Uganda Journal of **Agricultural Sciences**
ISSN: 1026-0919 (Print); 2410-6909 (Online)
Volume 21 Number 2 (2023) pp. 15 – 30
DOI: http://dx.doi.org/10.4314/ujas.v21i2.2

https://www.ajol.info/index.php/ujas

Coffee Berry Moth, *Prophantis smaragdina* (Butler) (Lepidoptera: Pyralidae): Another threat to Robusta coffee, *Coffea canephora* production in Uganda

Kagezi G.H.[1, *], Kyalo G.[2], Twesigye V.[1], Helerimana C.[1], Anyijuka M.[1], Musasizi J.K.[1], Ssenoga G.[1], Kobusinge J.[1], Sseremba G.[1], Arinaitwe G.[1], Niyibigira E.I.[2]

[1] National Coffee Research Institute (NaCORI). [2] Uganda Coffee Development Authority (UCDA).
*Corresponding author. gkagezi@naro.go.ug

Abstract. A structured questionnaire eliciting farmers' knowledge of Coffee Berry Moth (CBM) was administered to 10 coffee farmers selected in the villages surrounding Kaweri. Additionally, 10 coffee trees were assessed for CBM infestation in farmers' gardens and at Kaweri. Half of the farmers knew CBM and >50% of them first observed it on their coffee recently. However, 42.8% of them thought CBM causes no effect on coffee yields. Furthermore, 57.2% of them could identify the pest by the characteristic silk webs and the same percentage was aware that CBM causes more damage during the dry season. Majority (71.2%) of them did not know the effect of shade on its infestation while all of them were not aware of any alternative host for it. Lastly, only 14.2% of the farmers mentioned that they were managing CBM. At plot level, CBM was observed in all the Kaweri sections and farmers' gardens assessed and the infestation was significantly ($p \leq 0.05$) higher at Kaweri than in farmers' gardens. Infestation decreased significantly ($p \leq 0.05$) with increase in pruning and intercropping. The results showed that CBM is gaining economic importance as a pest of Robusta coffee in Uganda. However, limited farmers' knowledge about its management, coupled with scanty literature, points to urgent need for research towards developing integrated management strategies for it.

Keywords: *Coffea canephora*, Coffee-Berry-Moth, Intercropping, *Prophantis-smaragdina*, Pruning.

Introduction

The Coffee Berry Moth (CBM), *Prophantis smaragdina* (Butler) (Lepidoptera: Pyralidae) is a widely distributed coffee pest and has been reported in sub-Saharan Africa, Madagascar, the Indian Ocean islands and some parts of Asia (Waller *et al.*, 2007). This pest species has been existing in Uganda since the 1940's (Ghesquière, 1942) but with low economic importance as in other countries in the East African region (Ndungi, 1994; Lyimo *et al.*, 2004; Magina, 2009; Magina *et al*, 2016). However, it has of recent gained importance and is currently one of the major pests infesting coffee not only in Uganda (Liebig, 2017; Kagezi *et al.*, 2021), but also in the region (Mendesi and Tesfaye, 2009; Mugo *et al.*, 1997, 2011) and elsewhere (Mahdi, 2006; Gaitán *et al.*, 2015; Lavogez, 2017; Biru, 2019).

Female moth lays scale-like eggs singly on or near green berries. They hatch into larvae after 6-7 days and they are about 1.3 cm long when fully grown, pink/red in color, with dark markings. These then bore into the green berries to feed on the seed, starting near the stalk and hollow them out. One larva usually attacks several berries in one cluster. As the larvae move across the berry cluster, they spin a web of silk, thus joining the cluster together and this is the distinctive characteristic of CBM. After 14 days, the larvae fall to the ground and pupate between dry leaves for 6-42 days, depending on conditions. Adult moth is small and golden brown, with a wingspan of about 1.3-2.0 cm and may live for about 14 days (Crowe and Tadesse 1984; Waller *et al*., 2007; Gaitán *et al*., 2015). Damage of the larvae may also lead to secondary infection by the Coffee Berry Disease (CBD) fungus, *Colletotrichum kahawae* (Waller & Bridge). In absence of the green berries, the larvae may also attack the tips of the green branches (Hill, 1975; Crowe and Tadesse 1984).

Damage caused by the *P. smaragdina* has been reported to negatively affect coffee yield (Liebig, 2017) and therefore, has the capacity to cause high losses in coffee. For example, Derron (1977) reported that the moth destroyed up to 80% of the coffee yields in the island of Sao Tome´, Gulf of Guinea. Similarly, Gaitán *et al.* (2015) reported yield losses of more than 25% in eastern Africa whereas, in a study conducted in Karagwe District, Tanzania showed that 17% of the pests observed were CBM (Kubabigamba, 2015). More recently, the management of Kaweri Coffee Plantation Limited, Uganda, reported that the pest had caused an estimated more than 40% in the year 2020 (Kagezi *et al*., 2021).

Furthermore, though, research studies showed that CBM could be present on coffee throughout the year (Mendesi and Tesfaye, 2009), infestation has been reported to be higher during the wet than in dry season (Biru, 2019), as it increases with humidity (Mendesil and Tesfaye 2009). Infestation by CBM has also been observed to be higher at low altitude as compared to high and mid altitude (Chevalier, 1947; Liebig, 2017). Infestation has also been reported to decrease with increasing shade intensity (Biru, 2019). Additionally, apart from coffee (both *Coffea robusta* and *C. Arabica*), the pest has also been reported on a few close relatives of coffee including: - *Rubiaceae* spp., *Tricalysia* sp. (Hill, 1975; Le Pelley, 1959) and *Bertiera zaluzania* (Kaiser *et al*., 2008).

Managing CBM is difficult because, once the berry clusters are webbed, insecticide sprays will not penetrate them (Gaitán *et al*., 2015). However, cultural methods have been used to manage this insect pest. In case of heavy infestation, it is recommended to strip off the infested berry clusters by hand. These materials should them be placed in holes and covered with a fine mesh that prevents the adults from escaping but allowing adult parasitoids to go back to the coffee fields (Gaitán *et al*., 2015). Other cultural practices such as smoking treatments have also been reported to reduce the population density of CBM in comparison to the control (Mahdi et al., 2008). In addition, a number of chemicals including: - fenitrothion, fenthion, fenvalerate, chlorpyrifos and deltamethrine have been recommended for managing this insect pest (Crowe and Tadesse 1984). However, some of these chemical like fenitrothion have been banned from use in Uganda (Otut, 2017) whereas, others belong to class II chemicals that are defined as moderately hazardous (FAO/WHO, 2001). Concoctions of extracts of *Ficus salicifolia* have also been tested experimentally for managing CBM, with some success (Ba-Angood and Al-Sunaidi, 2004). On the other hand, a few natural enemies have been tested for managing CBM but with limited success. For example, *Trichogrammatoidea* sp., an egg parasite (Derron, 1977), parasitoids attacking larvae including: - four species of Braconids, an Ichneumonid, two Tachinids (Ndungi, 1994) and Elasmus sp (Eulophidae: Hymenoptera) (Mahdi *et al*., 2008) as well as entomopathogens such as *Bacillus thuringiensis* (Tapley and Materu, 1961).

Recently, the management of Kaweri Coffee Plantation Limited, Uganda, one of the major commercial coffee plantations in Uganda, reported that CBM had caused an estimated coffee loss of about 40% in the year 2020 (Kagezi *et al.*, 2021). In response, the National Coffee Research Institute (NaCORI) and Uganda Coffee Development Authority (UCDA), conducted a rapid assessment mini study at Kaweri and the surrounding villages to establish the damage levels and farmers' knowledge of CBM.

Materials and Methods

Study Site

This rapid assessment was conducted in Kaweri Coffee Plantation Limited and the surrounding villages to respond to concerns of an outbreak of Coffee Berry Moth (CBM) on coffee by the management of the plantation. The Plantation is located in Naluwondwa parish, Madudu sub-county, Buwekula County, Mubende District at 0°36'59"N 31°28'28" E (Figure 1).

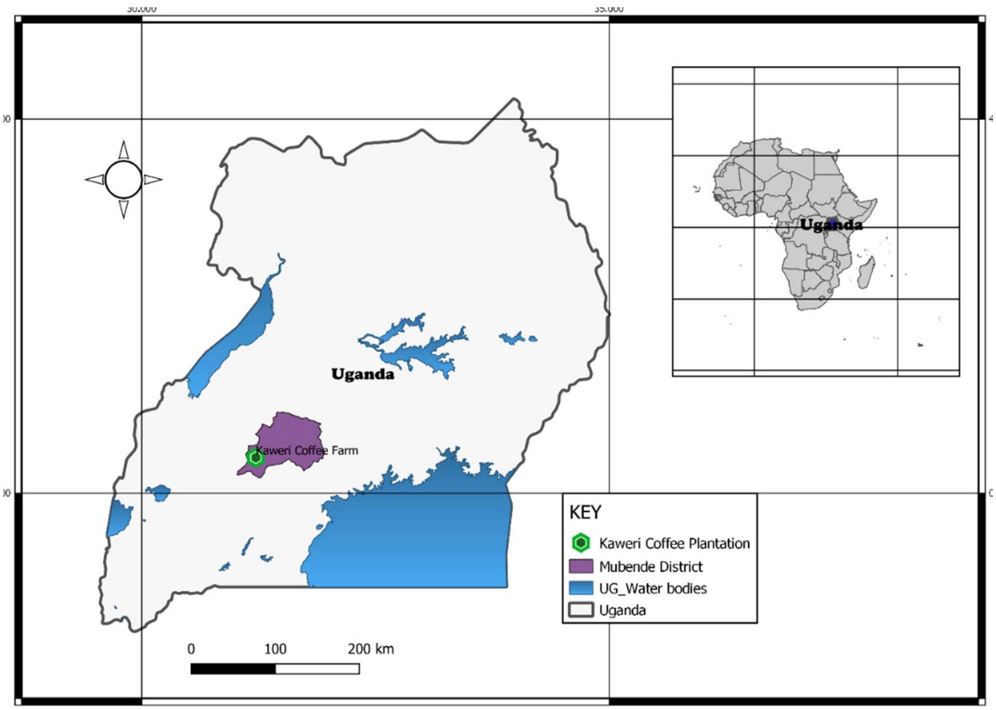


Figure 1. Location of Kaweri Coffee Plantation Limited

It sits on a total area of 2,512 ha of land, of which 80% is arable and can therefore be used for cultivation of coffee (Gissat Techno Consult Ltd, 2001). The main economic activity done this area is agriculture with the major crops grown include: - coffee, bananas, tea, beans, maize, sweet potatoes, and groundnuts while, cattle, goats, sheep, pigs, and poultry are the main livestock. Banana-coffee system is the commonest farming system in the area (NEMA, 2001).

The area receives an average of 1,125 mm, ranging from 875 and 1,250 mm per annum with minimum and maximum temperatures of 15 °C and 25 °C respectively. Furthermore, the area is made up of Pre-Cambrian and Cainozoic rocks overlain by red ferralitic soils and sandy loams characterized by large amounts of iron oxides. The altitude of the area varies between 1,245 and 1,350 m above sea level (Kaweri Coffee Plantation Ltd, 2001). The coffee plantation site and surrounding areas are dominated by savanna vegetation (Obua *et al*., 2005).

Data Collection

A structured questionnaire eliciting farmers' knowledge on the pest status, ecology and management of the Coffee Berry Moth (CBM) on Robusta coffee was administered to 10 randomly selected farmers surrounding Kaweri Coffee Plantation Limited in the sub-counties of Madudu and Kitenga.

In addition, a biological study was conducted in the coffee gardens of five of the farmers that were interviewed as mentioned above. The assessment was also done in the four sections of Kaweri - Kitagweta, Kyamutuma, Luwunga and Nonve. In each sampled garden, 10 coffee trees were randomly selected along a transect. The canopy of each of the selected coffee trees was divided into the upper and lower portions. One primary branch was selected randomly in each of the portions and the number of all the berry clusters and those damaged by CBM was established to compute the percentage damage. One berry cluster was then randomly selected and the number of all berries and those damaged by CBM was established and used to compute the percentage damage. CBM-infested coffee berries are brown/black, dry, hollow and usually webbed together (Crowe and Gebremedhin, 1984; Gaitán *et al*., 2015).

Analysis

Data on farmers' knowledge were entered into Microsoft Excel, cleaned and analyzed using descriptive statistics including: - means and percentages. In addition, the coffee berry cluster and berries damaged by CBM were compared across the four sections at Kaweri Coffee Plantation and between the five coffee gardens in the neighboring villages using analysis of variance (ANOVA) with the general linear model (GLM) procedure. The sections and farms acted as blocks. Means were separated by Tukey's test at 5%. In addition, Chi square analysis was performed to compare the damage caused by the coffee pests and diseases on coffee berry clusters and berries at Kaweri and the coffee gardens in the villages surrounding villages.

Simple linear regression analysis was also done to compare the level of plant management (pruning and de-suckering) with the damage caused by the pests and diseases on coffee berries at Kaweri. In addition, the level of field management (intercropping, weeding and shading) was also compared with the percentage of coffee berries infested by pests and diseases using a simple regression. All the analyses were done using Statistical Analysis System (SAS) software (SAS Institute, 2008).

Results

Farmers' knowledge of the Coffee Berry Moth (CBM)

Responses of farmers interviewed in villages surrounding Kaweri Coffee Plantation on their knowledge of Coffee Berry Moth (CBM) are summarized in Table 1.

Table 1. Farmers' knowledge of the bio-ecology and management of the Coffee Berry Moth (%)

Parameters	Respondents
Year when the pest was first observed on the farm	
Never observed on farm	28.6
2017	14.3
2018	14.3
2019	28.6
2020	14.3
Symptoms of damage of the pest	
Farmer does not know	28.6
Silk webs around infested berries	57.2
Brown, black, dry and hollow berries	14.2
Estimated coffee yield losses caused by CBM	
Farmer does not know	28.6
No effect	42.8
<25%	28.6
Season when the highest damage is observed	
Farmer does not know	42.8
Dry season	57.2
Effect of shade on CBM damage	
Does not know	71.4
Increasing	28.6
Management of CBM	
Farmer does not know	71.4
Nothing	14.2
Physical removal of infested berries and burn or bury	14.2

Our results showed that half of the farmers interviewed had knowledge of CBM and, of these, >50% of them mentioned that they first observed CBM in their coffee gardens in the last three years. In addition, 42.8% of these farmers were of the view that the pest had no effect on coffee yields whereas, 57.2% of them could identify the pest by the silk webs it forms around the infested coffee berries.

The study further revealed that farmers were aware of seasonal changes in damage caused by CBM with, 57.2% of those who knew the pest mentioning that it causes more damage on coffee in the dry season. On the other hand, 71.4% of the farmers who knew CBM, did not know the effect of shade on its infestation while, none of them knew alternative host plant species for the pest. Also, 71.4% of the farmers who knew CBM, did not have knowledge of its management, though, 14.2% of them mentioned that they were physically removing infested berries and burning or burying them.

Damage recorded on coffee berry clusters and berries

Table 2 summarizes the percentages of the coffee berry clusters and berries damaged by the CBM at Kaweri Coffee Plantation Limited and the surrounding villages in Mubende district, central Uganda.

Table 2. Percentage of coffee berry clusters and berries damaged by the Coffee Berry Moth at Kaweri Coffee Plantation Limited and the surrounding villages

		Coffee berry clusters (%)	Coffee berries (%)
Section	Kitagweta	48.9±31.7 a	22.5±21.5 a
	Kyamutuma	35.7±32.2 a	10.8±12.9 b
	Luwunga	20.4±24.7 b	7.6±11.8 b
	Nonve	20.1±23.9 b	9.3±13.1 b
	Mean	31.2±30.6	12.6±16.2
	CV	90.80	120.67
	F value	14.36	11.83
	P value	*<.0001*	*<.0001*
Farmer	Farmer 1	7.7±18.8 a	2.8±6.2 a
	Farmer 2	1.1±6.3 b	0.3±2.4 a
	Farmer 3	3.4±16.3 ab	2.0±6.7 a
	Farmer 4	0.3±1.6 b	1.7±7.6 a
	Farmer 5	0.9±5.4 b	0.8±5.0 a
	Mean	2.7±11.8	1.5±5.8
	CV	431.50	384.96
	F value	4.21	1.70
	P value	*0.0025*	*0.1504*

Results showed that CBM was recorded in all the sampled sections of Kaweri as well as the farmers' coffee gardens. The percentage of coffee berry clusters infested by CBM varied significantly ($p<0.05$) across both the sections at Kaweri and farmers' coffee gardens. However, the percentage of CBM-infested berries varied significantly ($p<0001$) for only Kaweri but not, in the farmers' gardens ($p=1504$). On average, 31.2 and 12.6% of the coffee berry cluster and berries respectively, were infested by CBM and for both, the highest infestation was recorded in Kitagweta section (48.9%).

Furthermore, results of the chi squared analysis showed that the percentage of both coffee berry clusters and berries damaged by CBM was significantly ($\chi2=23.96023$, $p<0.001$; $\chi2=8.7383$, $p=0.0031$, respectively) higher at Kaweri Coffee Plantation compared to the farmers' gardens (Table 3).

Table 3. Comparison of percentage of coffee berry clusters and berries damaged by the Coffee Berry Moth at Kaweri Coffee Plantation Limited and the surrounding villages

Site	Coffee berry clusters (%)	Coffee berries (%)
Kaweri Coffee Plantation Limited	31.2±30.6 a	12.6±16.2 a
Farmers' coffee gardens	2.7±11.8 b	1.5±5.8 b
Chi square value	23.9602	8.7383
P value	*<0.0001*	*0.0031*

Effect of plant management on the damage caused by the Coffee Berry Moth (CBM) on Robusta coffee berries

The level of management of the coffee plants in the different sections at Kaweri Coffee Plantation Limited is summarized in Table 4.

Table 4. Level of management of the coffee plants in the various sections at Kaweri Coffee Plantation Limited

Practice	Section	Level of management of the coffee plant (%)			
		Not practiced	*Lowly*	*Moderately*	*Highly*
Pruning	Kitagweta	10	90	0	0
	Kyamutuma	0	50	20	30
	Luwunga	0	50	20	30
	Nonve	0	50	0	50
De-suckering	Kitagweta	20	80	0	0
	Kyamutuma	50	20	0	30
	Luwunga	40	10	0	30
	Nonve	40	10	0	50

The highest percentage of badly managed coffee crops were observed in Kitagweta section – with all the coffee plants either not managed at all or lowly managed. This could have partly contributed to the higher level of CBM in this section as compared to other sections.

In addition, the regression analysis results showed that the percentage of coffee berries infested by CBM decreased with plant management (pruning and de-suckering). However, this relationship was significant (R^2=0.1087, p=0.0378) for pruning but not de-suckering (R^2=0.0403, p=0.2139) (Figure 2). This implies that pruning might be partly influencing damage caused by CBM.

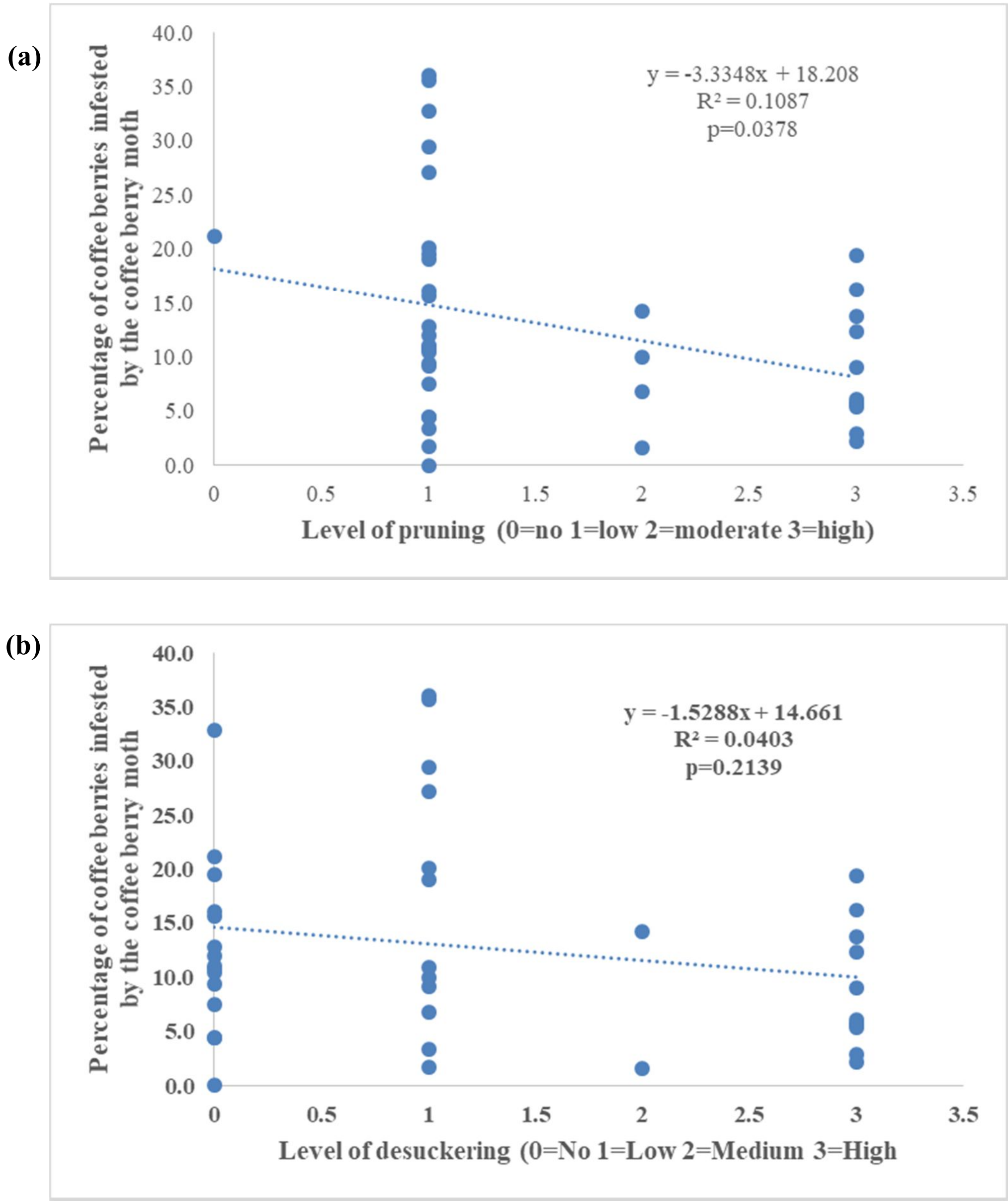
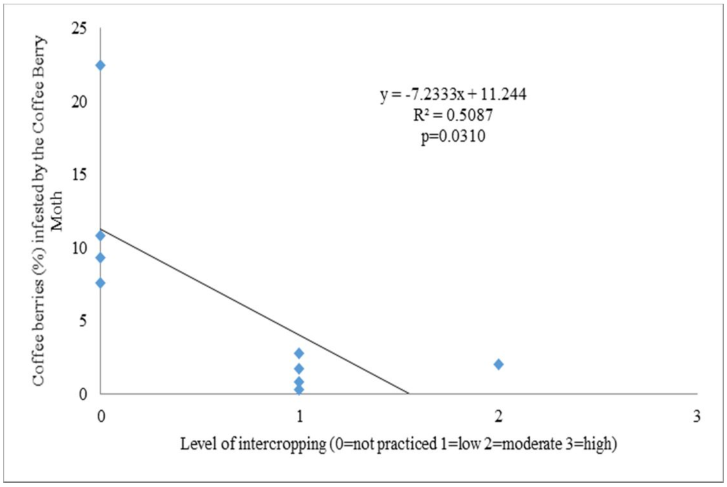


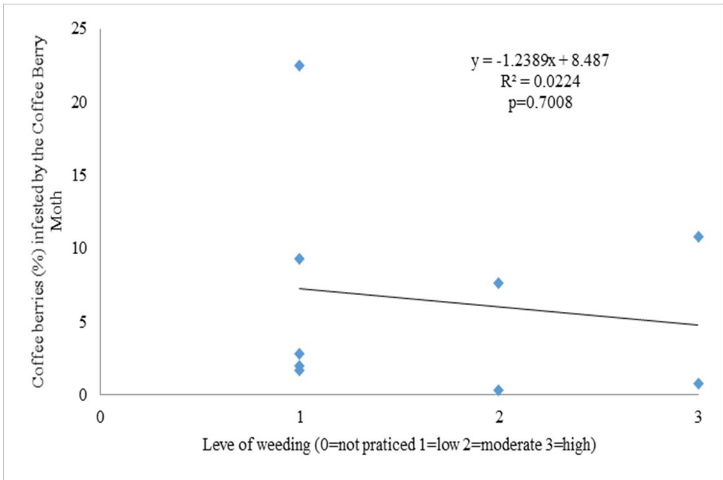
Figure 2. Effect of pruning (a) and de-suckering (b) on the percentage of coffee berries damaged by the Coffee Berry Moth (CBM) at Kaweri Coffee Plantation Limited

Figure 3 shows the effect of intercropping, weeding and shading of Robusta coffee plants on the percentage of coffee berries damaged by the Coffee Berry Moth (CBM) at Kaweri Coffee Plantation Limited, Mubende district, central Uganda. Results of the regression analysis showed that the percentage of coffee berries infested by CBM decreased significantly (R^2=0.5087; p=0.0310) with increasing level of intercropping but not weeding (R^2=0.0224; p=0.7008). On the other hand, the percentage of coffee berries infested by CBM increased with increasing level of shading but not significantly (R^2=0.0945; p=0.4210).

(a)



(b)



(c)

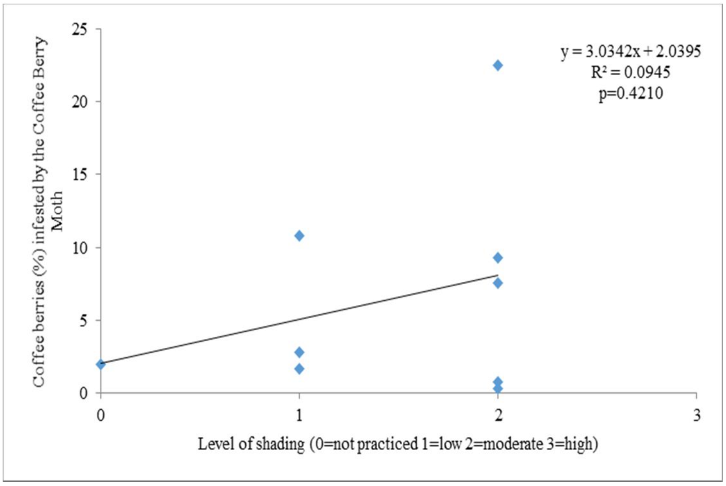


Figure 3. Effect of intercropping (a), weeding (b) and shading (c) of Robusta coffee plants on the percentage of coffee berries damaged by the Coffee Berry Moth at Kaweri Coffee Plantation Limited

Discussion

The success of any program for managing pests depends largely on farmers' motivations, skills and knowledge (Razzagh Borkhani *et al.*, 2013). This is because farmers have their own practices, knowledge, and ideas on how a given problem can be resolved in the most feasible way (Stuiver *et al.*, 2004). It is therefore important to understand the basic knowledge, perception and skills of farmers when developing and implementing sustainable pest and disease management strategies that can be adopted by many farmers (Matteson *et al.*, 1984; Morse and Buhler, 1997; Morales and Perfecto 2000; Liebig *et al.*, 2016). Our results showed that half of the farmers interviewed had knowledge of CBM and this funding agrees with Liebig *et al.* (2016) who also reported that more than half of the Arabica coffee farmers of Mt Elgon region, eastern Uganda knew CBM. Farmers' inability to correctly identify pests could result in indiscriminate application of pesticides resulting in the destruction of beneficial organisms in the ecosystem (Donald, 2004).

Furthermore, results also showed that more than half of those farmers who knew CBM, mentioned that they first observed it on their coffee in the last three years. This implies that this insect pest has just gained economic importance on coffee in the last few years (Liebig, 2017; Kagezi *et al.*, 2021), though, it has been in existence on coffee in the country for some time (Ghesquière, 1942). Our finding is in agreement with reports by the management of Kaweri Coffee Plantation Limited that showed that huge losses (>40%) caused by CBM were just noticed recently – in 2020 (Kagezi *et al.*, 2021). This is supported by the fact that almost half of the farmers were of the view that CBM had no effect on coffee yields. A study conducted in Tanzania also showed that only 4% of the farmers interviewed considered CBM as one of the most important insect pests infesting coffee (Ngowi, 2003). However, Liebig et al. (2016) reported that farmers perceived impact of CBM as intermediate problem affecting coffee productivity in Mt Elgon, Uganda.

Farmers' ability to properly identify insect pests is one of the ways that lead to their successfully control and therefore increase production and productivity (Liebig *et al.*, 2016). Our results showed that more than half of the farmers could identify the pest basing on the silk webs it forms around the infested coffee berries. This symptom is one of the most important distinctive features for CBM (Crowe and Gebremedhin, 1984; Waller et al., 2007). However, none of the farmers knew the most destructive stage of the pest, though examining the life stages as well as the most damaging and vulnerable stage of an insect pest is one of steps in implementing an Integrated Pest Management (IPM) Plan (https://extension.psu.edu/steps-of-integrated-pest-management-ipm). Therefore, understanding the life cycle and behavior of insect pests is the first step to the development of better techniques for their control (Soltani *et al.*, 2008; Goldy, 2012).

In addition, more than half of the farmers also mentioned that CBM causes more damage on coffee in the dry season. However, this finding contradicts experimental results that show that CBM causes more infestation in the wet season (Biru, 2019) due to increase in humidity levels (Mendesil and Tesfaye 2009). Furthermore, none of the farmers knew alternative host plant species for CBM. This could imply that the pest has few alternative plant host species. Research studies have in fact, reported a few close relatives of coffee as alternative hosts of CBM - including: - *Rubiaceae* spp., *Tricalysia* sp. (Hill, 1975; Le Pelley, 1959) and *Bertiera zaluzania* (Kaiser, 2005). Also, majority of the farmers were not aware of the effect of shade on the CBM, though research studies conducted in Ethiopia showed that CBM infestation decreased with increasing shade intensity (Biru, 2019). However, there are conflicting reports on influence of shade on coffee insect pests – some of them are negatively affected by high shade intensities

(Pardee and Philpott, 2011) while others are increased as shade intensities increased (Kucel *et al.*, 2011; Kagezi *et al.*, 2013; Jonsson *et al.*, 2015).

The majority of farmers had no knowledge on how to manage CBM, agreeing with earlier research studies conducted elsewhere on the general management of coffee pests (Aranka *et al.*, 2021). However, this contradicts studies by Liebig *et al.* (2016) that showed that >50% of the Arabica coffee farmers interviewed in the Mt Elgon region, eastern Uganda were using insecticides to manage CBM. Nevertheless, our results showed that a few (14.3%) of the farmers were using cultural practices (physical removal of infested berries and burn or bury) as compared to 3% in Mt Elgon region (Liebig *et al.*, 2016). Limited knowledge on cultural management of pests has been reported to result to heavy infestations within the coffee gardens (Aranka *et al.*, 2021) since, these methods have been recommended for managing pests, especially in cases of heavy infestation (Gaitán *et al.*, 2015). The low knowledge of farmers on the management of CBM therefore calls for more awareness campaigns (Aranka *et al.*, 2021).

On the other hand, the biological assessment showed that 31.2 and 12.6% of the coffee berry clusters and berries respectively, had been infested by CBM at Kaweri Coffee Plantation Limited. This finding is in line with other studies that have reported varying damage levels of CBM ranging between 0.65 and 11.62% in southern Ethiopia (Abedeta *et al.*, 2011). Nevertheless, higher infestation levels by CMB of more than 60% have been reported in Yemen (Ba-Angood and Al-Sunaidi, 2004) whereas, IAR (1981), observed that up to 85% of the coffee berries had been damaged by CBM in southern Ethiopia. Similarly, Mahdi (2006) reported that all the stored coffee grains sampled in Yemen had been infested by CBM. Our results also support reports from the management of the plantation that the moth is becoming a major insect pest at Kaweri and that it had caused a yield loss of about 40% in the year 2020 (Kagezi *et al.*, 2021). Literature shows that though this insect pest has been in existence on coffee in the Uganda and in the region for some time (Ghesquière, 1942), it has been all along considered to be of minor economic importance (Magina, 2009; Lyimo et al., 2004; Magina *et al*, 2016). However, it has recently gained economic importance in Uganda (Liebig, 2017) and elsewhere (Mendesi and Tesfaye, 2009; Mugo *et al.*, 2011; Gaitán *et al.*, 2015). Attacks by the moth has been reported to be more severe, especially in low altitude areas where it caused crop loss in the range of 25-50% (Le Pelley, 1968; Gaitán *et al.*, 2015).

Our results also showed that the damage caused by CBM on coffee berry clusters and berries was significantly ($p<0.001$) higher at Kaweri Coffee Plantation as compared to the farmers' gardens. This could in part be due to the difference in cropping system practices in the two settings. At Kaweri, coffee is grown as a monocrop whereas, coffee in farmers' gardens is grown with numerous plant species including: - bananas, legumes, fruit trees, vegetables, among others. This argument is supported by results of our study that showed that Robusta coffee berries infested by CBM decreased significantly ($p=0.0310$) with increasing level of intercropping. Intercropping increases biodiversity in the coffee agro-system and play a significant role in reducing the impact of pests on coffee (Pumariño *et al.*, 2015; van Asten *et al.*, 2015). For example, Coffee Leaf Miner (Androcioli *et al.*, 2018; Consolação Rosado *et al.*, 2021) and Coffee Berry Borer (Avelino *et al.* (2011). The ecological theory relating to the benefits of mixed versus simple cropping systems revolves around two possible explanations of how insect pest populations attain higher levels in monoculture systems than in diverse ones (Atanu, 2018). The two hypotheses proposed by Root (1973) and they are: - i) the 'enemies hypothesis', that argues that pest numbers are reduced in more diverse systems because the activity of natural enemies is enhanced by environmental opportunities prevalent in complex systems, and ii) the 'resource concentration hypothesis', which argues that the presence of a more diverse flora has direct negative effects on the ability of insect pests to find and utilize the host plant and to remain in the crop habitat. However, there is a need to undertake more detailed studies on the local and landscape scale factors causing outbreaks or resurgences of these insect pests in coffee in Uganda (Vaidya *et al*., 2017). Such information is vital for designing and implementing management options for these pests (Ramirez, 2018).

Furthermore, damage caused by the moth varied significantly ($p<.0001$) across the sections at Kaweri, with the highest values being recorded in Kitagwata section. This could have been due to a number of possible reasons. First, both crop and field management in this section were generally poorly practiced as compared to other sections. This argument is in part supported by the regression analysis results that showed that the level of pruning significantly ($R^2=0.1087$; $p=0.0378$) influenced the percentage of coffee berries infested by CBM. Pruning to open the coffee canopy is one of the cultural methods recommended for managing pests infesting coffee clusters and berries (Waller *et al*., 2007; Aristizábal *et al*., 2017; Kawabata *et al*., 2017). Pruning provides better microclimate that supports survival of natural enemies of most of these pests (Crowe and Tadesse, 1984). Microclimate, particularly humidity, is known to determine largely the development of hyper parasites such as entomopathogenic fungi (Staver *et al*., 2001). Secondly, the coffee in Kitagweta section was weedy – results in this study showed that the percentage of coffee berries infested by CBM decreased with increasing level of level of weeding, though not significantly ($R^2=0.0224$; $p=0.7008$; Figure 3). Weeds may increase 'bushy' conditions in the coffee plantation that may create microclimatic conditions favoring pest infestation (Avelino *et al*., 2004; Pumariño *et al*., 2015), but also some weed species have been reported to harbor coffee pests (Fornaciari *et al*., 2020). Thirdly, Kitagweta section neighbors a woodland that might probably be a source of alternative host plant species for this insect pest. CBM is known to have a few alternative host plant species in Uganda, belonging to the coffee family - woody *Rubiaceae* spp. and a *Tricalysia* sp. (Hill, 1975).

Conclusion

Our study clearly showed that the Coffee Berry Moth is gaining economic importance as a pest infesting Robusta coffee as evidenced at Kaweri Coffee Plantation Limited. Since, it directly attacks coffee berries (beans) and this is the final coffee product for consumption, the damage this moth causes does not affect only yields, but also quality. It was also observed that farmers' knowledge on the bio-ecology and management of this pest is limited. This coupled with scanty literature on CBM in Uganda calls for urgent research to develop integrated management strategies for this insect pest.

Acknowledgement

The authors wish to acknowledge funding for this study from the United States Agency for International Development (USAID)-funded activity "Climate-Smart Agriculture (CSA) Technology Scaling Project". The management of the National Coffee Research Institute (NaCORI) of the National Agricultural Research Organization (NARO) and Uganda development Authority (UCDA) provided logistic support. Last but not least, the management of Kaweri Coffee Plantation Limited and the neighboring farmers are also appreciated for allowing the researchers conduct the study in their coffee gardens.

References

Abedeta, C., Getu, E., Seyoum, E. and Hindorf, H. 2011. Coffee berry insect pests and their parasitoids in the afromontane rainforests of Southwestern Ethiopia. *East African Journal of Sciences* 5(1):41-50.

Androcioli, H.G., Hoshino, A.T., Menezes Júnior, A.O., Morais, H., Bianco, R. and Caramori, P.H. 2018. Coffee leaf miner incidence and its predation bay wasp in coffee intercropped with rubber trees. *Coffee Science* 13:389–400.

Aranka, J., Apis, B., Asiota, B., Bafeo, M., Bekio, J., Curry, G.N., Hamago, M., Inu, S.M., Kiup, E., Koczberski, G., Togonave, P. and Webb, M. 2021. Smallholder farmers' knowledge of coffee pests and diseases in Eastern Highlands Province, Papua New Guinea. *PNG Coffee Journal* 15(1):23-29.

Aristizábal, L.F., Johnson, M., Shriner, S., Hollingsworth, R., Manoukis, N.C., Meyers, R. Bayman, P. and Arthurs, S.P. 2017. Integrated pest management of coffee berry borer in Hawaii and Puerto Rico: current status and prospects. *Insects* 8:123.

Atanu, S. 2018. Role of Intercropping practices in farming system for Insect Pest Management. *Acta Scientific Agriculture* 2.2:8-11.

Avelino, J., Ten Hoopen, G. and deClerck, F.A.J. 2011. Ecological mechanisms for pest and disease control in coffee and cacao agro ecosystems of the Neotropics. In: B. Rapidel, F.A.J. deClerck, J. Le Coq and Beer, J. (Editors), *Ecosystem Services from Agriculture and Agroforestry: Measurement and Payment*. Earthscan Publications, London, UK, pp. 91–117.

Avelino, J., Willocquet, L. and Savary, S. 2004. Effects of crop management patterns on coffee rust epidemic. *Plant Pathology* 53:541-547.

Ba-Angood, S. and Al-Sunaidi, S.M.A. 2004. Assessment of damage caused by the coffee berry moth, *Prophantis smaragdina*, in different flowering and fruit setting dates in Yafe'a area, Republic of Yemen. Yemeni Scientific Research Foundation, Science Conference Sana'a, October 11–13, 2004.

Biru, T.S. 2019. Influence of production system, shade level and altitude on coffee insect pests and blotch miner parasitoids at Gera-Gomma, Ethiopia. MSc thesis. Jimma University College of Agriculture and Veterinary Medicine. 75 pp.

Chevalier, A. 1947. Les caféiers du globe. Fasc. 3: Systématique des caféiers et faux-caféiers maladies et insectes nuisibles, Maladies et Insectes Nuisibles, Paul Lechevalier, Paris. 356 pp.

Crowe, T.J. and Tadesse, G. 1984. *Coffee Pests in Ethiopia: Their Biology and Control*. IAR, Addis Ababa, pp. 45.

da Consolação Rosado, M., Araujo, G.J., Pallini, A, and Venzon, M. 2021. Cover crop intercropping increases biological control in coffee crops. *Biological Control* 160:104675.

Derron, M. 1977. *Prophantis smaragdina* Butler and *Cryptophlebia colivora* Meyrick (Lepidoptera): two important pests on *Coffea arabica* L. on the island of Sao Tome´. *Mitteilungen der Schweizerischen Entomologischen Gesellschaft* 50:149–151.

Donald. P.F. 2004. Biodiversity impacts of some agricultural commodities production systems. *Conservation Biology* 18 (1):17–38.

FAO/WHO, 2001. Amount of Poor-Quality Pesticides Sold in Developing Countries Alarmingly High. Food and Agriculture Organization/World Health Organization (FAO/WHO) press release, 01 February 2001.

Fornaciari, G., Borghi, E.J.A., Vieira, MJ., Aguiar, R.L., Filho, A.C.V., Comério, M., de Carvalho, J.R, Xavier, A.S., Neto, V.B. and de Assis, C.H.B. 2020. Survey of potentially host weeds of *Planococcus* spp. in Coffee crops. *International Journal of Advanced Engineering Research and Science* 7(5):333-337.

Gaitán, A.L., Cristancho, M.A., Castro-Caicedo, B.L., Rivillas, C.A. and Cadena-Gómez, G. 2015. *Compendium of Coffee Diseases and Pests*. The American Phytopathological Society (APS Press), Saint Paul, Minnesota, 79 pp.

Ghesquière, J. 1942. Lépidoptères Microlépidoptères (deuxième partie). - Annales du Musée du Congo belge, Zoologie [3, Arthropodes] section 2, *Catalogues raisonnés* (3)7:121-240.

Gissat Techno Consult Ltd., 2001. Environmental impact Report for Kaweri Coffee Plantation. Final Report, Kampala, Uganda, 67 pp.

Godoy, C., Bergamin Filho, A. and Salgado, C. 1997. Doenças do cafeeiro. In: Kimati, H., Amorin, L., Bergamin Filho, A., Camargo, L.E.A. and Rezende, J.A.M. (Editors.), Manual de fitopatologia: doenças das plantas cultivadas. São Paulo SP. Agronômica Ceres, pp. 184-200.

Hill, D.S. 1975. *Agricultural Insect Pests of the Tropics and their Control.* Cambridge University Press, London, 516 pp.

IAR, 1981. Coffee Department Progress Report for the Period April 1979 to March 1980. IAR, Addis Ababa.

Jonsson, M., Raphael, I.A., Ekbom, B., Kyamanywa, S., and Karungi, J. 2015. Contrasting effects of shade level and altitude on two important coffee pests. *Journal of Pest Sciences* 88:281–287.

Kagezi, G.H., Kucel, P., Kobusingye, J., Nakibuule, L., Wekhaso, R., Ahumuza, G., Musoli, P., Kangire, A., 2013. Influence of shade systems on spatial distribution and infestation of the black coffee twig borer on coffee in Uganda. *Uganda Journal of Agricultural Sciences* 14:1–12.

Kagezi, G.H., Kyalo, G., Helerimana, C., Twesigye, V., Musasizi J.K., Anyijuka, M. and Ssenoga, G. 2021. *A Rapid Assessment of the Coffee Berry Moth, Prophantis smaragdina (Butler) (Lepidoptera: Pyralidae) on Robusta Coffee at Kaweri Coffee Plantation Ltd and Surrounding Villages in Mubende District, Uganda*. A technical report submitted to Kaweri Coffee Plantation Limited, National Coffee Research Institute (NaCORI) and Uganda Coffee Development Authority (UCDA). 31 pp.

Kaiser, C.N., Hansen, D.M. and Mŭller, C.B. 2008. Exotic pest insects: another perspective on coffee and conservation. *Oryx* 42:143-146.

Kawabata, A.M., Nakamoto, S.T. and Curtiss, R.T. 2017. Recommendations for Coffee Berry Borer Integrated Pest Management in Hawai'i 2016. UH-CTAHR, IP-41, Honolulu, HI.

Kaweri Coffee Plantation Ltd. 2001. Kaweri Coffee Plantation Master Plan, 72 pp.

Kubabigamba, J. 2015. Impacts of Climate Change on Coffee Production: A Case of Karagwe District. MSc thesis. The University of Dodoma, 126 pp.

Kucel, P., Egonyu, J.P., Kagezi, G. and Musoli, P.C. 2011. Shade and varietal effects on diversity and prevalence of insect pests of Robusta coffee in central Uganda. CAFNET End of Project Report, 10 pp.

Lavogez, O. 2017. Biologie et écologie chimique de la pyrale du café *Prophantis smaragdina* (Lepidoptera, Crambidae, Spilomelinae) pour la mise au point d'une méthode de biocontrôle. Sciences agricoles. Université de la Réunion, 2017. Français. ffNNT: 2017LARE0034ff. fftel-01786009f.

Le Pelley, R. H. 1968. *Pests of Coffee*. Longmans, Green and Co., Ltd., London. 590 pp.

Le Pelley, R.H. 1959. *Agricultural Insects of East Africa*. East African High Commission, Nairobi, 307 pp.

Liebig, T., Jassogne, L., Rahn, E., Läderach, P., Poehling, H-M., Kucel, P., Van Asten, P. and Avelino, J. 2016. Towards a collaborative research: A case study on linking science to farmers' perceptions and knowledge on Arabica coffee pests and diseases and its management. *PLoS ONE* 11(8):

Liebig, T.I. 2017. Abundance of Pests and Diseases in Arabica Coffee Production Systems in Uganda-Ecological Mechanisms and Spatial Analysis in the face of Climate Change; PhD thesis. Universität Hannover, Hanovre, Germany, 135 pp.

Lyimo, S.D. and Owenya, M.Z. 2004. Farmers' Assessment of Improved Coffee Hybrids in Northern Tanzania. Paper presented to the Coffee Release Committee Meeting held at TaCRI Lyamungu, Ministry of Agriculture and Food Security Directorate of Research and Development, March 04, 2004.

Magina, F.L., Kilambo, D.L., Maerere, A.P. and Teri, I.J.M. 2016. Innovative Strategies for Control of Coffee Insect Pests in Tanzania: A Review. *Journal of the Open University of Tanzania* 22:1–9.

Magina, F.L.K. 2009. Spatial distribution and temporal abundance variations of three important insect pests of coffee in Kilimanjaro Region, Tanzania. MSc thesis. Sokoine University of Agriculture, Morogoro, Tanzania, 88 pp.

Mahdi, H.A.S. 2006. Survey of coffee insects under traditional storage conditions in Yemen. Ninth Arab Congress of Plant Protection, Damascus, Syria, November 19-23, 2006.

Mahdi, H.S., Al Hakimim, A., Mahyoub, M., Sayef, A., Al Shargabi, S. and Pelat, F. 2008. The traditional methods of integrated pest management: a promising strategy to reduce population density of coffee berry moth, Prophantis smaragdina (Butler) (Pyralidae: Lepidoptera) in the field. *Journal of King Abdulaziz University Meteorology, Environment and Arid Land Agriculture Sciences* 19: (1).

Matteson, P.C., Altieri, M.A. and Gagne´, W.C. 1984. Modification of small farmer practices for better pest management. *Annual Review of Entomology* 29:383-402.

Mendesil, E. and Tesfaye, A. 2009. The influence of weather on the seasonal incidence of coffee berry moth, *Prophantis smaragdina* (Butler). *Journal of Asia-Pacific Entomology* 12:203–205.

Mendesil, E., Jembere, B. and Seyoum, E. 2004. Population dynamics and distribution of coffee berry borer, *Hypothenemus hampei* (Ferrari) (Coleoptera: Scolytidae) southwestern Ethiopia. SINET: *Ethiopian Journal of Sciences* 27:127-134.

Morales, H. and Perfecto, I. 2000. Traditional knowledge and pest management in the Guatemalan highlands. *Agriculture and Human Values* 17:49-63.

Morse, S. and Buhler, W. 1997. *Integrated Pest Management: Ideals and Realities in Developing Countries*. Boulder, Colorado: Lynne Rienner Publishers

Mugo H.M., Irungu L.W. and Ndegwa P.N. 2011. The insect pests of coffee and their distribution in Kenya. *International journal of Science and Nature* 2(3):564-569.

Mugo, H.M., Omondi, G.O. and Ndugo, S.M. 1997. Biological control of coffee insect pests in Kenya. 17th International Scientific Colloquium on Coffee. Nairobi, Kenya, July 20–25. 1997.

Ndungi, A.W. 1994. New natural enemies of the coffee berry moth, *Prophantis smaragdina* (Butler) in Kenya. *Kenya Coffee* 59 (688):1725-1726

NEMA, 200I. State of the Environment Report for Uganda 2000-200I. National Environment Management Authority (NEMA), Kampala, Uganda. 153 pp.

Ngowi, A.V.F. 2003. A study of farmers' knowledge, attitude and experience in the use of pesticides in coffee farming. *African Newsletter on Occupational Health and Safety* 13:62.

Obua, J., Eilu, G., Agea, J.G., and Sekindi, S. 2005. Plant species diversity in a changing agricultural landscape: the case of Kaweri Coffee Plantation, Central Uganda. *Uganda Journal of Agricultural Sciences* 11:20-25.

Otut, A. 2017. Obsolete and Banned Pesticides. Ministry of Agriculture, Animal Industry and Fisheries (MAAIF), Uganda.

Pardee, G.L. and Philpott, S/M. 2011. Cascading indirect effects in a coffee agro ecosystem: effects of parasitic phorid flies on ants and the coffee berry borer in a high-shade and low-shade habitat. *Environmental Entomology* 40:581–588.

Pumariño, L, Sileshi G.W., Gripenberg, S., Kaartinen, R., Barrios, E., Muchane, M.N., Midega, C. and Jonsson, M. 2015. Effects of agroforestry on pest, disease and weed control: A meta-analysis. *Basic Applied Ecology* 16:573–582.

Ramirez, S.E. 2018. Effects of local and landscape scale factors on ant diversity and bio control of the coffee berry borer in Colombia. PhD Dissertation. University of Göttingen, Germany. 111 pp.

Razzagh Borkhani, R., Rezvanfar, A., Fami, H.S. and Pouratashi, M. 2013. Social factors influencing adoption of integrated pest management (IPM) technologies by paddy farmers. *International Journal of Agricultural Management and Development* 3:211–218.

Root, R.B. 1973. Organization of a plant-arthropod association in simple and diverse habitats: the fauna of collards (*Brassica oleraceae*). *Ecological Monographs* 43:94-125.

SAS Institute. 2008. SAS/STAT Software: Version 9.2, SAS Institute Inc., SAS Campus Drive, Cary, North Carolina 27513.

Soltani, R., Chaieb, I. and Ben Hamouda, M. 2008. The life cycle of the root borer, *Oryctes agamemnon*, under laboratory conditions. *Journal of Insect Science* 8:61.

Staver, C., Guharay, F., Monterroso, D., and Muschler, R. 2001. Designing pest-suppressive multistrata perennial crop systems: shade-grown coffee in Central America. *Agroforestry System* 53:151–170.

Stuiver, M., Leeuwis, C., and van der Ploeg, J.D. 2004. The power of experience: farmers' knowledge and sustainable innovations in agriculture. In: J.S.C. Wiskerke and van der Ploeg, J.D. (Editors), *Seeds of Transition. Essays on Novelty Production, Niches and Regimes in Agriculture*. Assen, The Netherlands: Royal van Gorcum, pp. 93-118.

Tapley, R.G. and Materu, M.E.A. 1961. Microbial control of lepidopteran coffee pests. *Kenya Coffee* 26:213.

Vaidya, C., Cruz, M., Kuesel, R., Gonthier, D.J., Iverson, A., Ennis, K.K. and Perfecto, I., 2017. Local and landscape constraints on coffee leafhopper (Hemiptera: cicadellidae) diversity. *Journal of Insect Science* 17(2):38.

van Asten, P., Ochola, D., Wairegi, L., Nibasumba, A., Jassogne, L. and Makusa, D. 2015. Coffee-Banana Intercropping: Implementation guidance for policymakers and investors. Climate-Smart Agriculture Practice Brief. Copenhagen, Denmark: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), 11 pp.

Waller, J.M. Bigger, M. and Hillocks, R. J. 2007. *Coffee Pests, Diseases and Their Management*. CABI, UK pp. 434.