Journal of Agricultural Science; Vol. 16, No. 5; 2024
ISSN 1916-9752 E-ISSN 1916-9760
Published by Canadian Center of Science and Education

Positional Effects of Bottle-Baited Traps in Reducing Infestation Level of Coffee Berry Borer *Hypothenemus Hampei* Ferrari in Kilimanjaro Region, Tanzania

Aden R. Mbuba[1,2] & Lilian F. Shechambo[1]

[1] Department of Crop Science and Horticulture, Sokoine University of Agriculture, Morogoro, Tanzania

[2] Tanzania Coffee Research Institute (TaCRI), Moshi, Tanzania

Correspondence: Aden R. Mbuba, Department of Crop Science and Horticulture, Sokoine University of Agriculture, Morogoro, Tanzania. Tel: 255-753-335-997.

Tanzania Coffee Research Institute (TaCRI), Moshi, Tanzania. Tel: 255-27-275-275-6868/759. E-mail: adenmbuba@yahoo.com

Received: February 17, 2024 Accepted: March 16, 2024 Online Published: April 15, 2024

doi:10.5539/jas.v16n5p32 URL: https://doi.org/10.5539/jas.v16n5p32

Abstract

Coffee berry borer (CBB) is among the key insect pests of coffee worldwide. The use of bottle-baited traps has been in practice in several coffee-growing areas including Tanzania. However, there is limited information about the influence of height and spacing of commonly used bottle-baited traps in managing CBB in coffee-growing areas in the country. Therefore, the objective of this research was to evaluate the effect of height where traps were placed (0.6, 1.2, and 1.6 m) on the reduction of infestation level of coffee berry borers at different developmental stages of coffee fruit (green and red fruit) under field conditions. The experiment followed a completely randomized block design with a factorial arrangement and four replications, three (lower, middle, and upper) levels of height and spacing were placed for 7 months. The number of captured CBB and damaged berries percentage was evaluated. The data were analyzed by R Software (2021) through an analysis of variance and means were separated by Turkey's (0.05). A significant minimum berries damage (0.26%) as an implication of the lowest CBB infestation level was shown at the height of 0.6 m (for all stages of berries). On the other hand, at the red berries stage, the lowest damage (11.12%) was observed at the height of 1.6 m. Generally, this study deduced that the lower the height from which the traps are placed, the lower the infestation level of CBB hence reducing crop damage by the pest.

Keywords: coffee berry borer, bottle baited traps, height, infestation level, developmental stages, crop damage, Tanzania

1. Introduction

Coffee (*Coffea* spp. L. (Rubiaceae)) is the second most-traded worldwide commodity after oil (Zewide, 2021). As an important economic crop, coffee is vital to the livelihood of millions of people globally (Tibpromma et al., 2022). According to Abate 2021 more than 80 countries grow coffee and some countries use coffee as a major cash crop. Among the major two economic coffee species are *Coffea arabica* L. (Arabica) and *Coffea canephora* Pierre ex A. Froehner (canephora). The Arabica has a higher market price due to its organoleptic properties (Gottstein et al., 2021). The organoleptic properties of Arabica coffee such as aroma and flavor are of higher quality which makes it more valuable in the market compared to the other coffee species. In Tanzania, it is estimated that over 320,000 smallholder farmers are responsible for 95% of the coffee production in the country (Kiwelu et al., 2021). Additionally, production has decreased and stagnated in several regions of the nation since the late 1990s, notably the Kilimanjaro region, and has averaged approximately 73,000 tons (FAO, 2021). The infestation of CBB has been playing a significant role in reducing and stagnating coffee production as the industry is still struggling to increase production to 300,000 t (TCB, 2017).

The *Hypothenemus hampei* Ferrari is considered the most significant insect pest in the fields worldwide due to its propensity to reproduce directly inside the developing berries and consequently reduce yield, berries quality, and price of harvested coffee (Vega et al., 2015; Asfaw et al., 2019; Azrag et al., 2020; Lemma et al., 2021). The adult female beetles bore holes into coffee berries and make galleries inside the endosperm, where they lay eggs

(Damtew, 2022; Azrag et al., 2023). The larvae feed on endosperm and consequently damage the seeds. Thus, qualitative losses or circular damage can be due to the low quality of the coffee seeds, as the galleries can allow pathogens to enter, leading to turmoil and spoiling of coffee flavours (Mohob et al., 2022). The *Profenofos* and *chlorpyrifos* are the most efficient and frequently used insecticides in Tanzania (Magina et al., 2016). Still, the use of insecticides has contributed greatly to environmental imbalance and pollution. The pesticide affects CBBs and natural nonentity adversaries and increases the threat that nonentity might develop. Thus, it has threatened communities that live around the coffee fields and increased production costs (Tome et al., 2020; Tunkur et al., 2021; Manson et al., 2022).

The environmentally friendly bottle-baited traps have been designed to reduce the CBB population in the coffee field. The use of traps that are baited with semiochemicals is one of the recognized tools for pest detection and mass-trapping of the female adult coffee berry borer (CBB). The major advantage of using traps is the rapid-fire discovery of the CBB, even when the insect pest density is low during either adult emergence or the movement of adults into the field from neighboring farms for infesting new berries and mating season (Mafra-Neto et al., 2022). The initial CBB captures can be used as an early-warning tool for farmers, to initiate the monitoring before the pest population reaches the economic injury level (EIL) (Sambony et al., 2021). The CBB developmental dynamics relate to indigenous conditions, including coffee phenology, management practices, and climate (Rodríguez et al., 2013). The objective of coffee farmers is the production of high-quality coffee at the best market price produce at a lower cost (Kiwelu et al., 2021). In Tanzania, most coffee is sold in grade-based quality. However, the CBB reduces quality and price, causing losses in yield and increased costs of production.

However, no studies in the country, specifically in Hai district in the Kilimanjaro region, have been done to investigate the proper positioning of bottle-baited traps that may reduce the infestation of this insect pest at different phonological developmental stages of the coffee fruits Arabica and Robusta in coffee fields. Therefore, the objective of this research was to evaluate the effect of height where traps were placed (0.6, 1.2, and 1.6 m) on the coffee fields.

2. Materials and Methods

2.1 Description of Study Site

The field experiments were conducted at Lyamungu Tanzania Coffee Research Institute (TaCRI) Station; Hai district in Kilimanjaro region, located at (0^{o}14′41.4353″S, 37^{o}14′47.65502″E) and 1268 m above sea level (m a.s.l.). The site received a total annual rainfall of about 1800 mm per annum and a maximum air temperature ranging from 21.2 to 31 ^{o}C per year while the average minimum air temperature ranged from 14 to 19 ^{o}C. The site was selected because it is a hotspot for (CBB) and the presence of a Meteorological Station nearby was another advantage of the site in ensuring the availability of weather data.

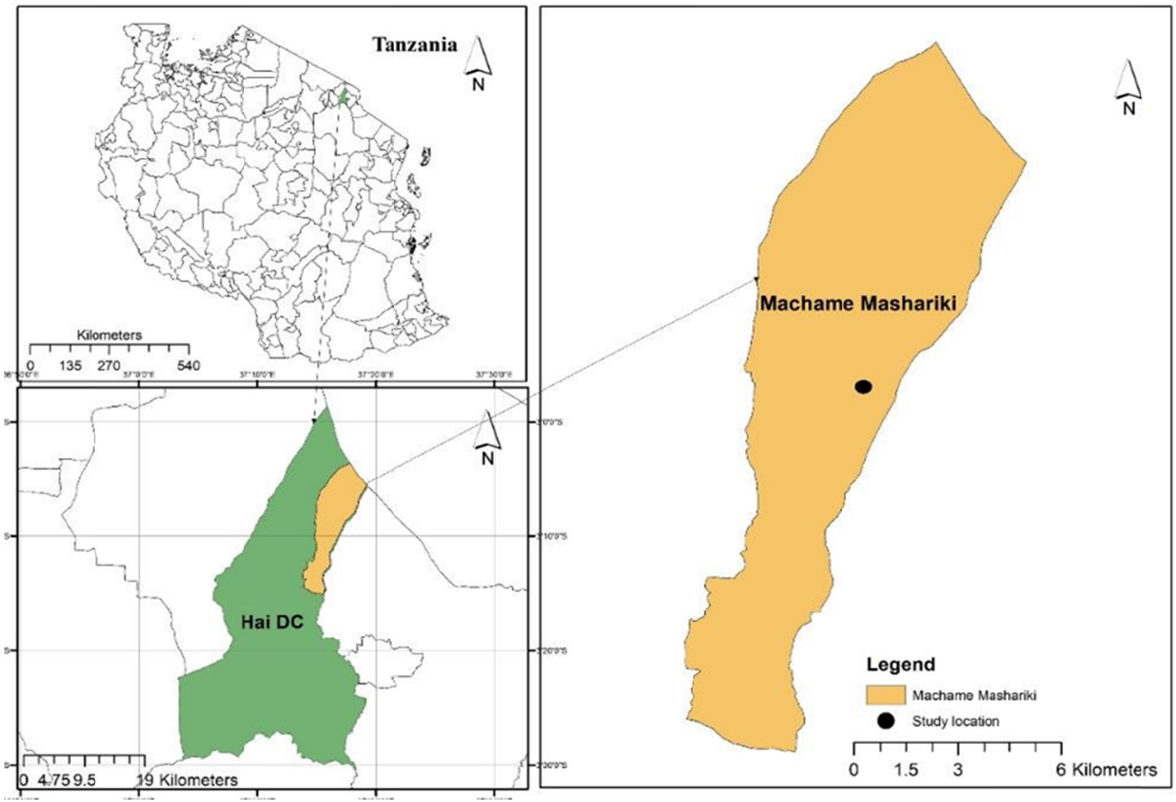

Figure 1. Map showing the study area

2.2 Trap, Dispenser, Counter Machine, and Semiochemicals

The trap used for the experiment was the cheap modified local trap model, developed by a researcher from the Tanzania Coffee Research Institute (TaCRI) to replace the expensive BROCAP® trap (Magina et al., 2016). They were constructed using a recycled empty clear plastic bottle of 1.5 L capacity, with a window opened on two sides (8 × 8 cm). All the traps were painted with red colour half of it to maximize attractiveness to the CBB (Dufour et al., 2019). A dispenser of 30 mL containing semiochemical lure (methylated spirit of 70% alcohol and water) at a ratio of (1:1) v/v having three small opened holes on the rubber cap of the dispenser which allow the semiochemical to evaporate vials those opening for attracting adult female CBB (Magina et al., 2016) was placed inside the trap to the CBBs. Water with detergent 5% was added at the bottom of the bottle to help drown the CBBs adults and other coffee pests captured by the trap. Also, the counter machine was used to count the damaged berries in the coffee field.

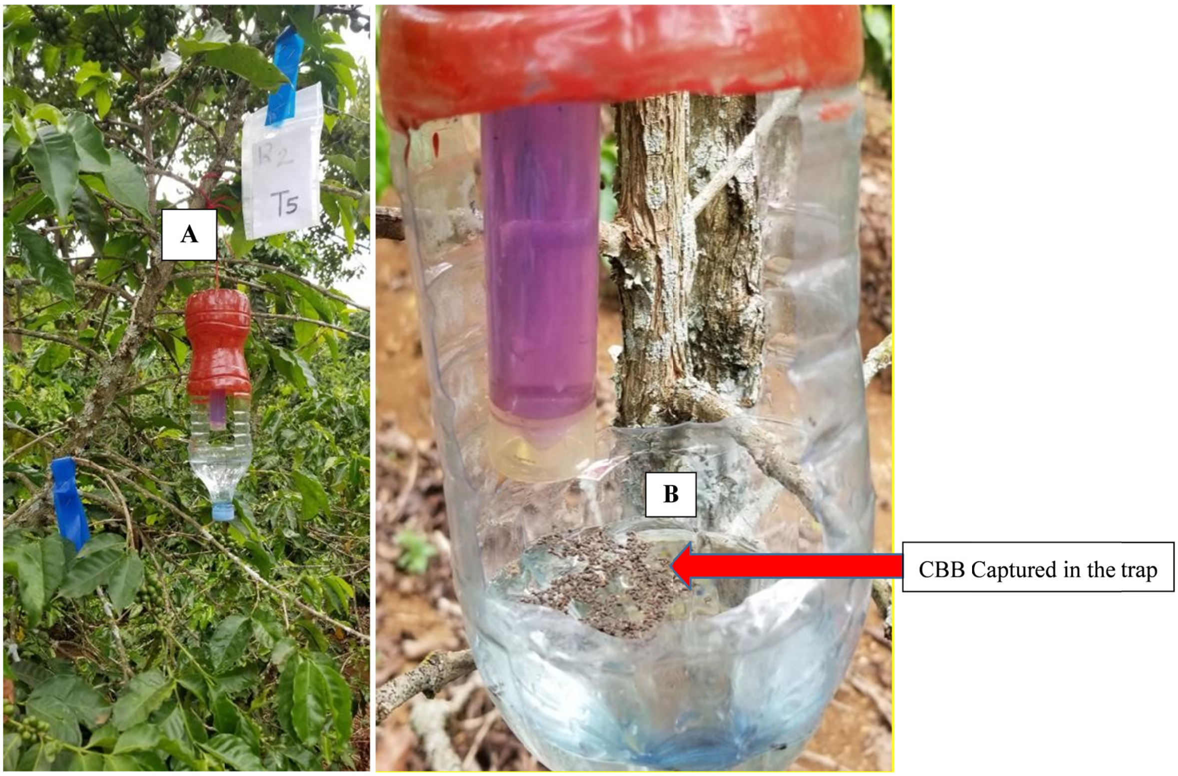

Figure 2. Trap placed in the coffee tree (A) and (B) Coffee berry borer captured in the trap

2.3 Experimental Design

The study used a factorial randomized complete block design (RCBD) with two factors, factor A the trap spacing (distance from one trap to another) in three levels (5 m, 10 m, and 15 m), and factor B was height (from ground level) in three levels (0.6 m,1.2 m, and 1.6 m), making nine treatments which were replicated four times. Four sample trees were randomly selected for each treatment, and two primary branches per height/tree were selected arbitrarily regarding the position lower at 0.6 m, middle at 1.2 m, and 1.6 m upper height of the coffee tree making a total of 2016 branches for fruit phenology observation. Therefore, each branch selected had a minimum of 50 berries.

2.4 Data Collection

The total number of green and red ripe berries with entrance holes, with a pest's damage symptom in the central disc in the selected branches of specific height were counted and recorded every 7 days for 7 months from February to August. Also, the number of (CBBs) attracted and caught in the trap was counted and recorded every 3 days for 7 months consecutively. However, weather variables including rainfall, temperature, and relative humidity were collected at the weather station near the field experiment.

2.5 Statistical Data Analysis

The data on the influences of spacing and height of bottle-baited traps on berry damage by coffee berry borer (CBB) were processed into percentages and then subjected to arcsine transformation before carrying out the analysis of variance (R Core Team, 2021). The means were separated by Turkey's test at a 5% significance level. The Pearson correlation was also done to evaluate the statistical relationship between damaged berries and CBB counts.

3. Results

3.1 Infestation of Coffee Berries by CBB in Relation to Field Positioning of Bottle-Baited Traps

There was a significant effect of the height at which the traps were placed on the percentage of damaged berries (PDB) by CBB ($p = 5.36 \times 10^{-8}$). At a trap height of 0.6 m, fewer berries were damaged by CBB (2.02%), while placing the trap at 1.2 m was related to a higher PDB (5.85%) (Figure 3). However, there was an insignificant effect of the trap's spacing ($p = 0.0964$) as well as the combining effect of the trap's height and spacing ($p = 0.6175$).

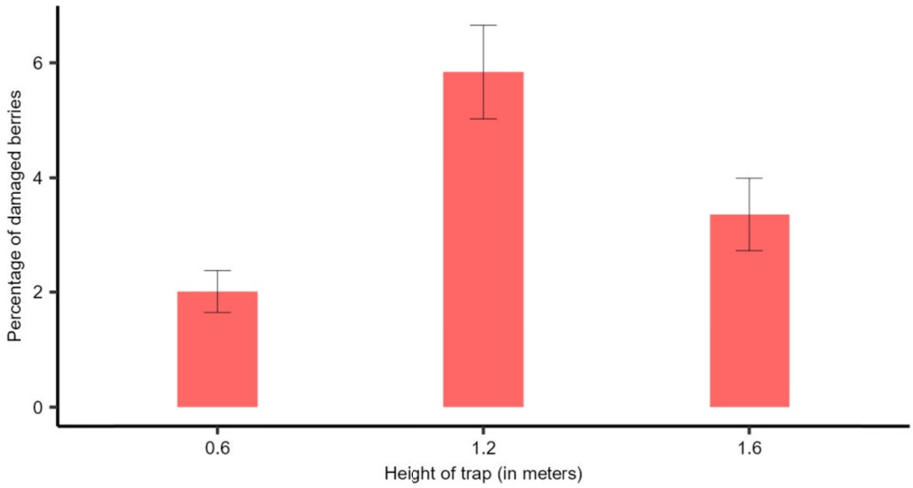

Figure 3. The use of bottle-baited traps at different heights to percentage of damaged berries by CBB

The percentage of damaged berries (PDB) significantly varied as the trap was placed at different trap heights over phonological berry developmental stages ($p = 3.85 \times 10^{-7}$). Minimum damage was recorded at 1.6 m trap height (0.26%) during the red stage of berry development while severe damage was recorded at 1.2 m trap height (11.12%) during the green developmental stage of coffee berries (Figure 4). There was no significant effect of trap spacing ($p = 0.0952$) as well as trap height and spacing ($p = 0.238$) on reducing the berry damage by CBB during the phonological developmental stages of berry.

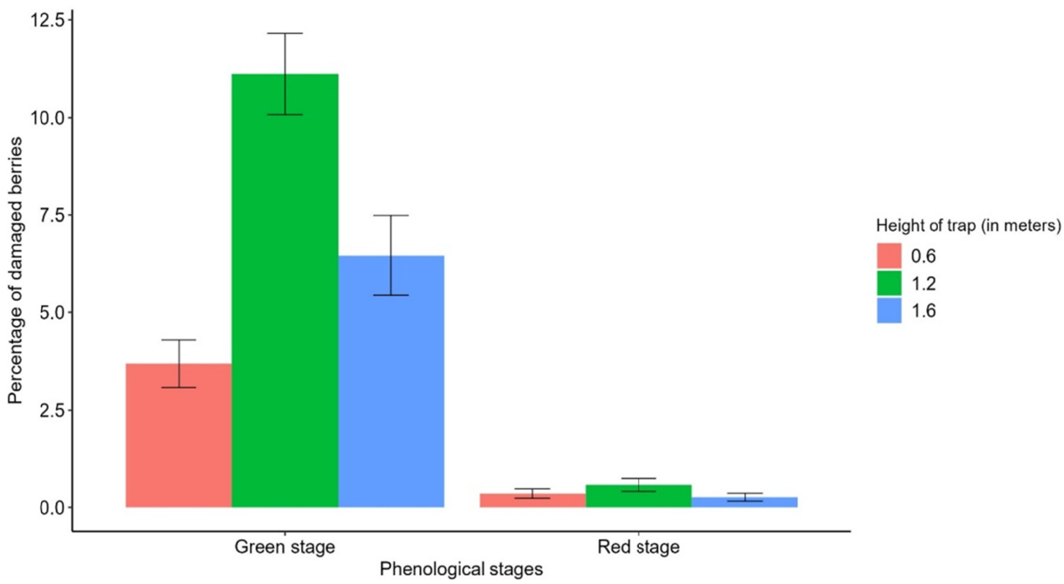

Figure 4. The use of bottle-baited traps at a different height with the percentage of damaged berries by CBB during phonological developmental stages of coffee berries

There was a significant positive statistical relationship between the number of adult CBB and the proportion of damaged berries by CBB during the study period ($r^2 = 0.22$, $p < 0.001$) (Figure 5).

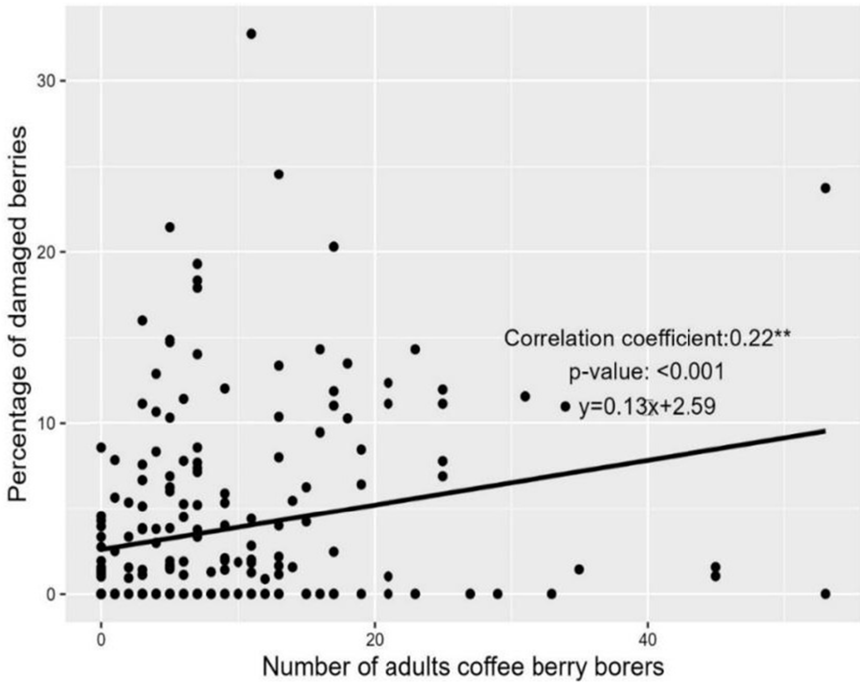

Figure 5. Relationship between the numbers of captured adult coffee berry borer (CBB) and level of infestation (percentage of damaged berries by CBB) in the study area

3.2 Influence of Rainfall, Temperature, and Relative Humidity on the Berry Damage by CBB

The weather information during the experimental period is shown in Table 1. Only temperature and relative humidity showed a significant statistical relationship with the percentage of damaged berries by CBB (Table 1). However, the temperature had a significant positive effect (r^2 = 0.545) while relative humidity had a negative effect (r^2 = -0.331) on the percentage of damaged berries by CBB (Table 1).

Table 1. Pearson's correlation between environmental conditions and coffee infestation by coffee berry borer (CBB)

	Rainfall	Temperature	Relative humidity
Berries damaged	**0.057**	**0.545*** **	**-0.331*** **
Number of adults CBB	**-0.008**	**0.007**	**0.002**

Note. *** Significant at 0.1% level of probability, ** significant at 1% level of probability, and * significant at 5% level of probability.

4. Discussion

4.1 Infestation of Coffee Berries by CBB in Relation to Heights of the Traps

The study revealed that both green and red coffee berries experienced less damage when positioned at a height of 0.6 meters above the ground compared to berries at other branch heights closer to the ground. This phenomenon could be attributed to the concentration of food resources, specifically coffee berries, within the branches of coffee trees situated above the 0.6-m height mark. Likewise, it's possible that the flight behavior of the (CBB) influenced this pattern, as CBBs tend to prefer flying within the range of one to two meters above the ground. This observation aligns with a similar finding reported by Prakoso et al. (2020), which suggests that insects can still be captured in traps positioned up to 1.4 m high, as coffee berries within this height range remain susceptible to infestation.

However, it's worth noting that our findings contradict the results reported by CABI in 2006, which indicated that CBBs prefer to fly in the evening at a significantly higher altitude, around 4-5 m, covering distances of 300-400 m. This discrepancy may stem from variations in environmental conditions or local factors influencing

CBB flight behavior. In light of the study's results, to enhance coffee berry production and quality, it is advisable to position traps at a height of 0.6 m. This approach appears effective in reducing infestation, particularly considering the population density of female adult CBBs (Durfour et al., 2008). Their research demonstrated that traps positioned at a vertical height of 0.5 m within coffee trees captured more adult CBBs, thus contributing to a potential reduction in the overall population density of this insect pest

4.2 Percentage of Damaged Berries by CBB During Phonological Developmental Stages of Coffee Berries at Different Heights

From the results, the minimum percentage of damage was recorded at 1.6 m trap height (0.26%) in the red (ripening) developmental stages of the berries, where numerous berries were inflicted during the period of green stage trap placed at the height of 1.2 m and 0.6 m from the ground. These results might be associated with the presence of berries at that specific height and green stage as preferred more than red because they are easy to penetrate (boring) for making galleries. Likewise, the adult females Coffee berry borer (CBBs) are always attracted to kairomones which are released by developing berries in the coffee field. A similar result was observed by Azrag et al. (2019) in a study where he revealed that adult female feeding injuries on developing fruit (green fruit) lead to berry drop, and offspring feeding galleries in the berry endosperm (coffee seeds) leading to bean dry weight loss and increased vulnerability to diseases infestation.

Furthermore, Asfaw et al. (2019) reported the same, CBBs start and prefer infesting the green stages berries in the field when the dry content of the berry which has to be 20% or higher as this usually acts as a determining factor for the progress of the penetration, also Damon (2000) reported the similar result that Low damage on red ripe berries by CBB regardless of attacking all developmental stages of coffee berries causing a considerable amount of losses. The female usually bore the coffee berry through the disc, originally the floral disc of the flower, the style passes through the floral disc in the flowering stage; during fruit development the hole close up as the style dies back. It has been presumed that the disc is the favourite area for boring as it provides a non-smooth surface for an insect pest to hold on to while initiating the boring process, where the average time to enter the green berry was 4 h and 16 min as reported by (Vega et al., 2015). Regardless of all the developmental stages of the coffee fruit to be attacked, the green berry stage is an important time for placing this trap in the field to avoid the infestation and damage of the berries which can reduce the production and quality of the coffee product.

4.3 The Influence of Temperature and Relative Humidity on the Berry Infestation by CBBs

Along with the positive effect of increasing temperature, we found a negative significant relationship between CBB berries damage and mean relative humidity. This is in line with the findings of several studies that reported temperature and relative humidity as the main abiotic factors positively influencing beetle CBB infestation in the coffee field (Chen et al., 2014). The mean diurnal air temperature was observed in the study to be the single weather variable with the strongest (positive) relationship to CBB damage to the berries in the field. Since insects are poikilotherms, meaning their body temperature in multitudinous aspects of insect biology are driven by temperature including generation length rate of development, mating activities, and dispersal. Thus, the increase in temperature may enhance the production of more CBBs in the area which lead to more infestation of coffee berries in the specific study area. Furthermore, Jaramillo et al. (2011) reported that the thermal conditions necessary for the development of the CBBs range between 13.9 to 15 °C and 25 to 27 °C mean and maximum temperature respectively are optimal for reproduction. The normal range for minimum and maximum temperature at the study site was (14 to 19 °C and 21.2 to 31 °C) which is relevant to the other findings. Moreover, the study done by (Constantino et al., 2021) revealed that infestation of CBBs in the coffee tree was positively correlated with the temperature. Therefore, these changes in temperature favour or limit the biology, development, and emergence of the CBB (Marinol et al., 2016; Johson et al., 2019). Contrary to the study by (Hamiliton et al., 2019) that mentions that the development time of CBB increases with increasing elevation and decreasing temperature, making a negative correlation with CBB damage. An increase in mean temperature is expected in the face of global climate change which may cause changes in insect populations at different altitudinal ranges such as differences in insect-host-plant interaction lags in the synchronization of host insect and parasitoid activity periods and changes to the growth and abundance survival, feeding rates and life cycles of herbivorous insect (Jaramillo et al., 2009; Hil et al., 2011). Therefore knowledge of natural climate variation and the impacts of climate change on insect pests and beneficial insects is important to prevent phytosanitary problems and to develop strategies to adapt to the expected change.

Also, the study showed that relative humidity had negative effects (relationship with CBBs to the berries damage. The negative correlation between CBB emergence and the positive correlation with temperature obtained in this study can be explained by the study of (Hamiliton et al., 2019) which mentions that the development time of CBB increases with increasing elevation and decreasing temperature with the mean requirement. Increase of relative humidity decrease of damage weak correlation and negative correlation.

The CBBs prefer more humidity therefore coffees under shade are susceptible more because they multiply more in such conditions (Damon et al., 2000). Emergence of coffee berry borer from gleanings showed a maximum emergence of borer when the samples were exposed under a natural shower and minimum emergence at 90% relative humidity. This is in confirmation of the earlier result that heavy rain also triggered the emergence of the beetle (Screedharan et al., 1994) and low humidity < 60%, RH 25 ^{o}C) provoked rapid evacuation of adults and while it was minimum at 90% RH (Baker et al., 2009). The knowledge that CBB responds to the vertical distribution of the traps also accelerated with some weather variables such as rainfall temperature and relative humidity as reported by Uemura-Lima et al. (2010). The findings presented here are an important first step in exploring plastic baited traps for the protection of coffee from CBB as part of the comprehensive Integrated Pest Management Program.

5. Conclusion and Recommendation

This research found that a plastic bottle-baited trap, placed at a 0.6 m height from the ground always maintained the lowest PDB throughout the study period. Furthermore, the lowest damage in the phonological stage was observed in red berries fruit. Therefore, proper harvesting at the red ripe stage is important to minimize the occurrences of CBB and increase the quality of coffee berries. Furthermore, it is imperative to implement an integrated pest management strategy for the control of CBB especially in the green berries fruit stage as the highest damage inflicted in this stage. Still, similar damage to berries deserves timely and due attention, because the similar huge amount of damage can cause a direct loss in terms of yield quality of harvestable coffee berries.

References

Abate, B. (2021). Coffee Berry Borer, *Hypothenemus hampei* (Ferrari) (Coleoptera: Scolytidae): A challenging coffee production and future prospects. *American Journal of Entomology, 6*(53), 39-46. https://doi.org/10.11648/j.aje.20210503.11

Abewoy, D. (2022). Impact of Coffee Berry Borer on Global Coffee Industry. *International Journal of Novel Research in Engineering and Science, 9*(1), 1-8.

Aristizábal, L. F., Shriner, S., Hollingsworth, R., & Arthurs, S. (2017). Flight activity and field infestation relationships for coffee berry borer in commercial coffee plantations in Kona and Kau districts, Hawaii. *Journal of Economic Entomology, 110*(6), 2421-2427. https://doi.org/10.1080/03235408.2019.1594541

Asfaw, E., Mendesil, E., & Mohammed, A. (2019). Altitude and coffee production systems influence the extent of infestation and bean damage by the coffee berry borer. *Archives of Phytopathology and Plant Protection, 52*(2), 170-183. https://doi.org/10.1080/03235408.2019.1594541

Azrag, A. G., & Babin, R. (2023). Integrating temperature-dependent development and reproduction models for predicting population growth of the coffee berry borer, *Hypothenemus hampei* Ferrari. *Bulletin of Entomological Research, 113*(1), 79-85. https://doi.org/10.1017/S0007485322000293

Baker, P. S., Ley, C., Balbuena, R., & Barrera, J. F. (2009). Factors affecting the emergence of *Hypothenemus hampei* (Coleoptera: Scolytidae) from coffee berries. *Bulletin of Entomological Research, 82*(2), 145-150. https://doi.org/10.1017/S000748530005166X

Constantino, L. M., Gil, Z. N., Montoya, E. C., & Benavides, P. (2021). Coffee berry borer (*Hypothenemus hampei*) emergence from ground fruits across varying altitudes and climate cycles, and the effect on coffee tree infestation. *Neotropical Entomology, 50*(3), 374-387. https://doi.org/10.1007/s13744-021-00863-5

Damon, A. (2000). A review of the biology and control of the coffee berry borer, *Hypothenemus hampei* (Coleoptera: Scolytidae). *Bulletin of Entomological Research, 90*(6), 453-465. https://doi.org/10.1017/S0007485300000584

Gottstein, V., Bernhardt, M., Dilger, E., Keller, J., Breitling-Utzmann, C. M., Schwarz, S., & Bunzel, M. (2021). Coffee silver skin: Chemical characterization with special consideration of dietary fiber and heat-induced contaminants. *Foods, 10*(8), 1705. https://doi.org/10.3390/foods10081705

Hamilton, L. J., Hollingsworth, R. G., Sabado-Halpern, M., Manoukis, N. C., Follett, P. A., & Johnson, M. A. (2019). Coffee berry borer (*Hypothenemus hampei*) (Coleoptera: Curculionidae) development across an elevational gradient on Hawaii Island: Applying laboratory degree-day predictions to natural field populations. *PLoS One, 14*(7), 218321. https://doi.org/10.1371/journal.pone.0218321

Hernández-Castro, E., Sotelo-Nava, H., Godínez-Jaimes, F., Durán-Trujillo, Y., García-Escamilla, P., & Valenzuela-Lagarda, J. L. (2021). Coffee berry borer (*Hypothenemus hampei* Ferrari) trapping in coffee (*Coffea arabica* L.) with artisan traps at el Paraíso, Guerrero, Mexico. *Agro Productividad, 14*(05), 1-2 https://doi.org/10.32854/agrop.v14i2.1970

Infante, F., Armbrecht, I., Constantino, L. M., & Benavides, P. (2023). Coffee pests. *Forest Microbiology* (pp. 213-225). Academic Press. https://doi.org/10.1016/B978-0-443-18694- 3.00015-8

Jaramillo, J., Muchugu, E., Vega, F. E., Davis, A., Borgemeister, C., & Chabi-Olaye, A. (2011). Some like it hot: The influence and implications of climate change on coffee berry borer (*Hypothenemus hampei*) and coffee production in East Africa. *Public Library of Science One, 6*(9), 24-28. https://doi.org/10.1371/journal.pone.0024528

Johnson, M. A., & Manoukis, N. C. (2021). Influence of seasonal and climatic variables on coffee berry borer (*Hypothenemus hampei* Ferrari) flight activity in Hawaii. *Public Library of Science One, 16*(12), 25-61 https://doi.org/10.1371/journal.pone.0257861

Johnson, M. A., Fortna, S., Hollingsworth, R. G., & Manoukis, N. C. (2019). Postharvest population reservoirs of coffee berry borer (Coleoptera: Curculionidae) on Hawai'i Island. *Journal of Economic Entomology, 112*(6), 2833-2841. https://doi.org/10.1093/jee/toz219

Johnson, M. A., Ruiz-Diaz, C. P., Manoukis, N. C., & Verle Rodrigues, J. C. (2020). Coffee berry borer (*Hypothenemus hampei*), a global pest of coffee: Perspectives from historical and recent invasions, and future priorities. *Insects, 11*(12), 882. https://doi.org/10.3390/insects11120882

Kiwelu, L. K., Damas, P., & Mpenda, Z. (2021). Assessment of Factors Causing Coffee Yield Gap among Smallholder Farmers in Mbinga and Mbozi Districts. *International Journal of Agricultural Economics, 6*(1), 21. https://doi.org/10.21203/rs.3.rs-181896/v1

Lemma, D. T., & Megersa, H. G. (2021). Impact of climate change on East African coffee production and its mitigation strategies. *World Journal of Agricultural Sciences, 17*(2), 81-89. https://doi.org/10.5829/idosi.wjas.2021.81.89

Mafra-Neto, A., Wright, M., Fettig, C., Progar, R., Munson, S., Blackford, D., & Stelinski, L. L. (2022). Repellent semiochemical solutions to mitigate the impacts of global climate change on arthropod pests. *Advances in arthropod repellents* (pp. 279-322). Academic Press. https://doi.org/10.1016/B978-0-323-85411-5.00010-8

Pereira, A. E., Gontijo, P. C., Fantine, A. K., Tinoco, R. S., Ellersieck, M. R., Carvalho, G. A., & Vilela, E. F. (2021). Emergence and Infestation Level of *Hypothenemus hampei* (Coleoptera: Curculionidae) on Coffee Berries on the Plant or the Ground during the Post-harvest Period in Brazil. *Journal of Insect Science, 2*(12), 10-11. https://doi.org/10.1093/jisesa/ieab022

Sambony, L., & Gerarldo, E. (2021). *The conceptual model for detecting favorable conditions of coffee pests in a smart farming environment* (Doctoral dissertation, University of Cauca, Columbia).

Tibpromma, Lu, L., S., Karunarathna, S. C., Jayawardena, R. S., Lumyong, S., Xu, J., & Hyde, K. D. (2022). A comprehensive review of fungi on coffee. *Pathogens, 11*(4), 411. https://doi.org/10.3390/pathogens11040411

Vega, F. E., Infante, F., & Johnson, A. J. (2015). The genus Hypothenemus, with emphasis on H. hampei, the coffee berry borer. *Bark beetles* (pp. 427-494). Academic Press. https://doi.org/10.1016/B978-0-12-417156-5.00011-3

Wraight, S. P., Galaini-Wraight, S., Howes, R. L., Castrillo, L. A., Griggs, M. H., Carruthers, R. I., & Keith, L. M. (2021). Efficacy of Beauveria bassiana strain GHA sprays applications against coffee berry borer *Hypothenemus hampei* on Hawaii Island. *Biological Control, 7*(161), 10-45. https://doi.org/10.1016/j.biocontrol.2021.104587

Zewide, I. (2021). Review on the status of organic farming. *European Journal of Agriculture and Forestry Research, 9*(3), 34-40.

Acknowledgments

The authors would like to thank the Sokoine University of Agriculture (SUA) through the Department of Crop Science and Horticulture for their advice, positive criticism, and knowledge acquisition during the study. The authors also wish to acknowledge the generous financial support from Coffee farmers in Tanzania and the Ministry of Agriculture to the Tanzania Coffee Research Institute (TaCRI) which facilitated the Institute's funding of this study.

Authors Contributions

Not applicable.

Funding

The research is financed by the Tanzania Coffee Research Institute (TaCRI).

Competing Interests

The authors have no conflict of interest to declare that are relevant to this article.

Informed Consent

Obtained.

Ethics Approval

The Publication Ethics Committee of the Canadian Center of Science and Education.

The journal's policies adhere to the Core Practices established by the Committee on Publication Ethics (COPE).

Provenance and Peer Review

Not commissioned; externally double-blind peer reviewed.

Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Data Sharing Statement

No additional data are available.