficiaries and their households, this is rarely conducted among beekeeping interventions (Bradbear, pers. comm., 2020; Chambers, 1993).

To manage a successful beekeeping operation[1] requires:

1. A sound understanding of the available floral resources within the operational range of the beekeeper;
2. Technical beekeeping skills to manage swarming, multiply colonies and manage pest and disease pressures, and;
3. Business management and marketing skills.

While beekeeping programs may evaluate numbers of beekeepers in a region, honey production and numbers of hives as measurable indicators of program success, the factors responsible in determining beekeeper's profitability, are not always clear. Beekeeping requires a range of inputs, and there are multiple income generating opportunities which exist in the production of nucleolus colonies, beekeeping hardware, beekeeping training, queen bees and value-added products. In addition to pursuing a range of income generating strategies within a beekeeping operation, farmers social capital and market linkages can also be key drivers in the overall enabling environment that allows beekeepers to pursue a profitable enterprise and livelihood strategy (Bradbear, 2009; Suryahadi *et al*., 2006). Access to mentors, training, extension, inputs, finance and credit also play a major role in developing profitable agricultural production systems (Gebrehiwot, 2015; Hinton *et al*., 2020; Legesse, 2014; Tamang & Gurung, 2015). Therefore, it is important to understand which combination of livelihood assets and technical skills are most likely to influence the productivity and profitability of an enterprise.

[1]This context is primarily concerned with beekeeping with Apis mellifera in Langstroth or removable frame hive technologies.

Making beekeeping a more profitable activity could attract new entrepreneurs and improve outcomes for existing aid programs and beekeeping enterprises, and thus increase its relevance as a means to achieve sustainable development (Bradbear, 2009). This requires the optimisation of management practices and effective intervention strategies in order to increase the production of bee products and raise beekeeping incomes from their sales.

Optimising beekeeping enterprises can be difficult, given the huge diversity of management practices, bee species, climatic conditions, prevailing honey bee pests and diseases, floral resources, technologies and markets between regions. Important efforts have been made to train beekeepers and standardise management practices (Lal *et al*., 2012; Yirga *et al*. 2012; Nazzi *et al*., 2014; Singh *et al*., 2016), quantify returns on investment in beekeeping operations (John *et al*., 2017; Qaiser *et al*., 2013), assess honey markets, quality and commercialisation (Howard & Tchana, 2015; Legesse, 2014) and diagnose the overall situation of the apiculture sector in different regions (Orlegge & Gonapa, 2011; Lowore & Bradbear, 2013; Qaiser *et al*., 2013; Engindeniz *et al*., 2014; Abrol, 2016; John *et al*., 2017; Jung & Lee, 2018; Thai & Van Toan, 2018; Thapa *et al*., 2018; Zheng *et al*., 2018; Gratzer *et al*., 2019;). However, no attempt has yet been made to relate production and income indicators to management practices and other confounding variables across a large geographic scale. Here we used the diversity of beekeeping practices in the Eastern Highlands Province of Papua New Guinea (PNG) to assess the impact of particular management practices and livelihood assets on productivity and economic revenues within beekeeping enterprises. This study represents the first large-scale effort aiming to optimise smallholder beekeeping enterprises using a quantitative approach.

2 Materials and methods

2.1 Survey data

A questionnaire was developed in January 2018 in collaboration with local researchers and apicultural officers from the National Department of Agriculture and Livestock (NDAL), the University of Goroka and the Coffee Industry Cooperative (CIC) in order to to achieve the aims and objectives of the study (AusAID, 2003; Coughlan & Coughlan, 2002; Martin, 2006; Reason & Bradbury, 2007). Participants were identified and contacted in consultation with key informants from the above-mentioned organisations involved in the apiculture sector and from local beekeeping associations. A pilot study of five beekeepers from the province of Goroka was used to refine the questionnaire. The analysis of the data

retrieved from this initial pilot study enabled the survey to be refined, with poorly worded questions reworded to obtain more accurate answers, eliminating meaningless questions and adding new ones.

This paper utilises a subset of data derived from a larger survey which comprised 126 questions and took respondents on average 50 minutes to complete. A total of 117 beekeepers were surveyed using random sample design. Survey data was collected over two months, between May and June 2018 under human research ethics approval (Approval Number ECN-17-188), which was obtained from Southern Cross University, Human Research Ethics Committee. Only data from beekeepers having at least one bee colony at the time of interview were included in this study. Although respondents might have provided false or inaccurate answers in some cases, we have no reason to expect systematic response biases that could compromise our analyses. To minimise such potential biases, we carefully curated the data eliminating duplicated entries, contacting some beekeepers again to confirm certain answers, cross validating replies, and checking for outliers in each response. Questionnaires were conducted in seven districts of the Eastern Highlands Province (EHP) (Table 1).

Table 1: *Frequency of questionnaire respondents in the Eastern Highlands Province.*

No.	*District*	*Frequency*
1	Unggai-Benna	56
2	Goroka	35
3	Asaro	9
4	Lufa	7
5	Kainantu	7
6	Okapa	2
7	Doalo	1
	Total	117

The reason for using questionnaires was to collect in-depth information on the perspectives of beekeepers with key insights on the issues being examined (Carter & Beaulieu, 1992). Questions focused on beekeeping management practices, such as supplementary feeding, ability to breed queen bees and make colony splits, as well as questions relating to beekeeping experience, access to honey collection services, honey yields, beekeeping inputs and access to beekeeping training and extension and incomes. Descriptive statistics and figures were generated using Microsoft Excel™ to explain response distributions and general trends.

2.2 Statistical analysis

One-way analysis of variance, person product-moment correlations and independent-samples t-tests were used to statistically compare and relate production and income indicators to management practices and other confounding variables. Such an approach has gained substantial support in the natural sciences during the last decade, and is particularly well suited to analyse complex datasets, when several different competing hypotheses can be put forward (Burnham& Anderson, 2002; Johnson & Omland, 2004). All analyses were conducted with IBM SPSS, version 25.0.

3 Results

3.1 Beekeeping enterprises

The majority of beekeepers were from Unggai-Benna (46.7 %) and Goroka (29.2 %) districts and were male (75.6 %). No significant difference was found between average annual honey production per hive or total average annual honey production between districts ($p = > 0.05$). The mean age of beekeepers was 44, mean household size was five and subsistence farming was the main occupation for 52.5 % of beekeepers. Beekeepers had low education levels, with 47.1 % having completed primary level education, followed by high school year 10 (24.4 %) and no formal education (9.2 %). The majority of beekeeper's gross annual earnings fell within lower middle-income GNI groups (Table 2).

Table 2: *GNI per capita income brackets for beekeepers in the Eastern Highlands Province of Papua New Guinea.*

*GNI per capita income (USD)**	*Respondents (%)*
Low income ($1,025 or less)	12
Lower middle-income ($1,025 - $3,995)	73
Upper middle-income ($3,995 - $12,375)	13
High-income ($12,376+)	2

*Gross National Income (GNI) classification of income is based on the 2020 fiscal year and is calculated using the World Bank Atlas method.

The majority of beekeepers (69.2 %) were reliant on public transport to get their honey to market while 30.8 % had access to a vehicle or honey collection services. Only 11 % of beekeepers reported having ongoing input costs to manage their operations, with the remainder (89 %) reporting having no operational costs. Most beekeepers harvested 2-3 times per year (74 %) and 7 % of beekeepers reported harvesting honey in times of financial hardship. Further, 84.8 % indicated that they use honey as a form of a bank and 81.4 % indicated that their bee hives and honey act as security in times

of financial hardship. The majority of beekeepers (90.4 %) indicated that in comparison to other forms of income, income from beekeeping was either important or very important and the median proportion of income generated from beekeeping was 45 %. Of respondents, 94 % indicated that beekeeping had either positively or very positively impacted upon their wellbeing.

Five year average percentage change in number of bee hives owned was found to be increasing by 20 % annually. In 9 % of cases, the average number of hives owned over five years was found to be declining by a median of 36 % (range: 8 % - 189 %). Beekeepers with 7 or more members in their housholds had significantly lower chances of having declining numbers of hives than beekeepers with 1-3 people in their hosueholds ($p = 0.02$). Beekeepers had 2.5 years of experience on average and beekeepers with 11+ years' experience ($M = 1111.65$, SD = 2.87) were found to have significantly higher net incomes from beekeeping than beekeepers with 1-5 years of experience ($M = 413.52$, SD = 4.03, $\eta^2 = 0.08$).

3.2 Education and training

Most beekeepers (83.8 %) had completed basic beekeeping training, while only 6 % of beekeepers indicated they had completed training on how to breed queen bees. Despite limited queen bee training, 53 % of respondents reported being able to make queen bees and 79 % of beekeepers reported being able to make colony splits. When comparing beekeepers who had received training and those who had not, independent-samples t-test revealed no significant influence of training on net income from beekeeping, ($p = 0.11$), five year average numbers of bee hives owned ($p = 0.85$), five year average production per hive ($p = 0.55$), five year average percentage change in numbers of bee hives owned ($p = 0.19$) or five year average total annual honey yield ($p = 0.62$). Pearson correlation coefficient also found no significant correlation between number of days of beekeeping training and net income from beekeeping, ($r = 0.13$, $n = 115$, $p = 0.16$), five year average numbers of bee hives owned ($r = 0.14$, $n = 115$, $p = 0.12$), five year average production per hive ($r = 0.08$, $n = 115$, $p = 0.4$), five year average percentage change in numbers of bee hives owned ($r = 0.06$, $n = 115$, $p = 0.5$), or five year average total annual honey yield ($r = 0.16$, $n = 115$, $p = 0.08$).

3.3 Numbers of bee hives

Beekeepers owned 13 bee colonies on average and a maximum of 70 colonies was reported. Six key factors were identified as being significant predictors of five-year average number of hives owned by beekeepers, including owning protective equipment, the ability to make hive splits, owning more than one apiary, net income from beekeeping, years of beekeeping experience and reinvestment back into beekeeping operations (Table 3). A significant positive relationship was found between five-year average number of hives owned and net income from beekeeping ($r = 0.20$, $n = 115$, p = 0.03) and number of years of beekeeping experience ($r = 0.27$, $n = 115$, $p = <0.01$). Turkey HSD test revealed that beekeepers who reinvested 200+ PNG Kina ($57 USD) ($M = 9.6$, SD = 2.45) annually into their beekeeping operations had significantly more hives on average over five years than beekeepers who spent 50 PNG Kina or less ($M = 5.8$, SD= 2.29) F (2,115) = 3.64, $p = 0.02$ (Table 3).

Beekeepers who were unsure about why and how to supplementary feed bees ($M = 2.5$, SD = 2.17) had significantly fewer hives over five years than beekeepers who did know why and how to supplementary feed bees ($M = 7.0$, SD = 2.21; t (113) = 3.07, $p = <0.01$, two-tailed).

Table 3: *Results of t-tests and Descriptive Statistics for three response variables influencing five year average number of hives owned.*

				95 % CI for Mean Difference			
Groups	*M*	*SD*	*n*	*Lower*	*Upper*	*t*	*df*
Doesn't own gloves and veil	5.9	2.27	81	0.49	0.94	-2.33*	113
Owns gloves and veil	8.7	2.17	34				
Cannot make splits	1.5	0.90	27	0.45	0.93	-2.39**	113
Can make splits	2.0	0.77	88				
Has one apiary	1.7	0.83	82	0.43	0.84	-2.99**	111
Has more than one apiary	2.2	0.69	31				

* p< 0.05, ** p< 0.01 (two-tailed)

3.4 Honey yields

We investigated which factors influenced five-year average annual total honey yield and productivity per hive (kg). Average production per hive over five years was 12.3 kg with 71 % of beekeepers producing 20 kg per hive or less. Five-year average annual total honey yield was 97.3 kg per beekeeper with the majority (66 %) producing between 50-150 kg of honey annually. Beekeepers who owned the land where their apiaries were located produced significantly higher yields per hive (M = 13, SD = 2.29) than those who did not (M = 8.4, SD = 1.85; t (112) = -2.01, p = 0.04, two-tailed). The average number of hives owned over five years was found to have a significant negative relationship with average production per hive over five years (r = -0.30, n = 115, p = <0.01) (Fig. 1). However, the five-year average number of hives owned had a significant positive relationship with five-year average total honey yields (r = 0.435, n= 115, p = <0.01) (Fig. 2).

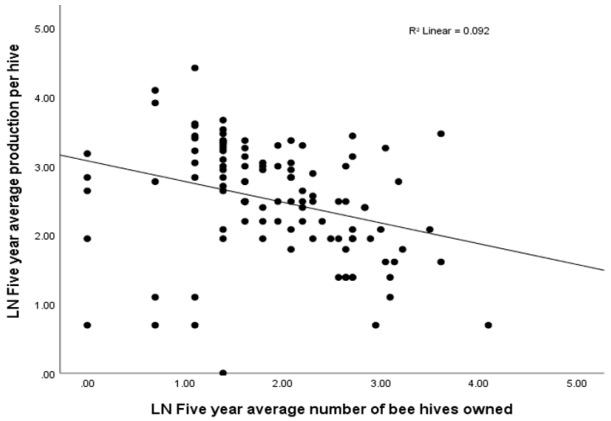

Fig. 1: *Pearson product-moment correlation between five-year average total honey yield and five-year average number of bee hives owned.*

Independent samples t-test revealed that having more than a single apiary, having access to a vehicle or honey collection services and knowing why and how to supplementary feed bees were significant factors influencing five year average annual honey yields (Table 4).

3.5 Net income from beekeeping

Net income from beekeeping was found to be $715.50 USD with 43 % generating $0-500 USD, 31 % generating $501-1000 USD and 27 % generating > $1000 USD annually (Fig. 3). Beekeepers who had more than a single apiary site had significantly higher net incomes from beekeeping (M = 862.90, SD = 3.31) than those with a single apiary site (M = 441.65, SD = 3.69; t (111) = -2.49, p = <0.01, two-tailed). Further, beekeepers who owned the land where their

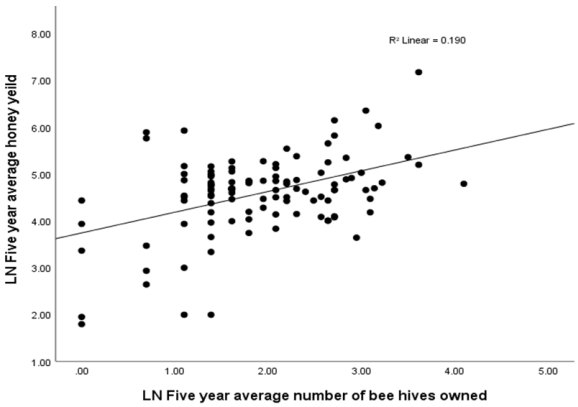

Fig. 2: *Pearson product-moment correlation between five-year average production per hive and five-year average number of bee hives owned.*

apiaries were located (M = 601.36, SD =3.52) generated significantly higher net incomes from beekeeping than those who didn't (M = 224.90, SD = 3.52; t (112) = -2.82, p = <0.01, two-tailed). Education was found to be significantly negatively correlated with net income from beekeeping (r = -0.20, n = 115, p = 0.04). Net income from beekeeping was significantly positively correlated with number of years of beekeeping experience (r = 0.38, n = 115, p = <0.01) and average numbers of hives owned over five years (r = 0.20, n = 115, p = 0.03).

3.6 Interest as a reason for starting beekeeping

Of respondents, 31 % mentioned interest as a reason for starting beekeeping. Independent-samples t-test was conducted to compare six response variables for these beekeepers (Table 4). Beekeepers who mentioned interest as a reason for starting beekeeping produced significantly higher mean honey yields per hive over five years (p = 0.02), had significantly higher numbers of hives on average over five years (p = 0.03) and had significantly higher annual percentage increases in hive numbers over five years (p = 0.02) than beekeepers who did not mention interest as a reason for starting beekeeping. Further, mentioning interest as a reason for starting beekeeping was the only significant predictor of percentage change in number of hives over five years (Table 4).

4 Discussion

This study sought to relate production and income indicators to management practices and other confounding beekeeping variables in the Eastern Highlands Province of Papua New Guinea. The impact of particular management

Table 4: *Results of t-tests and descriptive statistics for three response variables influencing five-year average annual honey production.*

				95 % CI for Mean Difference			
Groups	*M*	*SD*	*n*	*Lower*	*Upper*	*t*	*df*
Has one apiary	84.8	2.36	82	0.45	0.89	-2.63**	111
Has more than one apiary	133.0	1.97	31				
Doesn't own vehicle	91.4	2.28	104	0.31	0.88	-2.49**	113
Owns vehicle	174.5	2.10	11				
Dependant on public transport	87.7	2.27	84	0.48	0.96	-2.21*	113
Access to collection services	128.6	2.29	31				
Cannot supplementary feed	101.2	2.24	6	1.08	4.26	2.22*	113
Can supplementary feed	47.1	3.13	109				

* p< 0.05, ** p< 0.01 (two-tailed)

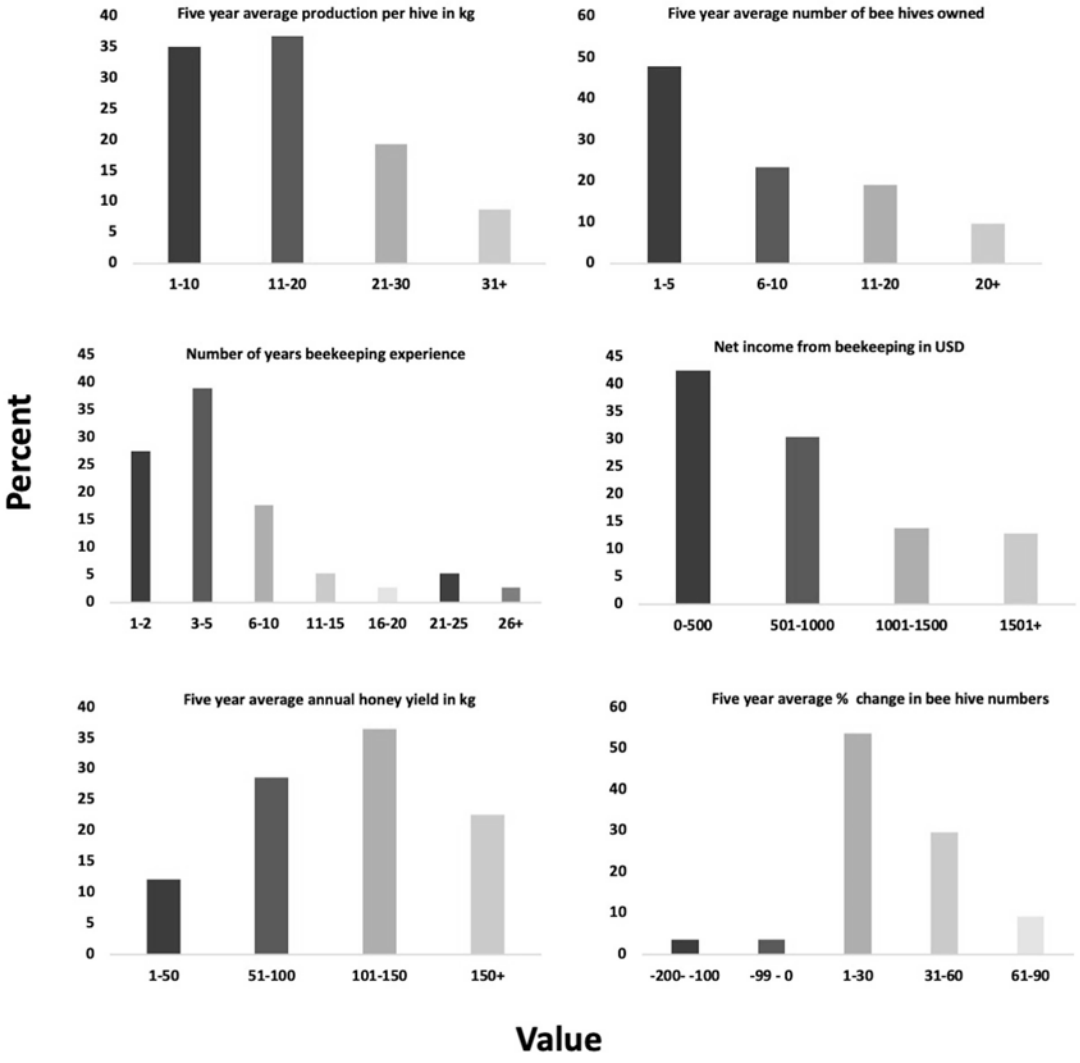

Fig. 3: *Bar charts showing the percentage distribution of six indicators of beekeeping productivity and income.*

practices on productivity and economic revenues was investigated to identify strategies for optimising smallholder beekeeping enterprises and to develop strategic priority areas for beekeeping training and programs using a quantitative approach. While numbers of hives owned by beekeepers was considered to be small scale, the contributions of income generated from the sales of honey was found to be a significant source of cash income, particularly for less educated farmers, with average annual net incomes from beekeeping of $715.50 USD.

Of respondents, 89 % reported they did not have any ongoing input costs to manage their beekeeping operations. While beekeeping development programs may seek to enhance beekeeping yields, it should be noted that low input systems with low productivity can, in some cases, be less risk prone and more profitable than high input systems. Local methods, while not necessarily appropriate in other regions, have often proven to be feasible and sustainable (Lowore & Bradbear, 2009).

Beekeeping enterprises were found to be increasing their hive numbers by 20 % per annum on average over the past five years, indicating steady growth within the sector. Concerningly, 9 % of beekeepers surveyed had five-year average declines in numbers of bee hives. Further research is needed to better understand why these beekeepers hive numbers were found to be declining as no significant indicators were found as contributing factors in this decline during this study.

With approximately 85 % of beekeepers in the EHP using their honey as a form of a bank, this research demonstrates the important contributions of beekeeping in improving resilience and security in times of financial hardship. Similarly, Girma & Gardebroek (2015) reported beekeeping as important in the livelihood security of Ethiopian farmers, particularly during periods of crop failure due to environmental factors or death of livestock. A participant from this study remarked: 'For me, the honey business supports me during bad crop seasons when yields and incomes are low'. As found in the EHP, research from Nigeria suggests that cash income from beekeeping can be made year-round, which enables income smoothing and reduction of risk from shocks (Ojo *et al*., 2016).

While beekeepers may have rapid access to cash incomes from honey sales, it is important that strategies be put in place for beekeepers to improve their ability to save cash incomes so that harvesting can be conducted at times which will optimise honey yields. For example, harvesting honey before an extended dearth period will put bee colonies in poor condition to exploit future honey flows and risk colony collapse. This situation may be exacerbated where there are high honey bee pest and disease pressures, as is the case with *Varroa jacobsoni* and *Tropilaelaps mercedesae* mites in PNG. While no major seasonal fluctuations in prices received for honey were reported by key informants of this study, beekeepers in some rural contexts may need financial and technical support to improve the storage capacity of their honey in order to store their honey for more favourable market times, rather than selling directly after harvest (Famuyide *et al*., 2014).

4.1 Beekeeping training and extension

Beekeeping training was found to have no significant effect on beekeepers' honey yields, numbers of bee hives owned or net incomes from beekeeping. Recent research has reported similar situations in Tanzania (Wagner *et al*., 2019) and Ethiopia (Gebeyehu *et al*., 2010) where beekeeping training did not result in improved beekeeping incomes or honey yields. Number of extension visits was also found to have no influence on income from beekeeping (Gebeyehu *et al*., 2010). Studies by Aksoy *et al*. (2018) and Okpokiri *et al*. (2015) however, found that number of days of beekeeping training was significantly correlated with honey yields and income from beekeeping. This variation in impact resulting from training and extension services highlights that beekeeping training length, delivery and content can be both valuable to improving outcomes for beekeepers, yet it can also be inadequate and ineffective. This stresses the need to prioritise the availability of technical beekeeping skills and efforts to enhance the quality rather than quantity of beekeeping training interventions.

Ineffective beekeeping training may be due to inefficient teaching skills and a focus on theoretical rather than practical skills development, limited technical beekeeping knowledge, incorrect concepts and information being conveyed or minimal adoption of new practices by beekeepers. While beekeeping technical skills exist in the EHP, capacity building for trainers to upskill and provide effective, outcome based training, and access to enhanced teaching materials, may help to improve learning outcomes and beekeeping incomes among beekeepers. Additionally, improving skills in queen bee breeding so that trainees can learn with non-aggressive bees, reducing numbers of participants, thoughtful selection of participants and ensuring access to protective equipment may also help to facilitate learning outcomes for beekeeping trainees (Schouten & Lloyd, 2019).

4.2 Factors influencing beekeeping success

Nine factors were found to significantly influence beekeeping success in terms of honey yields, numbers of hives owned and income from beekeeping:

1. Owning more than one apiary
2. Years of beekeeping experience
3. Beekeepers who owned the land where apiaries were situated
4. Owning protective equipment
5. The ability to make colony splits
6. Net income from beekeeping
7. Reinvestment back into beekeeping operations
8. Having access to a vehicle or honey collection services
9. Understanding why and how to supplementary feed bees

4.2.1 Apiary sites

Owning more than a single apiary was a significant determinant in the three response outcomes of yield, numbers of hives and income from beekeeping. It is intuitive that beekeepers with more hives would have more than a single apiary and should generate more honey and therefore higher incomes from beekeeping. However, increasing numbers of hives was found to be negatively correlated with average production per hive over five years. Nevertheless, total five-year average production was significantly higher among beekeepers with greater numbers of hives owned over five years. This indicates that, while beekeepers who own more hives produce more honey overall, honey production per hive is likely being reduced due to overstocking and limited access to floral resources. This may further be explained by the fact that those beekeepers who understood why and how to supplementary sugar feed their bees produced significantly more honey than those who did not.

While beekeepers owned 13 colonies on average, it is important that beekeepers be supported to develop localised floral calendars in order to determine optimal stocking rates for any given site and be aware of other bee colonies within their operational range. Owning more than a single apiary may also help beekeepers to withstand shocks such as pest or disease pressures, drought or theft. If a single apiary is negatively impacted, the other apiary may help to recover and rebuild colony numbers. Therefore, owning multiple apiaries may help to reduce shocks in smallholder beekeeping businesses.

4.2.2 Land tenure

Recent studies (Nazzi *et al*., 2014; Girma & Gardebroek, 2015; Pocol & McDonough, 2015; Yap *et al*., 2015; Shrestha, 2018; Jeil *et al*., 2019) suggest that a major attraction of beekeeping for improving rural livelihoods is that honey production does not require large areas or the ownership of land. This study suggests land tenure should not be overlooked as a factor influencing the ability of beekeepers to maintain and generate income from beekeeping. In the EHP, beekeepers who owned the land where apiaries were situated had significantly higher total honey yields and average numbers of hives over five years. Wagner *et al* (2019) also found that land ownership was an important factor limiting the adoption of beekeeping in Tanzania. Owning land may improve access to apiary sites and therefore beekeepers may check on and manage these sites more frequently and with greater ease than beekeepers that have to travel further from their households. Beekeepers may also have increased costs associated with renting of apiary sites and have increased risk of theft of bee equipment among apiaries situated in areas without secure tenure.

4.2.3 Beekeeping finance

Beekeepers who re-invested back into their beekeeping operations were found to own significantly more hives on average than beekeepers who indicated they had no operating costs. While small scale beekeeping can be developed around low input systems, and some equipment can be made from available materials, there are essential components of Langstroth beekeeping systems that require ongoing input costs to optimise production and maintain bee health. This can include replacement of old combs and frames with new wax foundation and frames (20 % of brood frames annually), use of miticides to manage damaging mite populations and sugar for supplementary feeding during extended dearth periods. Access to finance to purchase beekeeping inputs is essential to further development of beekeeping enterprises: for example, getting honey to market may require cash to pay for public transport and successful marketing may depend on purchasing of containers for packaging (Bradbear, 2009). Beekeeping projects should aim to ensure that all available capital assets are taken into consideration, without dependence on any that are not. For example, where projects depend on the importation of beeswax foundation, those beekeepers that do not have financial savings are more likely to fail (Chaudhuri *et al*., 2002).

4.2.4 Improving honey collection services

A common limitation in developing countries for beekeepers and honey cooperatives is the challenge of collecting honey from a dispersed population of smallholder producers (Bradbear, 2009; Schouten *et al*., 2019). In this study, access to a vehicle or collection services played an important

role in beekeepers total average annual honey yields, with the majority of beekeepers (69.2 %) being reliant on public transport to get their honey to market. In the EHP the terrain is steep and road access to apiaries can be limited, particularly during the rainy season. Collection of honey represents a considerable increase in cost of production for honey companies in maintaining vehicles and providing collection services. Further compounding the issue of rural isolation is the fact that the majority of beekeepers do not own honey extraction and processing equipment (e.g. buckets with lids, strainers, and funnels). This reduces efficiencies as honey frames and boxes are required to travel to cooperatives in town and then be returned to rural areas where beekeepers live. Where beekeepers can access honey extraction and processing equipment and containers for storage, they may be able to more effectively and efficiently supply honey to local markets. It should also be noted that this consideration may increase the prevalence of honey adulteration and support services are required to enhance harvesting and post harvesting handling and quality assurance to ensure honey quality is not compromised in rural settings.

A solution to the challenge of rural isolation may lay in the formation of beekeeping clubs, whereby extraction and processing equipment, and transport costs could be joint funded. Equipment could be loaned for use in order to generate group savings to repair equipment when malfunctions occur. A similar situation was reported in Nepal, where the formation of beekeeper's associations enabled beekeepers to collect greater quantities of honey which lead to improved market security (Suryahadi *et al*., 2006). In turn, this process also facilitated market confidence in the quality of the honey and improved consistency of supply. Activities like branding and packaging also became feasible and enabled beekeepers to fetch higher prices through the intervention of an organisation working collectively on issues (Suryahadi *et al*., 2006). Social beekeeping networks can also play an important role in providing access to beekeeping equipment where inputs can be borrowed or loaned from one another (Girma & Gardebroek, 2015). However, studies by Wagner *et al*. (2019) in Tanzania also suggests that beekeeping group members may perceive little to no benefit from collective action. Whilst beekeepers may see advantages in joining beekeeping associations in principle (i.e. improved market access; security; knowledge sharing; pooling of resources), beekeeping groups were reported to face a multitude of internal problems related to lack of transparency, leadership, market knowledge, poor honey quality assurance mechanisms, capacity to produce economies of scale and member buy-in to the associations' goals. Reviewing the governance structures of current agricultural clubs in the EHP which are operating effectively and developing beekeeping club pilot studies based on these approaches may be useful in optimising structures and policies for beekeepers in PNG.

4.3 Selection of beneficiaries

Mentioning interest as a reason for starting beekeeping was found to have a significant positive influence on five-year average annual production per hive (kg), five-year average number of bee hives owned and was the only predictor of five-year average percent change in number of beehives owned. Recent studies highlight the importance of having clearly defined mechanisms for targeting the most suitable beneficiaries in order to sustainably support beekeeping in developing countries (Lloyd *et al*., 2016; Lloyd *et al*., 2019; Schouten & Lloyd, 2019; Schouten *et al*., 2019; Wagner *et al*., 2019). For example, Mwakatobe *et al*. (2016) suggest that the success of a four year beekeeping program in Kenya was due to the selection of appropriate beneficiaries (high school students) who, unlike other beekeepers involved in projects in the area, which focused on adults, were 'receptive to novel ideas and ready to get the most out of the training activities'. In Tanzania, beekeeping adoption was contingent upon whether parents had previously kept bees as a livelihood activity and inheritance of hives from parents and acquisition of beekeeping skills from a young age highlighted that tradition can be an important factor in the uptake of beekeeping (Wagner *et al*., 2019). This highlights that in addition to selecting farmers who are enthusiastic, hardworking, eager to learn, who enjoy beekeeping and have good planning skills (Schouten & Lloyd, 2019), family history may be an important consideration in the beneficiary selection criteria for beekeeping development programs.

5 Conclusion

Our findings have important implications for beekeeping industries and apiculture development programs in low and middle-income countries. We identified particular management practices, which could help beekeepers produce and sell more honey, own more colonies and earn more money, thus making beekeeping a more profitable income generating livelihood strategy. Specifically, our results highlight the importance of teaching beekeepers to inspect and supplementary feed their colonies, how to multiply them by making splits, reinvesting back into beekeeping operations, placing bees in more than a single apiary location, owning protective equipment and improving access to honey collection services. Future research could investigate optimal systems for developing social beekeeping support groups, with a focus on ensuring quality control at the farm gate.

Importantly, our results emphasise that beekeeping plays an important role in supporting rural farmers' incomes and that because honey doesn't easily spoil, beekeeping can also contribute to improving resilience and security in times of financial hardship. Our work underlines the need for more research devoted to optimising management practices, as well as efforts to improve the effectiveness, accountability and frequency of beekeeping extension and research to transfer knowledge on approaches which will result in positive outcomes for beekeeping enterprises. Such efforts could help improve the impact of beekeeping as an effective tool to achieve sustainable development and help rural communities improve their livelihoods.

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Disclosure statement

No potential conflicts of interest are reported by the authors.

References

Abrol, D. (2016). Current scenario of beekeeping in India-challenges and opportunities. *Beneficial Insect Farming-Benefits and Livelihood Generation*, 11, 1–44.

Aksoy, A., Demir, N., & Bilgiç, A. (2018). A study on identifying the effectiveness of the beekeeping grants provided by IPARD program: examples of Erzurum, Kars and Agri provinces. *Costs and Agriculture Online*, 14(3), 269–283.

Allsopp, M. H., De Lange, W. J., & Veldtman, R. (2008). Valuing insect pollination services with cost of replacement. *PloS one*, 3(9), e3128.

Anderson, M. B., Brown, D., & Jean, I. (2012). Time to Listen - Hearing People on the Receiving End of International Aid: CDA Collaborative Learning Projects, 1–45.

Austin, A., Schouten, C. N., Hinton, J., & Lloyd, D. J. (2020).. Barriers to Women's Participation in Beekeeping in Papua New Guinea. *Bee World*, 1–5. doi:10.1080/0005772X.2020.1818465

Burnham, K. P., & Anderson, D. R. (2002). A practical information-theoretic approach. Model selection and multimodel inference, 2nd ed. Springer, New York.

Bradbear, N. (2009). Bees and their role in forest livelihoods: a guide to the services provided by bees and the sustainable harvesting, processing and marketing of their products. *Non-wood Forest Products* (19).

Cortopassi-Laurino, M., Imperatriz-Fonseca, V. L., Roubik, D. W., Dollin, A., Heard, T., Aguilar, I., . . . Nogueira-Neto, P. (2006). Global meliponiculture: challenges and opportunities. *Apidologie*, 37(2), 275–292.

Coughlan, P., & Coghlan, D. (2002). Action research for operations management. *International journal of operations & production management*, 22(2), 220–240.

Crane, E. E. (1999). The world history of beekeeping and honey hunting. Routledge.

de Figueiredo Junior, H. S., Meuwissen, M. P., Van Der Lans, I. A., & Lansink, A. G. O. (2017). Beyond upgrading typologies–In search of a better deal for honey value chains in Brazil. *PloS one*, 12(7).

Engindeniz, S., Ucar, K., & Basaran, C. (2014). Economic Aspects and Problems of Beekeeping in Izmir, Turkey. *Agricultural Economics Journal*, 20(2), 113–120.

Famuyide, O., Adebayo, O., Owese, T., Azeez, F., Arabomen, O., Olugbire, O., & Ojo, D. (2014). Economic contributions of honey production as a means of livelihood strategy in Oyo State. *International Journal of Science and Technology*, 3(1), 5–11.

Gebrehiwot, N. T. (2015). Honey production and marketing: the pathway for poverty alleviation the case of Tigray Regional state, Northern Ethiopia. Zenith International *Journal of Business Economics & Management Research*, 5(6), 342–365.

Girma, J., & Gardebroek, C. (2015). The impact of contracts on organic honey producers' incomes in southwestern Ethiopia. *Forest Policy and Economics*, 50, 259–268.

Gratzer, K., Susilo, F., Purnomo, D., Fiedler, S., & Brodschneider, R. (2019). Challenges for beekeeping in Indonesia with autochthonous and introduced bees. *Bee world*, 96(2), 40–44.

Gupta, R. K., Reybroeck, W., van Veen, J. W., & Gupta, A. (2014). Beekeeping for Poverty Alleviation and Livelihood Security: Springer.

Hinton, J., Schouten, C., Austin, A., & Lloyd, D. (2019). An Overview of Rural Development and Small-Scale Beekeeping in Fiji. *Bee world*, 97(2), 39–44.

Howard, R., & Tchana, M. (2015). Exporting Honey and Beeswax from Africa to Europe (Vol. Guide 4): Bees for Development.

Jeil, E. B., Alexander Yao, S., Kabila, A., & Adjaloo, M. (2019). Livelihood security along beekeeping value chain: lessons from Ghana's beekeeping experience. *GeoJournal*, 1–13.

John, R., Dar, J., Beigh, M., Bhat, M. A., & Dar, I. (2017). Benefit-Cost Analysis of Apiculture Enterprise in District Pulwama and Srinagar. *Int. J. Pure App. Biosci*, 5(4), 51–53.

Johnson, J. B., & Omland, K. S. (2004). Model selection in ecology and evolution. *Trends in ecology & evolution*, 19(2), 101–108.

Jung, C., & Lee, M. (2018). Beekeeping in Korea: Past, Present, and Future Challenges. In Asian Beekeeping in the 21st Century (pp. 175-197): Springer.

King, A., Daniels, J., Lim, J., Cochrane, D., Taylor, A., & Ansermino, J. (2010). Time to listen: a review of methods to solicit patient reports of adverse events. *BMJ Quality & Safety*, 19(2), 148–157.

Lal, R., Sharma, S., Sharma, J., Sharma, V., & Singh, D. (2012). Impact of Beekeeping Training on Socio-economic Status of Farmers and Rural Youths in Kullu and Mandi Districts of Himachal Pradesh. *Journal of Human Ecology*, 39(3), 205–208.

Legesse, G. Y. (2014). Review of progress in Ethiopian honey production and marketing. *Livestock Research for Rural Development*, 26(1), 1–6.

Lloyd, D., Schouten, C., Somerville, D., & Roberts, J. (2019). Novel Approaches for Increasing Participation in the Honeybee Industries of the Pacific. Retrieved from https://www.aciar.gov.au/project/LS-2017-100.

Lloyd, D., Somerville, D & Schouten, C. (2016). Using *Apis mellifera* and *Apis cerana* in Landless and Subsistence Communities in Timor-Leste and Indonesia. Report for the Australian Centre for International Agricultural Research (ACIAR).

Lowore, J. (2020). Understanding the Livelihood Implications of Reliable Honey Trade in the Miombo Woodlands in Zambia. *Frontiers in Forests and Global Change*, 3, 28.

Lowore, J., & Bradbear, N. (2013). Beekeeping Economics in Uganda. *Bees for Development Journal*, 108.

Mogni, F., Tresoldi, C., Senesi, S., Palau, H., & Vilella, F. (2009). Sustainable development in food and agribusiness: application of the theoretical model to the Argentine beekeeping sector. Paper presented at the VII International Pensa Conference.

Nazzi, F., Annoscia, D., Del Fabbro, S., & Del Piccolo, F. (2014). Research and education for sustainability in a beekeeping project in sub-Saharan Africa. *Environment, development and sustainability*, 16(3), 619–632.

Okpokiri, C. I., Nwachukwu, I. N., & Onwusiribe, C. N. (2015). Determinants and profitability of honey production in ikwuano local government area, Abia State, Nigeria. *Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development*, 15(3), 211–216.

Ojo, I., Omokore, D., Auta, S., Yakubu, L., & Hiikyaa, A. (2016). Profitability Of beekeeping among women in Ogun State. *Journal of Animal Production Research*, 28(1), 275–282.

Orlegge, W. T., & Gonapa, M. B. (2011). Apiculture Industry Development and Expansion in Papua New Guinea. Contemporary PNG Studies, 14, 51.

Otis, G., & Bradbear, N. (2003). Creating a successful beekeeping development program. *Bee Culture*, 27–32.

Partap, U. (2002). Improving agricultural productivity and livelihoods through pollination: some issues and challenges. Beyond the gene horizon: sustaining agricultural productivity and enhancing livelihoods through optimization of crop and crop-associated biodiversity with emphasis on semi-arid tropical agroecosystems, 118–136.

Pocol, C. B., & McDonough, M. (2015). Women, Apiculture and Development: Evaluating the Impact of a Beekeeping Project on Rural Women's Livelihoods. Bulletin of the University of Agricultural Sciences & Veterinary Medicine Cluj-Napoca. *Horticulture*, 72(2), 487–492

Qaiser, T., Tahir, A., Taj, S., & Murad, A. (2013). Benefit-cost analysis of apiculture enterprise: A case study in district Chakwal Pakistan. *Pakistan Journal of Agricultural Research*, 26(4), 295–298.

Roberts, J. M. K., Schouten, C. N., Sengere, R. W., Jave, J., & Lloyd, D. (2020). Effectiveness of control strategies for *Varroa jacobsoni* and *Tropilaelaps mercedesae* in Papua New Guinea. *Experimental and Applied Acarology*, 80(3), 399–407.

Schouten, C. (2020a). *The five pillars for agricultural development: A case study of beekeeping in Papua New Guinea.* PhD Thesis. Southern Cross University, Lismore, Australia. pp 70-99.

Schouten, C. (2020b). Factors influencing beekeepers income, productivity and welfare in developing countries – a scoping review. *Journal of Apicultural Research*, *In Press.*

Schouten, C., & Lloyd, D. (2019). Considerations and Factors Influencing the Success of Beekeeping Programs in Developing Countries. *Bee World*, 96(3), 75–80.

Schouten, C., Lloyd, D., & Lloyd, H. (2019). Beekeeping with the Asian Honey Bee (*Apis cerana javana* Fabr) in the Indonesian Islands of Java, Bali, Nusa Penida, and Sumbawa. *Bee World*, 96(2), 45–49.

Schouten, C., Lloyd, D., Salminah, M., Ansharyani, I., Somerville, D., & Stimpson, K. (2019). The role of honey hunting in supporting livelihoods in Sumbawa, Indonesia. *Geographical Research*, 58, 64–76. doi:https://doi.org/10.1111/1745-5871.12380.

Shrestha, A. (2018). Study of Production Economics and Production Problems of Honey in Bardiya District, Nepal. *Sarhad Journal of Agriculture*, 34(2), 240–245.

Singh, N., Yadav, V., Raina, V., & Chand, R. (2016). Training needs of Bee keepers in Haryana. *Indian Research Journal of Extension Education*, 11(21), 66–69.

Suryahadi, A., Suryadarma, D., Sumarto, S., & Molyneaux, J. (2006). Agricultural demand linkages and growth multiplier in rural Indonesia. SMERU Research Institute, Working Paper. Accessed on 8/12/19 online from: https://www.academia.edu/download/47414832/Agricultural_Demand_Linkages_and_Growth_20160721-14223-it523d.pdf.

Tamang, N., & Gurung, K. (2015). Honey value chain study in Bhutan: Towards linking smallholder beekeepers to market. International Centre for Integrated Mountain Development (ICIMOD), Kathmandu, Nepal.

Thai, P. H., & Van Toan, T. (2018). Beekeeping in Vietnam. In Asian Beekeeping in the 21st Century (pp. 247-267): Springer.

Thapa, R., Aryal, S., & Jung, C. (2018). Beekeeping and Honey Hunting in Nepal: Current Status and Future Perspectives. In Asian Beekeeping in the 21st Century (pp. 111-127): Springer.

Yap, N., Devlin, J. F., Otis, G., Dang, T. V., & Nguyen, H. T. (2015). Beekeeping, Wellbeing, Transformative Change: Development Benefits According to Small Farmers in Vietnam. *Journal of Rural and Community Development*, 10(1), 19–31.

Yirga, G., Koru, B., Kidane, D., & Mebrahatu, A. (2012). Assessment of beekeeping practices in Asgede Tsimbla district, Northern Ethiopia: Absconding, bee forage and bee pests. *African Journal of Agricultural Research*, 7(1), 1–5.

Zheng, H., Cao, L., Huang, S., Neumann, P., & Hu, F. (2018). Current Status of the Beekeeping Industry in China. In Asian Beekeeping in the 21st Century (pp. 129-158): Springer.