International Journal of Sciences: Basic and Applied Research (IJSBAR)

ISSN 2307-4531
(Print & Online)

https://gssrr.org/index.php/JournalOfBasicAndApplied/index

Within-Canopy Distribution of Incidence and Damage of Pests and Diseases of Robusta Coffee, *Coffea Canephora* and Implications for their Management

Winnie Nanjego[a], Godfrey H. Kagezi[b]*, Samuel Kyamanywa[c], Judith Kobusinge[d] ,Geofrey Arinaitwe[e]

[a,b,d,e]*National Coffee Research Institute (NaCORI), National Agricultural Research Organisation (NARO), P.O. Box 185 Mukono, Uganda*

[c]*Makerere University, P.O. Box 7062, Kampala, Uganda*

[a]*Email: winnie.nanjego@gmail.com*

[b]*Email: gkagezi@gmail.com*,[c]*Email: skyamanywa@gmail.com*

[d]*Email: judithkobusinge24@yahoo.com*,[e]*Email: aggarinaitwe@gmail.com*

Abstract

Due to its perennial and robust vegetative growth nature, the Robusta coffee harbors a diversity of pests and diseases that are not necessarily evenly distributed within the coffee canopy and this has management implications. We thus, conducted a study in a Kaweri Coffee Plantation Limited in central Uganda to determine the distribution of incidence and damage caused by the pests and diseases within the Robusta coffee canopy. In each of the four section of plantation (Kitagweta, Kyamutuma Luwunga and Nonve), a plot measuring 100 x 100 m was demarcated and 20 Robusta coffee trees were systematically selected along two diagonals in each of the plots. All the stems on each of the selected coffee tree were assessed for pest and disease incidence and damage on the leaves, berry clusters and berries. The coffee canopy was divided into three sections (lower, middle and upper) and incidence and damage of the pests and diseases were determined on coffee leaves, berry clusters and berries. Results showed that the pests and diseases were not evenly distributed within the canopy.

Received: 12/23/2023
Accepted: 2/23/2024
Published: 3/3/2024

* Corresponding author.

On the leaves, the incidence and damage caused by *Leucoptera coffeella*, *Leucoplema dohertyi* and *Hemilleia vastatrix* varied significantly ($p \leq 0.05$) across the canopy sections, with the highest levels (23.1, 36.1 and 30.5%) being recorded in the lower section. On the other hand, though the damage caused by *Epicampoptera andersoni* and the leaf eating beetles was not significantly ($p \geq 0.05$) different within the canopy, the highest infestation was recorded in the upper (26.9%) and middle (19.3%) sections, respectively. For the berry cluster, only damage caused by *Planococcus* spp. varied significantly ($p=0.0188$) across the canopy, with the highest infestation (18.6%) being recorded in lower section. However, incidence and damage caused by *Prophantis smaragdina* and *Cercospora coffeicola* were not significantly ($p \geq 0.05$) different within the canopy but, the highest levels were recorded in the upper section of the canopy (15.8 and 24.4%, respectively). On the coffee berries, the incidence and damage of both *Hypothenemus hampei* and *Cercospora coffeicola* did not significantly ($p \geq 0.05$) across the canopy sections but the highest levels were recorded in the lower (28.5%) and upper (20.7%), respectively. Our findings enlightened the understanding of the vertical distribution of the incidence and damage of pest and disease within the Robusta coffee canopy. This information will contribute to developing and implementing monitoring techniques and regimes as well as ecologically-informed management strategies for these pests and diseases.

Keywords: Dynamics; ecologically-informed; *Hemilleia-vastatrix*;*Leucoplema-dohertyi*; *Leucoptera-coffeella*; *Planococcus*-spp; variation.

1. Introduction

Robusta coffee (*Coffea canephora*) contributes over 80% of Uganda's total production as well as export volume [1]. The country accounts for 7% of global *C. canephora* exports and the whole coffee sector provides a livelihood for about 8 million people [2]. The sustainability of Ugandan *C. canephora* production is thus of major national and global importance, particularly for smallholder farmers [3]. However, despite its socioeconomic importance, the current farm productivity of 0.6 kg of clean coffee per tree (kgcc/tree) of Robusta coffee [1, 4] is far below that of the newly released improved Coffee Wilt Disease resistant (CWD-r) Robusta coffee varieties. For example, the NARO KR10 variety yields 4.8kgcc/tree [5]. The sustainability of the Robusta coffee industry in Uganda is therefore threatened by various challenges with pests and diseases, particularly, the Black Coffee Twig Borer (BCTB), *Xylosandrus compactus* (Eichhoff) being partly prominently responsible for this observed yield gap [4]. Due to its perennial and robust vegetative growth nature – tall with irregular structure and multi-caulate stems [6, 7], the Robusta coffee canopy can harbor diversity of pests and diseases. These include, *X. compactus*, coffee berry borer (CBB), *Hypothenemus hampei* (Ferrari), coffee leaf skeletonizer, *Leucoplema dohertyi* (Warren), tailed caterpillar, *Epicampoptera andersoni* (Tams), leaf eating beetles, coffee berry moth, *Prophantis smaragdina* (Butler), mealybugs, *Planococcus* spp., coffee leaf miner, *Leucoptera coffeella* (Guérin-Mèneville & Perrottet), coffee wilt disease (CWD), *Fusarium xylarioides*, coffee leaf rust (CLR), *Hemileia vastatrix* and red blister disease (RBD), *Cercospora coffeicola* (B. & CKE.) [8, 9]. However, these pests and diseases may not be evenly distributed within plant canopies and their movements depend on the level of connectedness between plant organs [10]. The population, incidence and damage caused by some pests and diseases, for example, *X. compactus* on coffee [11] and on southern magnolia, *Magnolia grandiflora* [12] as well as *H. hampei* and *H. vastatrix* on coffee [13, 14] have been reported to be higher in the lower section of the canopy. On the other hand, pests such as the white mango scale, *Aulacaspis tubercularis* and the neotropical brown stink bug, *Euschistus heros* adults have been reported to be more abundant in the middle canopy of mango [15] and cotton canopies [16], respectively. But, incidence and damage of some pests and diseases have been reported to higher in the middle canopy, for example, the larvae of the avocado seed moth, *Stenoma catenifer* on avocado trees [17], the Swiss needle cast disease, *Nothophaeocryptopus gaeumannii* on Douglas-fir [18] and leaf spotting disease, *Pyrenophora tritici* on wheat plant [19]. Other authors have reported no difference in the distribution of the incidence and damage caused by pests and diseases within the canopy. For example, *L. coffeella* on coffee [20] and the almond bark beetle, *Scolytus amygdali*, on almond orchards [21]. Understanding the distribution of these pests and diseases within the coffee tree canopy is therefore vital for developing and implementing monitoring techniques and regimes as well as ecologically-informed management strategies [22]. Management options such as phyto-sanitary, spraying with pesticides or bio-pesticides and trapping with lures should target the canopy sections with the high incidence and damage of these pests and diseases. This could reduce labor as well as amounts of pesticides used and thus, costs and risks to human beings and environment in general [10, 11]. However, such studies on Robusta coffee are limited in Uganda, apart from *X. compactus* [11]. We therefore conducted a study to determine the distribution of incidence and damage caused by the pests and diseases within the Robusta coffee canopy.

2. Materials and Methods

2.1 Study site

The study was conducted on Robusta coffee in the four sections (Kitagweta, Kyamutuma Luwunga and Nonve) of Kaweri Coffee Plantation Limited. The plantation is located in Naluwondwa parish, Madudu sub-county, Buwekula county, Mubende District, central Uganda at 0°36'59"N 31°28'28" E (Fig. 1). It lies at an average of 1,300 meters above sea level (a.s.l) and receives an average of 1,125 mm (range: 875 and 1,250 mm) per annum of rain, with minimum and maximum temperatures of 15 °C and 25 °C respectively. The soils are red ferralitic and sandy loams, characterized by large amounts of iron oxides [23]. The plantation is located on an area of 2,512 hectares of which 1,570 hectares are covered by Robusta coffee grown as a single crop under natural or planted shade trees [24].

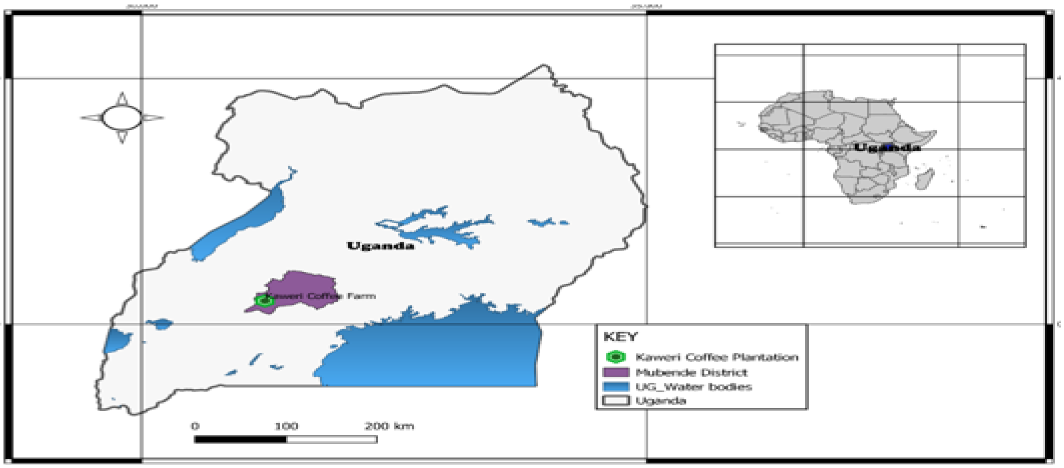

Figure 1: Location of Kaweri Coffee Plantation Limited in Naluwondwa parish, Madudu sub-county, Buwekula County, Mubende District, central Uganda

Source: Nanjego et al. (in press)

2.2 Data collection

In each of the four sections of the plantation, a plot measuring 100 x 100 m (1 hectare) was demarcated. Twenty (20) Robusta coffee trees were systematically sampled along two cross diagonal transects running the full length of the demarcated plot (one running from left to right and the other one from right to left). In each diagonal, 10 trees were selected every after 14 m, derived from dividing the length of the diagonal (141 m) and the number of required trees (10). All the stems on each of the selected coffee tree were assessed for pest and disease incidence and damage on the leaves, berry clusters and berries. The canopy of each sampled coffee stem was divided into three imaginary sections– upper, middle and lower [6, 25] and each canopy section was assessed separately. One primary branch (twig) was then randomly selected in each of the three canopy sections for assessment. The total number of leaves as well as those damaged by *L. coffeella, L. dohertyi, E. andersoni*, leaf eating beetles, *C. coffeicola* and *H. vastatrix* was established and used to estimate the percentage incidence and damage. Then, the number of berry clusters on each of the selected primary branch as well as those damaged by *Planococcus* spp., *P. smaragdina* and *C. coffeicola* was established and used to calculate their percentage incidence and damage. One berry cluster was then randomly selected from the sampled berry cluster and the total number of berries as well as those damage by *H. hampei* and *C. coffeicola* was established and used to estimate their incidence and damage.

2.3 Statistical analysis

Percentage incidence and damage were compared across the Robusta coffee sections using analysis of variance (ANOVA) with general linear model (GLM) procedure of Statistical Analysis System (SAS) software [26]. Means were separated by Tukey's test at 5%.

3. Results and Discussion

3.1 Distribution of damage caused by pests and diseases on leaves of Robusta coffee

Table 1 below shows that the damage caused by the coffee leaf miner (CLM), *L. coffeella*, on Robusta coffee leaves varied significantly (p=0.0002) within the canopy sections. The highest infestation (23.1%) was recorded in the lower section of the canopy while the lowest (13.5%) was in the upper section of the canopy. Our finding agrees with [27], who recorded higher damage of *L. coffeella* in the lower portions of the coffee canopy while, [28] and [29] reported higher abundance of the leaf miner in lower-canopy leaves of two oak species, *Quercus geminate* and *Q. laevis*. This could in part due to the fact that selection of the oviposition site by the female *L. coffeella* may be highly influenced by variation in the structure [30], age and size [31] as well as chemistry [32] of the leaves. In fact, the leaves located in the lower canopy portion contain less tannins [28, 33] and therefore more attacked by the miners since increased tannin concentration has been reported to negatively affect the growth of lepidopteron caterpillars [34]. The ability of tannins to form complexes with proteins enhances defense mechanism of plants and thereby affecting the growth of insects [35]. Since leaf quality is a major determinant of host choice by many herbivores [36, 37], its variation is expected to influence leaf-miner distribution, abundance and survivorship [29]. Research studies further show that young coffee leaves contain more secondary metabolites such as phenolic compounds [38] and these may offer protection to these leaves against herbivory by the leaf miners [39]. Our results further showed that the damage caused by the coffee leaf skeletonizer, *L. dohertyi*, varied significantly (p<.0001) within the Robusta coffee canopy. The highest infestation (36.1%) was recorded in the lower section whereas, the lowest (19.1%) was observed in the upper section of the coffee canopy (Table 1). This could in part be due to the fact that the lower portion of the coffee canopy is more shaded than the upper portion due to self-shading of the coffee [40] since the incidence of *L. dohertyi* has been reported to increase with increase in shade intensity or canopy [22]. This argument is also supported by a study conducted by [41] that observed higher damage by this insect pest on coffee grown in a dense contiguous forest than in less-shaded forest patches in southwestern Ethiopia. This self-shading provides conducive microenvironment for the reproduction, development and survival of the leaf miners through reduction of maximum daily temperatures as well as protecting them from direct impact of rainfall by providing partial shelter [42]. In addition, the incidence of coffee leaf rust (CLR), *H. vastatrix* on Robusta coffee leaves also varied significantly (p=0.0049) within the coffee canopy, with the highest infection (30.5%) being recorded in the lower while the lowest (21.3%) in the upper section of the coffee canopy (Table 1). Similarly, [13,43,44] observed higher *H. vastatrix* severity on leaves located at lower coffee strata. This could in part be due to the fact the self-shading coffee in the lower section of the coffee canopy [40] might alter a number of conditions such as reducing amount of light and temperature as well as increasing leaf area, leaf wetness and soil moisture [13]. All these in turn favor germination and penetration of the *H. vastatrix* urediniospore into the leaves [45]. The self-shading also increases survival of the leaves [46], and thereby the lifespan of sporulating lesions. This results in maintaining stocks of inoculum in the canopy [47], rendering leaves more susceptible to infection. Research studies further show that the less through-fall that reaches the lower sections of the coffee tree [48] prevents wash-off of sporulating lesions, thus, maintaining the viable inoculum stock at the lower tree canopy section [49]. However, the damage caused by the tailed caterpillar, *E. andersoni* on coffee leaves did not significantly (p=0.4972) vary within the coffee canopy but, the highest infestation (26.9%) was recorded in the upper section of the canopy whereas, the lowest (24.3%) was in the lower section of the coffee canopy (Table 1). Our finding supports laboratory studies by [50] that showed that the larvae of another lepidopteran, the forest tent caterpillar, *Malacosoma disstria* (Lepidoptera: Lasiocampidae) consumed more surface area from leaves collected in the upper crown section of the trees. Similarly, [51] reported that leaf biomass removed by herbivores was significantly higher in the upper than lower crown within an Australian rain forest tree. This could in part be due to the fact that herbivores usually prefer young expanding leaves in the upper canopy, because they have higher nutritional value and lower toughness than mature leaves [52]. Higher total nitrogen found in leaves from the upper tree crown could therefore explain the higher performance of this insect [50].

Table 1: Variation of incidence and damage of pests and diseases on leaves within the canopy of Robusta coffee, Coffea canephora at Kaweri Coffee Plantation, Mubende district, central Uganda

Canopy section	Lc (%)	Ld (%)	Ea (%)	LEB (%)	Hv (%)
Upper	13.5±30.4 b	19.1±31.6 c	26.9±27.1 a	17.4±23.7 a	21.3±33.6 b
Middle	17.7±25.6 b	27.5±27.3 b	24.9±26.0 a	19.3±23.2 a	26.5±32.8 ab
Lower	23.1±21.7 a	36.1±25.2 a	24.3±26.2 a	19.2±20.6 a	30.5±28.8 a
CV	145.2772	102.6048	104.1380	120.8416	122.2893
F value	8.79	23.38	0.70	0.56	5.36
P value	0.0002	<.0001	0.4972	0.5710	0.0049

Lc=*Leucoptera coffeella* (Coffee leaf miners), Ls=*Leucoplema dohertyi* (Leaf skeletonizers), Ea=*Epicampoptera andersoni* (Tailed caterpillar), LEB=Leaf eating beetles and Hv=*Hemilleia vastatrix* (Coffee leaf rust). Same letters within a column indicate means are not significantly different by Tukey's test (P≥0.05).

3.2 Distribution of damage caused by pests and diseases on Robusta coffee clusters

Table 2 below shows that the damage caused by *Planococcus* spp. varied significantly (p=0.0188) across the canopy sections of Robusta coffee, with the highest infestation (18.6%) being recorded in lower section and lowest (9.8%) in the upper section of the coffee canopy. Our finding is in agreement with [53] who recorded more *Planococcus* spp. on the lower third of conilon coffee crops in Brazil. Similarly, [54] observed higher frequency of the striped mealybug, *Ferrisia virgata* (Cockerell) in the lower stratum of cotton canopy, 50 days after infestation. This could in part be due to the fact that mealybugs usually migrate to more conducive habitats created by the self-shading of coffee in the lower canopy [38] so as to find protection against extreme weather conditions and natural enemies [55]. Secondly, since the tending ants that protect *Planococcus* spp. from their predators [56] nest in the soil and under stones [57], they can easily access the leaves located in the lower parts of the coffee canopy. Thirdly, *Planococcus* spp. may prefer to feed on older leaves located in the lower canopy because the young leaves usually accumulate alkaloids such as caffeine [58] that may deter insects from feeding [59]. On the other hand, damage caused by *P. smaragdina* did not significantly (p=0.6167) differ within the coffee canopy but, the highest infestation (15.8%) was recorded in the upper section while the lowest (13.5%) was in the lower section of the coffee canopy (Table 2). Similarly, [60] and [17] reported that another related Lepidopteran pest, avocado seed moth, *Stenoma catenifer* preferred to oviposit and consequently attack fruits located in the upper stratum of the avocado trees. The codling moth, *Cydia pomonella* (L.) (Lepidoptera: Tortricidae) has also been reported to be more active or causing more damage in the upper parts compared with the lower parts of its host trees [61]. Other studies also showed that pheromone traps placed near the top of a tree generally captured more *C. pomonella* than traps those placed in the lower parts of the canopy [62]. This could in part due be due to the female *P. smaragdina* probably preferring to oviposit her eggs in areas that are more exposed to sunshine and thus, avoiding the shaded areas in the lower coffee canopy created by the self-shading effect [40]. This is true for a number of other moths [e.g. 17, 63]. This argument is further supported by research studies that showed high correlation between oviposition site selection and larval infestation by *S. catenifer* in avocado [60]. Similarly, the incidence of red blister disease (RBD), caused by the fungus, *C. coffeicola* on the Robusta coffee berry clusters did not significantly (p=0.4536) vary within the coffee canopy sections. However, the highest incidence (24.4%) was recorded in the upper section and the lowest (20.6%) was in the lower section of the Robusta coffee canopy (Table 2). This finding is in line with [64] who recorded the highest values of *C. coffeicola* severity and incidence on coffee leaves located in the upper branches. This could in part be due to the less self-shedding in the upper canopy section compared to the lower sections [40]. Shady conditions have been reported to reduce the incidence and severity of *C. coffeicola* [46, 64]. This is most probably because the high solar radiation and temperature in the unshaded systems favor the occurrence and development of *C. coffeicola* [64, 65]. High solar radiation and temperature have been observed to increase both water deficit and nutrition stress conditions [66], thus, increasing susceptibility of the coffee plant to *C. coffeicola* infection [67]. Secondly, high radiation increases production of the photoactive toxic pigment, cercosporin by some isolates of *C. coffeicola* that kills plant cells [68].

Table 2: Variation of incidence and damage of pests and diseases on berry clusters within the canopy of Robusta coffee, *Coffea canephora* at Kaweri Coffee Plantation, Mubende district, central Uganda

Canopy portion	Pl (%)	Ps (%)	Cc (%)
Upper	9.8±35.9 b	15.8±24.9 a	24.4±31.7 a
Middle	16.8±33.4 ab	13.9±21.6 a	21.2±30.8 a
Lower	18.6±27.2 a	13.5±27.0 a	20.6±34.7 a
CV	211.4101	170.8772	147.4737
F value	4.00	0.48	0.79
P value	0.0188	0.6167	0.4536

Pl=*Prophantis smaragdina* (Coffee mealybugs), Ps=*Prophantis smaragdina* (Coffee berry moth), Cc=*Cercospora coffeicola* (Red blister disease). Same letters within a column indicate means are not significantly different by Tukey's test ($P \geq 0.05$).

3.3 Distribution of damage caused by pests and diseases on Robusta coffee berries

We further observed that damage caused by the *H. hampei* did not significantly (p=0.0689) vary across the Robusta coffee canopy sections (Table 3). Similarly, [69], [70] and [71] reported no significant differences in the level of infestation by of *H. hampei* in the various coffee canopy positions and branch types. However, the highest infestation (28.5%) was recorded in the lower section whereas, the lowest (21.2%) was in the upper section of the coffee canopy (Table 3), as also reported by [72]. Similarly, [14] and [71] observed that traps placed at the lowest level of the coffee tree from the ground (0.5 m) captured the highest number of *H. hampei* compared to traps placed at higher levels above the ground. This could in part be due to the fact that the coffee berries remaining on the ground after harvest have a big potential refuse for *H. hampei* [14] and on hatching, the adult beetles will first colonize the berries in the branches near the ground, resulting into higher population and thus, damage in this section [72]. Secondly, the shady conditions created by self-shading of the coffee in the lower section of the canopy [40] could also in part have contributed to increase in damage by *H. hampei* since shade is known to promote populations and damage of this pest [73]. Furthermore, there was no significant (p=0.8922) difference in the incidence of *C. coffeicola* on the Robusta coffee berries. However, the highest incidence (20.7%) was recorded in the upper section while the lowest (19.1%) was in the middle section of the coffee canopy (Table 3), agreeing with our observations on the berry clusters. Therefore, these observed results could in part be attributed to the same reasons as in case of the berry clusters.

Table 3: Variation of incidence and damage of pests and diseases on berries within the canopy of Robusta coffee, *Coffea canephora* at Kaweri Coffee Plantation, Mubende district, central Uganda

Canopy section	Hh (%)	Cc (%)
Upper	21.2± a	20.7± a
Middle	23.9± a	19.1± a
Lower	28.5± a	20.1± a
CV	132.1574	174.8970
F value	2.69	0.11
P value	0.0689	0.8922

Hh=*Hypothenemus hampei* (Ferrari) and Cc=*Cercospora coffeicola* (Red blister disease). Same letters within a column indicate means are not significantly different by Tukey's test ($P \geq 0.05$).

4. Conclusion

Variations in the distributions of pests and diseases within the Robusta coffee canopy sections were observed in this study but, only significant ($p \leq 0.05$) for *L. coffeella, L. dohertyi, Planococcus* spp and *H. vastatrix. L. coffeella, L. dohertyi, Planococcus spp., H. hampei* and *H. vastatrix* attained the highest incidence and damage in the lower section while, *E. andersoni* and tailed caterpillars in the middle section, and, E. *andersoni*, *P. smaragdina* and *C. coffeicola* in the upper section of the Robusta coffee canopy. This information is vital for developing and implementing monitoring techniques and regimes as well as ecologically-informed management strategies for these pests and diseases. Basing on our results therefore, to effectively manage the specific pests and diseases, options such as phyto-sanitary, spraying with pesticides or bio-pesticides and trapping with lures should be targeted in the canopy section where they attain the highest levels. This could reduce labor and the amounts of pesticides used and thus, the costs and risks to human beings and environment in general.

5. Limitations of the Study

The main limitation of this study was that it was not repeated, a one-off.

6. Conflict of interest

The authors declare that they have no conflicts of interest.

Acknowledgement

This study formed part of Winnie Nanjego's MSc thesis research work. We wish to acknowledge support from the United States Aid for International Development (USAID)-funded project, Enhancing Resilience and Adaptive Agricultural Livelihoods in Uganda (ERAAL). Management and staff of Kaweri Coffee Plantation Limited are also appreciated for allowing us to use the Plantation for the study and also helping in the field work. Last but not least, a vote of thanks goes to the National Coffee Research Institute (NaCORI) and International Institute of Tropical Agriculture (IITA) project members who participated in data collection.

References

[1] UCDA "A Sustainable Coffee Industry with High Stakeholder Value for Social Economic Transformation. Robusta Coffee Handbook", Uganda Coffee Development Authority (UCDA), Ministry of Agriculture, Animal Industry and Fisheries (MAAIF), 2019.

[2] UCDA "25 years of empowering lives. Kampala, Uganda" Uganda Coffee Development Authority (UCDA), 2017.

[3] R.J. Bakema and J. Schluter. "Consultancy to develop a detailed and costed implementation plan for the coffee roadmap for Uganda". Final report for the Delegation of the European Union to Uganda, 2017.

[4] N. Wang, L. Jassogne, P.J.A. van Asten, D. Mukasa, I. Wanyama, G.H. Kagezi et al. "Evaluating coffee yield gaps and important biotic, abiotic, and management factors limiting coffee production in Uganda". European Journal of Agronomy vol. 63, pp. 1-11, Feb. 2015.

[5] P.C. Musoli, A. Nalukenge, H.G. Kagezi, B. Magambo, S. Olal, P. Aluka et al. "Yield and Response of 24 Wilt-Resistant Robusta Coffee Clones to Major Diseases in Different Coffee Growing Regions of Uganda". Presentation to the Variety Release Committee of the Ministry of Agriculture, Animal Industry and Fisheries (MAAIF), Uganda, 2016.

[6] G. Sseremba G.H. Kagezi, J. Kobusinge P., Musoli, D. Akodi, N. Olango et al. "High Robusta coffee plant density is associated with better yield potential at mixed responses for growth robustness, pests and diseases: which way for a farmer?". Australian Journal of Crop Science vol. 15(4), pp. 494–503. May 2021.

[7] L.F. Campuzano-Duque and M.W. Blair. "Strategies for Robusta coffee (*Coffea canephora*) improvement as a new crop in Colombia". Agriculture vol. 12, pp. 15 pp., Sept 2022.

[8] NaCORI/MAAIF/UCDA. "A Rapid assessment report on the status of pests and diseases in southwestern, eastern, greater Masaka, western and Rwenzori regions" a Joint Survey Undertaken by the National Coffee Research Institute (NaCORI), Ministry of Agriculture, Animal Industry and Fisheries (MAAIF) and Uganda Coffee Development Authority (UCDA), 2022.

[9] N.D. Olango, S. Olal, G. Kagezi, P. Kucel, R. Ekwaru, J. Kobusinge et al. "Occurrence and damage/severity of coffee pests and diseases in central Uganda" in 3rd Biennial National Agricultural

research Organisation – Makerere University (NARO-MAK) Joint Scientific Conf., 14-16 March 2023, Kampala, Uganda, Munyonyo, Uganda, 2023, pp. 62-62.

[10] E.S. Marboh, A.K. Gupta, N. Lal, V., Nath "Canopy architecture management impacts pest and disease development in fruit tree" in National Conference on Integrated Plant Health Management in Fruit Crops. K. Srivastava, S.K. Singh, P.K. Patel, A. Kumar, A.K. Gupta, E.S. Marbon et al. Eds, September 3-4, 2019. Confederation of Horticulture Associations of India (CHAI), Pusa Unit, 2019, pp 72-73.

[11] G.H. Kagezi, P. Kucel, J. Kobusingye, L. Nakibuule L., Wekhaso R., Ahumuza G., et al. "Influence of shade systems on spatial distribution and infestation of the Black Coffee Twig Borer on coffee in Uganda", Journal of Agricultural Sciences vol. 14(1), pp. 1-12, Mar 2013.

[12] J.H. Chong, L. Reid, M. Williamson. "Distribution, host plants, and damage of the Black Twig Borer, *Xylosandrus compactus* (Eichhoff) in South Carolina" Journal of Agricultural and Urban Entomology vol. 26(4), pp. 199-208, Oct. 2009.

[13] L. Alvarado-Huaman, R. Borjas, V. Castro, L. García, J. Iménez, A. Julca et al. "Dynamics of severity of coffee leaf rust (*Hemileia vastatrix*) on Coffee, in Chanchamayo (Junín-Peru)" Agronomía Mesoamericana vol. 31(2), pp. 517-529, Sept 2020.

[14] C.P. Ruiz-Diaz and J.C.V. Rodrigues J.C.V. "Vertical trapping of the coffee berry borer, *Hypothenemus hampei* (Coleoptera: Scolytinae), in coffee" Insects vol. 12(7), 9 pp., Jul 2021.

[15] M.M.S. Bakry and F.M. Tolba. "Factors affecting distribution pattern of the white mango scale insect, *Aulacaspis tubercularis* (Newstead) (Hemiptera: Diaspididae) on mango trees at Esna District, Luxor Governorate, Egypt" Assiut Journal of Agricultural Sciences vol. 50(4), pp. 87-101, Dec. 2019.

[16] A.E.O. Tulli, E. Kodama, E.P. De Souza, P.E. Degrande, A-Z. De Lima Filho and G. Jr. Bonfanti. "Intraplant distribution, preferred sites, and damage caused by *Euschistus heros* (Hemiptera: Pentatomidae) on cotton" Journal of Entomological Science vol. 56(1), pp. 32-42, Feb 2021.

[17] A.M. Vacari, F. Damato, B.G. Dami, M.L.F De Lima, L.S.M.U Lim., G.P. Figueiredo et al. "Within-canopy distribution of *Stenoma catenifer* (Lepidoptera: Elachistidae) infestation in avocado orchards" Journal of Insect Science vol. 21(5), pp. 4, Sept 2021.

[18] Y-H. Lan, D.C. Shaw, E.H. Lee and P.A. Beedlow. "Distribution of a foliage disease fungus within canopies of mature douglas-fir in Western Oregon" Frontiers in Forests and Global Change, vol. 5, pp. 1-15 pp, Feb. 2022.

[19] M. Pastircak, R. Rodeva, Z. Stoyanova, S., Nedyalkova and M. Hudcovicova. "Vertical distribution of foliar pathogens on wheat" Agricultural Science and Technology vol. 6, pp. 341-345, Jan 2014.

[20] F. Gallardo-Covas. "Faunal survey of the coffee leaf miner, *Leucoptera coffeella*, parasitoids in Puerto Rico" The Journal of Agriculture of the University of Puerto Rico, vol. 72(2), pp. 255–263, 1988.

[21] A, Zeiri, M. Ahmed, A. Cuthbertson, M. Braham and M. Braham. "Monitoring the attack incidences and damage caused by the almond bark beetle, *Scolytus amygdali*, in almond orchards" Insects 9(1), 1, 9 pp, Jan 2018.

[22] B. Ayalew, K. Hylander, B. Zewdie, T. Shimales, G. Adugna and E. Mendesil et al. "The impact of shade tree species identity on coffee pests and diseases" Agriculture, Ecosystems and Environment 340: 108152, 14pp, Dec 2022.

[23] Kaweri Coffee Plantation Ltd. Kaweri Coffee Plantation Master Plan, 2001.

[24] Gissat Techno Consult Ltd. Environmental Impact Report for Kaweri Coffee Plantation. Final report, Kampala, Uganda, 2001.

[25] G.H. Kagezi, P. Kucel, J. Kobusinge, N. Olango, L. Nakibuule and W.W. Wagoire. "Predicting the response of insect pests and diseases of Arabica coffee to climate change along an altitudinal gradient in Mt. Elgon region, Uganda" Journal of Agricultural and Environmental Sciences vol. 7(1), pp. 134-140, 2018.

[26] SAS. SAS/STAT Software: Version 9.2, Cary, NC: SAS Institute Inc., 2008.

[27] F. Gallardo-Covas. "Distribution of the coffee leaf miner, *Leucoptera coffeella*, and its parasitoids in the canopy of coffee, *Coffea arabica* in Puerto Rico " Journal of Agriculture of the University of Puerto Rico, vol. 72(1), pp. 141–146, 1988.

[28] T. Cornelissen. "Herbivory by leaf-miners on Florida scrub oaks" PhD thesis. University of South Florida, 2006.

[29] T. Cornelissen and P. Stiling." Clumped distribution of oak leaf miners between and within plants" Basic and Applied Ecology vol. 9(1), pp. 67-77, Jan 2008.

[30] P.R. De Sibio and M.N. Rossi. "Oviposition of a leaf-miner on *Erythroxylum tortuosum* (Erythroxylaceae) leaves: hierarchical variation of physical leaf traits" Australian Journal of Botany vol. 60, pp. 136-142, Mar 2012.

[31] S. Facknath. "Leaf age and life history variables of leafminer: the case of *Liriomyza trifolii* on potato leaves" Entomologia Experimentalis et Applicata vol. 115, pp. 79-87, Apr 2005.

[32] T. Katte, S. Shimoda, T. Kobayashi, A. Wada-Katsumata, R. Nishida, I. Ohshima et al. "Oviposition stimulants underlying different preferences between host races in the leaf-mining moth *Acrocercops transecta* (Lepidoptera: Gracillariidae)" Scientific Reports vol. 12(1), pp. 1–12, Aug 2022.

[33] Y. Maxiselly, P. Anusornwanit, A. Rugkong, R. Chiarawipa, P. and Chanjula. “Morpho-physiological traits, phytochemical composition, and antioxidant activity of Canephora coffee leaves at various stages” International Journal of Plant Biology vol. 13, pp. 106-114. May 2022.

[34] G.C. Varley and G.R. Gradwell. “The interpretation of insect population changes” Proceedings of the Ceylon Association of Advancement of Science vol. 18, pp. 142–156, 1962.

[35] F. Feeny. “Seasonal changes in Oak leaf tannins and nutrients as a cause of spring feeding by winter moth caterpillars” Ecology vol. 51, pp. 565–581. July 1970.

[36] C.S. Awmack and S.R. Leather S.R. “Host plant quality and fecundity in herbivorous insects” Annual Review of Entomology vol. 47, pp. 817-844, Jan 2002.

[37] N.A. Barber and R.J. Marquis “Leaf quality, predators, and stochastic processes in the assembly of a diverse herbivore community” Ecology vol. 92, pp. 699-708, Mar 2011.

[38] O. Guerreiro Filho, M.B. Silvarolla and A.B. Eskes. “Expression and mode of inheritance of resistance in coffee to leaf miner *Perileucoptera coffeella*” Euphytica vol. 105, pp. 7-15, Jan 1999.

[39] G.A. Melo, M.M. Shimizu and P. Mazzafera, “Polyphenoloxidase activity in coffee leaves and its role in resistance against the coffee leaf miner and coffee leaf rust” Phytochemistry vol. 67(3), pp. 277–285, Feb 2006.

[40] N.V. Long, N.Q. Ngoc, N.N. Dung, P. Kristiansen, I. Yunusa and C. Fyfe, “The effects of shade tree types on light variation and Robusta coffee production in Vietnam” Engineering vol. 7, pp. 742-753, Nov 2015.

[41] U. Samnegard, P.A. Hamback, S. Nemomissa and K. Hylander. “Local and regional variation in local frequency of multiple coffee pests across a mosaic landscape in *Coffea arabica*'s native range” Biotropica vol, 46(3), pp. 276-284, Apr 2014.

[42] J.R. Lomelí-Flores, J.F. Barrera and J.S. Bernal. “Impacts of weather, shade cover and elevation on coffee leafminer Leucoptera coffeella (Lepidoptera: Lyonetiidae) population dynamics and natural enemies” Crop Protection vol. 29(9), pp. 1039–1048. March 2010.

[43] L.F. Aristizábal and M.A. Johnson. “Monitoring coffee leaf rust (*Hemileia vastatrix*) on commercial coffee farms in Hawaii: early insights from the first year of disease incursion” Agronomy vol. 12(5), 1134, pp., May 2022.

[44] J. Gagliardi, J. Avelino, A.R. Martin, M. Cadotte, Ed.M. Virginio Filho and M.E Isaac. “Leaf functional traits and pathogens: Linking coffee leaf rust with intraspecific trait variation in diversified agroecosystems” PLoS ONE vol. 18(4), pp. 16, Apr 2023.

[45] J. Avelino, L. Willocquet and S. Savary. "Effects of crop management patterns on coffee rust epidemics" Plant Pathology vol. 53, pp, 541–547, Nov 2004.

[46] C. Staver, F. Guharay, D. Monterroso and R. Muschler. "Designing pest-suppressive multistrata perennial crop systems: shade-grown coffee in Central America" Agroforestry Systems vol. 53, pp. 151–170, Jan 2001.

[47] A. Jaramillo-Robledo and B. Chaves-Córdoba, "Aspectos hidrológicos en un bosque y en plantaciones de café (*Coffea arabica* L.) al sol y bajo sombra" Cenicafé vol. 50, pp. 97–105, 1999.

[48] P. Siles, P. Vaast, E. Dreyer and J-M. Harmand. "Rainfall partitioning into throughfall, stemflow and interception loss in a coffee (*Coffea arabica* L.) monoculture compared to an agroforestry system with *Inga densiflora*" Journal of Hydrology vol. 395(1–2), pp. 39–48, Dec 2010.

[49] K. Li, Z. Hajian-Forooshani, J. Vandermeer and I. Perfecto. "Coffee leaf rust (*Hemileia vastatrix*) is spread by rain splash from infected leaf litter in a semi-controlled experiment" Journal of Plant Pathology vol. 105, pp. 667–672, May 2023.

[50] M. Fortin and Y. Mauffette. "The suitability of leaves from different canopy layers for a generalist herbivore (Lepidoptera: Lasiocampidae) foraging on sugar maple" Canadian Journal of Forest Research vol. 32(3), pp. 379-389, Mar 2002.

[51] Y. Basset. 1991. "The spatial distribution of leaf damage, galls and mines within an Australian rainforest tree" Biotropica vol. 23(3), pp. 271–281, Sept 1991.

[52] P.D. Coley, M.L. Bateman and T.A. Kursar. "The effects of plant quality on caterpillar growth and defense against natural enemies" Oikos vol. 115(2), pp. 219–28, Nov 2006.

[53] E. Borghi, G. Fornaciari, M. Vieira, R. Aguiar, A. Holtz and A. Filho et al. "*Planococcus* spp.: behavior and monitoring in conilon coffee crops" Coffee Science vol. 16, e161820, pp. 7, Apr 2021.

[54] M.D. Oliveira, C.S.A. Silva-Torres, J.B. Torres and J.E.M. Oliveira. "Population growth and within-plant distribution of the striped mealybug *Ferrisia virgata* (Cockerell) (Hemiptera, Pseudococcidae) on cotton" Revista Brasileira de Entomologia 58(1), pp. 71-76, Mar 2014.

[55] M. Mani and C. Shivaraju. "Mode of spread of mealybugs" in Mealybugs and their Management in Agricultural and Horticultural Crops. M. Mani and C. Shivaraju Eds. Springer India, New Delhi, 2016. pp. 113-116.

[56] J. Pérez-Rodríguez, A. Pekas, A. Tena and F.L. Wäckers. "Sugar provisioning for ants enhances biological control of mealybugs in citrus" Biological Control vol. 157, 104573, pp. 8, Jun 2021.

[57] J.S. Lapolla, S.P. Cover and U.G. Mueller. "Natural history of the mealybug-tending ant, *Acropyga*

epedana, with descriptions of the male and queen castes" Transactions of the American Entomological Society vol. 128(4), pp. 367–376, Dec 2002.

[58] H. Ashihara. "Metabolism of alkaloids in coffee plants" Brazilian Journal of Plant Physiology vol. 18(1), pp. 1-8, May 2006.

[59] K. Tougeron and T. Hance. "Cascading effects of caffeine intake by primary consumers to the upper trophic level" Bulletin of Entomological Research vol. 112(2), pp. 197-203, Apr 2022.

[60] C.L. Hohmann, A.M. Meneguim, E.A. Andrade, T.G. Novaes and K. Zandoná. "The avocado fruit borer, *Stenoma catenifer* Wals. (Lepidoptera: Elachistidae) egg and damage distribution and parasitism" Revista Brasileira de Fruticultura vol. 25(3), pp. 432–435, Dec 2003.

[61] C.H. Wearing. "Distribution Characteristics of Eggs and Neonate Larvae of Codling Moth, *Cydia pomonella* (L.) (Lepidoptera: Tortricidae)" International Journal of Insect Science vol. 9(8), pp. 33–53, June 2016.

[62] T.J. Weissling and A.L. Knight. "Vertical distribution of codling moth adults in pheromone-treated and untreated plots" Entomologia Experimentalis et Applicata vol. 77(3), pp. 271-275, Dec 1995.

[63] X. Yang, L. Ziyun, R. Hongfan, M. Aihong, L. Wenxu L, Jiancheng et al. "Oviposition site selection in the crepuscular moth, *Grapholita molesta*: does light matter?" Entomologia Experimentalis et Applicata vol. 170 (5), Feb 2022.

[64] A.G.C. Souza, L.A. Maffia, F.F. Silva, E.S.G. Mizubuti and H. Teixeira. "A time series analysis of brown eye spot progress in conventional and organic coffee production systems" Plant Pathology vol. 64(1), pp. 157-166, May 2015.

[65] M.G. Silva, E.A. Pozza, F.P. Monteiro and C.V.R. Lima. "Effect of light and temperature on *Cercospora coffeicola* and *Coffea arabica* pathosystem" Coffee Science vol. 11(2), pp. 148–160, Jan 2016.

[66] F.S. Santos, P.E. Souza, E.A. Pozza, J.C. Miranda, E.A. Carvalho, L.H.M. Fernandes et al. "Organic fertilization, nutrition and the progress of brown eye spot and rust in coffee trees" Pesquisa Agropecuária Brasileira vol. 43(7), pp. 783-791, Jul 2008.

[67] S.C. Nelson. Cercospora leaf spot and berry blotch of coffee. University of Hawaii; Mänoa, Hawaii, 2008.

[68] J.B. Ramos, M.L.V. De Resende, M.E.R. Andrade, A.R. Teixeira. W.D. Santiago, E.A. Pozza et al. "Quantification of cercosporin from coffee leaves infected by *Cercospora coffeicola*" Australasian Plant Pathology vol. 51(4)**,** pp. 429-432, Jun 2022.

[69] S. Kidanu. "Bio-Ecological and management studies of coffee berry borer, *Hypothenemus hampei*

Ferrari (Coleoptera: Scolytidae) in Ethiopia" International Journal of Forestry and Horticulture vol. 6(3), pp. 39–47, 2020.

[70] E. Mendesil, B. Jembere and E. Seyoum. "Occurrence of coffee berry borer, *Hypothenemus hampei* (Ferrari) (Coleoptera: Scolytidae) on *Coffea arabica* L. in Ethiopia" Ethiopian Journal of Biological Science vol. 2, pp. 61-72, Jan 2003.

[71] M.C. Tobing, S.C.T, Sinaga, Bintang, Widihastuty, N. Pramayudi. "The used of attractants from coffee at various heights traps to control coffee berry borer and quality test of coffee berry" in IOP Conf. Ser. Earth Environ. Sci., 2022, pp. 10.

[72] S. Wiryadiputra "Distribution pattern of coffee berry borer (*Hypothenemus Hampei)* on Arabica and Robusta coffee" Pelita Perkebunan vol. 30(2), pp. 123–136, Aug 2014.

[73] Y.A. Mariño, M. Pérez, F. Gallardo, M. Tri, M. Cruz M. and P. Bayman. "Sun vs. shade affects infestation, total population and sex ratio of the coffee berry borer (*Hypothenemus hampei*) in Puerto Rico" Agriculture, Ecosystems and Environment vol. 222, pp. 258-266, Apr 2016.