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Efficacy of Plastic Bottle-Baited Traps for Capturing Coffee Berry Borer and Other Coffee Insects Pests in Kilimanjaro Region-Tanzania

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Abstract: Globally, the coffee industry loses millions of dollars per annum due to the effects caused by Coffee Berry Borer (CBB) (*Hypothenemus hampei* Ferrari) which reduces the yield and quality of coffee by boring into the coffee fruit and destroys the marketable product. Plastic bottle-baited traps with methylated spirit and water ratio 1:1 (v/v) have been locally designed to control CBB. However, there is limited information on proper height and spacing for placing the traps in controlling this insect pest. The present study aimed to evaluate the efficiency of this trap placed at different heights and spacing in capturing CBB and other coffee pests in the coffee field. Unlike spacing, the trap's heights showed a significant effect on the total number of captured CBBs ($p=2.01\times10^{-9}$) and other coffee insect pests, in this case, only Black coffee twig borer BCTB were captured (p=0.007671). The trap height at 1.2 m and 1.6 m captured a total of CBB (208) and BCTB (19) respectively. However, there was a significant effect of the trap's spacing on capturing the CBB over time (p=0.04540). But there was a significant effect of spacing (p=0.0004910), height (p= 0.0007209), and interaction of spacing and height ($p=1.428\times10^{-5}$) traps on which traps were placed. According to the study findings placing the trap at a height of 1.2m and spacing of 5m is more efficient in capturing CBB and lowering their population in the field. The study found that plastic baited traps could be explored as a useful tool for capturing the CBB, considering its monitoring and management.

Keywords: *Coffea arabica*, *Hypothenemus Hampei*, Coffee Berry Borer, Baited Trap Spacing, Height

1. Introduction

Coffee (*Coffea* spp.) (Gentianales; Rubiaceae) is one of the major perennial cash crops that contributes significant income for more than 80 tropical countries in the international agricultural trade [1, 2]. It is the most important agricultural commodity in the globe, ranking second after oil with annual revenue exceeding the USA 70 billion [3, 4]. According to the United States Department of Agriculture USDA [5], the world production of Coffee is estimated at 175.8 million bags (a bag weighing 60 kg) in 2020–2021, and world exports at 120.3 million bags. In Africa, the largest coffee producers are Ethiopia, Uganda, Cote D`lvoire, and Tanzania where coffee employs about a 22million people [6].

From Coffee, Tanzania generates average export earnings of 100 million USD per annum, whereas about 320,000 households are benefited from the crop [2]. Approximately 90% of total coffee is produced by smallholder farmers averaging one hectare while the remaining 10% is grown on more than 110 estates [7]. Regardless of this downward trend of coffee production, coffee remains a key driver of the Tanzania economy [8] Despite the importance of coffee in the Tanzania economy, the average annual production in the country has stagnated at a level of about 50,000 metric tons over the past 35 years [8]. At the same time, yields have fluctuated significantly and quality potential has not been fully exploited [8] Insect pests, diseases, decreasing soil fertility, and susceptibility of coffee cultivars to climate variability are major constraints threatening Arabica coffee production in East Africa including Tanzania [1, 9, 10].

One of the causes of decreased coffee production is the attack of Coffee berry borer (CBB) *Hypothenemus hampei*

Ferrari. The Coffee berry borer is the primary insect pest that attacks coffee plants around the world [11]. Originating from Central Africa, CBB can be found in most coffee-growing countries throughout the world [12]. Female beetle borer holes into developing berries attached to the tree through the blossom scar and create “galleries” where they remain and deposit their eggs [13]. The developing larvae feed on the bean, or endosperm of the seed, reducing yield as well as the quality of coffee and its price [14, 15]. Various studies have shown the impact of climatic variables that directly affect the biology of this insect pest and have influenced the population and infestation of Coffee in the field [13, 16]. The fact that CBB and their larvae live in coffee beans means they are protected against harsh environmental conditions, predators, and contact insecticides [17]. In Africa, CBB is regarded as the most prevalent insect pest. Losses in untreated farms and cases of high parasitic pressure have been estimated to be 60% in Colombia, 58-85% in Jamaica, 50-90% in Malaysia, 60% in Mexico, 90% in Tanzania, and 80% in Uganda [18].

Strategies that have been used for the management of CBB include chemical, biological, and cultural controls. But due to concerns for human and environmental health, chemicals such as *endosulfan* and *chlorpyrifos* are being phased out or banned in several coffee-growing countries [11, 12]. Biological control using parasitoids has also been executed, particularly in Latin America, but with limited success due to the need for augmentative releases [19, 20]. Cultural controls are typically the furthermost cost-effective method for managing CBB [21, 22]. A critical aspect of most successful Integrated Pest Management (IPM) programs is the monitoring of pest flight activity and control with traps. Trap baited with ethanol and methanol lure ethanol are used in many countries to monitor CBB activity [20, 23, 24, 25]. Mass-trapping using Bottle baited traps with a mixture of methylated spirit and water (1:1) in the coffee field has been suggested as a possible method of reducing the population of CBB in Tanzania, which significantly can reduce infestation up to 75% [26]. Consequently, the Bottle baited traps developed by the Tanzania Coffee Research Institute (TaCRI) for capturing adult coffee berry borer have continued to be used by farmers as they are simpler and cheaper than other traps like the BROCAP® trap [26].

Furthermore, the effectiveness of bottle-baited traps in capturing coffee insect pests is influenced by many factors, including weather variables rainfall, wind speed, relative humidity, temperature, and trap type [27]. Bottle-baited trap height and spacing strongly influence the catch number of CBB and other coffee insect pests [28]. However, little is known about the best height and space distance for placing these traps in the fields for proper controlling and monitoring of the insect pest population.

Therefore, an assessment of the factors that influence bottle-baited trap efficacy such as trap height and inter-trap distance (spacing) is required to successfully implement a plastic bottle-baited trap for coffee berry borer in the coffee field. In this study, the effects of trap height and trap distance (spacing) were investigated to reveal their efficacy on CBB and other coffee insect pests captured in bottle-baited traps.

2. Materials and Methods

2.1. Study Site and Duration

The field experiments were conducted at Lyamungu Tanzania Coffee Research Institute (TaCRI) Station; Hai district in Kilimanjaro region, located at (14’41.4353” S, 37^{o} 14’47.65502" E) and 1268 meters 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 21.2C^{0} to 31C^{0} per year while the average minimum air temperature ranged from 14C^{0} to 19C^{0}. The evaluation was carried out from November 2021 to October 2022. The site was selected because it is a hotspot for Coffee berry borer (CBB) and the presence of a Meteorological Station nearby was another advantage of the site in ensuring the availability of weather data.

2.2. Trap, Dispenser, and Semiochemicals

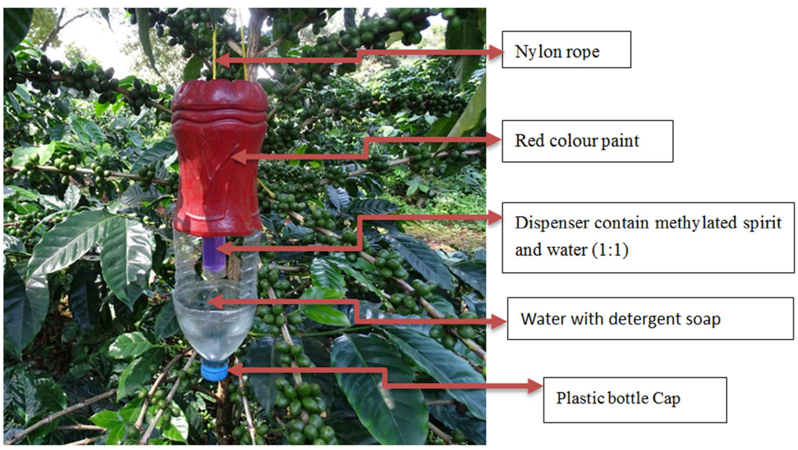


Figure 1. *Plastic Bottle Trap Baited with a 1:1 Methylated Spirit and Water (Photo by Aden Mbuba).*

The study used a Modified local trap model, developed by Researchers from (TaCRI) using a recycled empty clear plastic bottle of 1.5-litre capacity, with a window opened on two sides (8 cm x 8 cm) (Figure 1). Half of the trap was painted with red colour to maximize attractiveness to the CBB [21]. A dispenser of 30mls containing semiochemical (70% methylated spirit 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 through those opening for attracting adult female CBB [26]. Water with 5% detergent was added at the bottom of the bottle to help drown the CBBs adults and other coffee pests captured by the trap.

2.3. Placement of Traps and Experimental Design

A coffee monocrop field of a 1-hectare area was purposively selected for the establishment of the experiment. The area was planted with *Coffea arabica* (variety Compact) at a spacing of 2m x1.5m (inter-row x Plants within the row). The coffee plants had an average height of 1.8m. The area was sufficient enough to allow enough space for the allocation of the bottle-baited traps. A Randomized Complete block design (RCBD) with a factorial arrangement of two factors was used. Factor A was trap Spacing, with three levels (5m, 10m, and 15m), and factor B was trap Height, with three levels (0.6m, 1.2m, and 1.6m), making Nine treatments that were replicated four times. A total of 36 bottle-baited traps were fixed to the coffee plant at the respective heights and spacing. The bait in each trap was changed after every 2 weeks to maintain the trapping efficiency of the lure. The CBB and other coffee pests caught in each trap were collected every after 3 days for 12 months consecutively.

2.4. Data Collection

The observed variables in this study were the number of adult CBB Captured and the number of other coffee pests captured in the trap (Black coffee twig borer). The catches were duly separated and identified for each baited trap and the corresponding height and spacing. Then, the samples were taken to the laboratory for identification of insect species based on morphological characters under a stereomicroscope as per [29] and recorded. The total CBB and other beetles in the family Scolytidae were recorded separately.

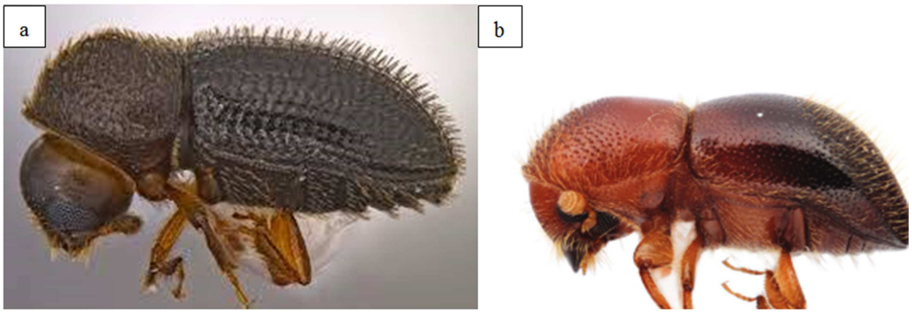


Figure 2. *Coffee Berry Borer (Hypothenemus hampei) (a) and Black Coffee Twig Borer (Xylosandrus compactus) (b). (Source Johnson et al., 2022).*

2.5. Data Analysis

Data were analysed using R-statistical software version 4.0.4 (R Core Team, 2021). The normality and homozygosity distribution of data was checked using the Shapiro-Wilk test and Levene test respectively at a 5% significance level. Furthermore, the data on trap capture of adult Coffee berry borer (CBB) and adult Black coffee twig borer (BCTB) at specific heights and spacing over time were analysed by a generalized linear model by data transformation using the log link gamma function according to Ruiz-Diaz and Rodrigues, 2021. Correlation analyses were also performed for the statistical relationship between CBB captured and weather variables at a 5% significance level.

3. Results

3.1. Effect of Height on Trap Efficiency

The total adult CBB captured significantly varied in different heights of trap ($p=2.01\times10^{-9}$). The highest total captures were 208 CBB at 1.2 m trap height while the minimum capture of CBB was 98 CBB at 0.6 m trap height (figure 3a). The total captured Black coffee twig borer also differed, significantly due to trap heights (p=0.007671). At 1.6 m trap height, there was a significantly higher total captured BCTB (19) and fewer captured BCTB (11) were recorded at 0.6 m trap height (figure 3b).

3.2. Effect of Spacing on Trap Efficiency

There were no significant differences due to the spacing of traps (p=0.43) and the interaction between height and spacing of traps (p=0.35) on total captured CBB. However, there was no significant effect of the trap's spacing (p=0.322051) and the interaction of height and spacing of the trap (p=0.148210) on the total number of captured BCTB.

3.3. Seasonal Variation in Trap Catches

The trap's capturing of CBB showed a slightly significant variation in the spacing of traps over time (p=0.04540). The capturing of CBBs was significantly higher in May at both trap spacing distances, however, more CBBs (30 CBBs) were captured at 10 m during the same month (figure 4). However, there was no significant difference in traps captured CBB by heights of traps over time (p=0.06201) and by the interaction of height and spacing of traps over time (p=0.81396).

The trap's capturing of BCTB showed significant variation by height over time (p= 0.0007209), by spacing over time (p= 0.0004910), and by the interaction effect of height and spacing over time (p= 1.428×10^{-5}). The BCTBs were more captured (10 BCTBs) at a spacing of 15 m in November (figure 5c), followed by a spacing of 5 m (5 BTCBs) in May and a spacing of 10 m (5 BTCBs) both height of 1.6 m (figure 5b and 5a respectively).

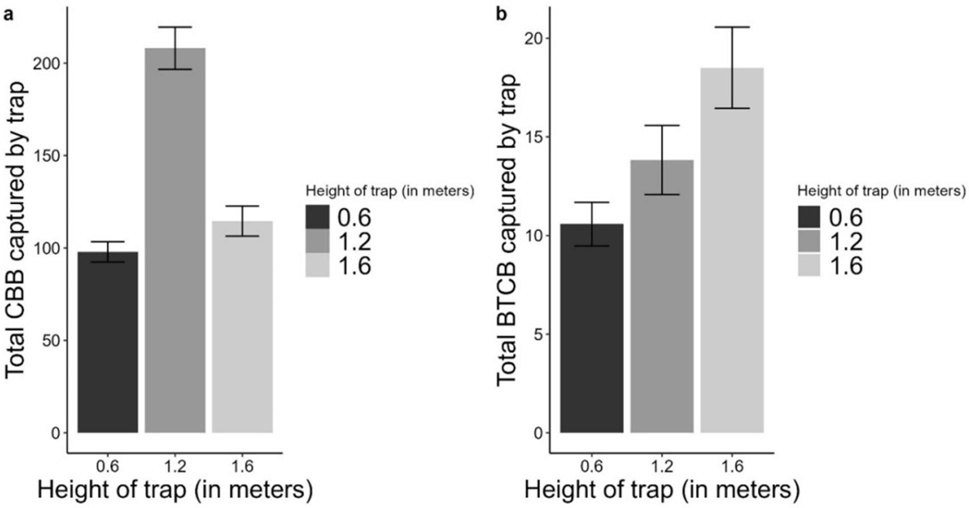


Figure 3. *Total Number of Captured CBB (a) and BTCB (b) at Different Heights during the Study Period (12 months).*

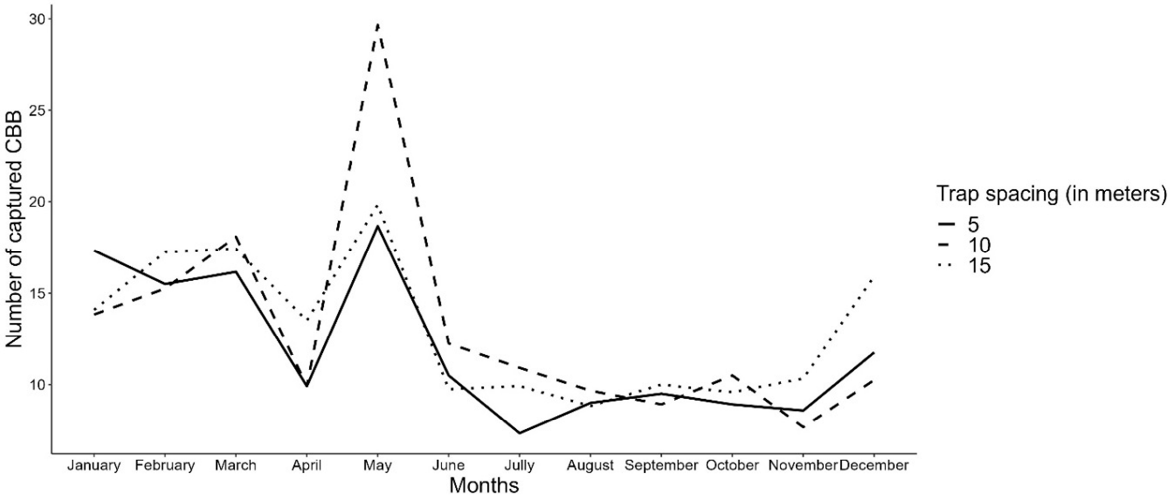
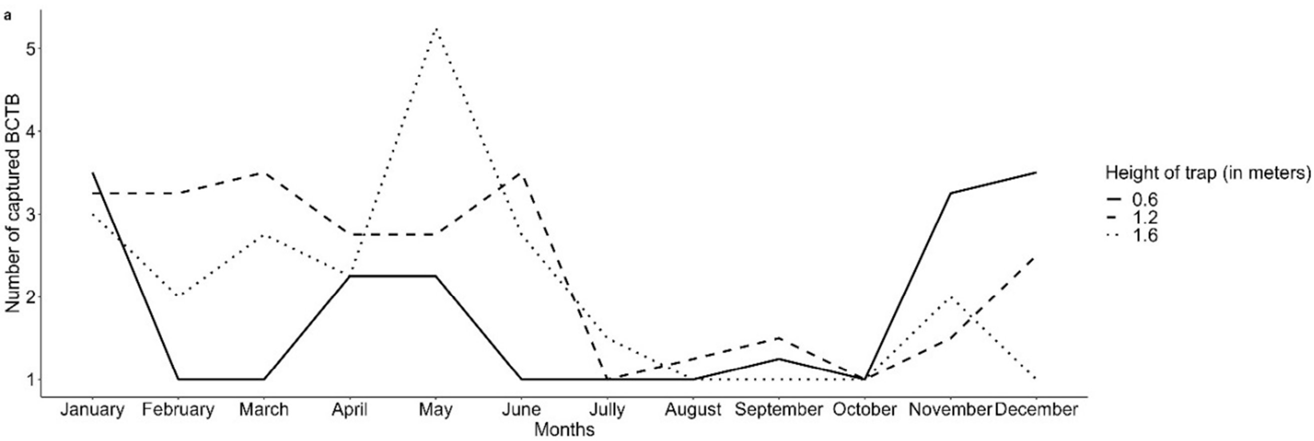


Figure 4. *The Number of Captured CBB in Each Month at a Different Spacing Distance (in meters) Throughout the Study Period (12 months).*



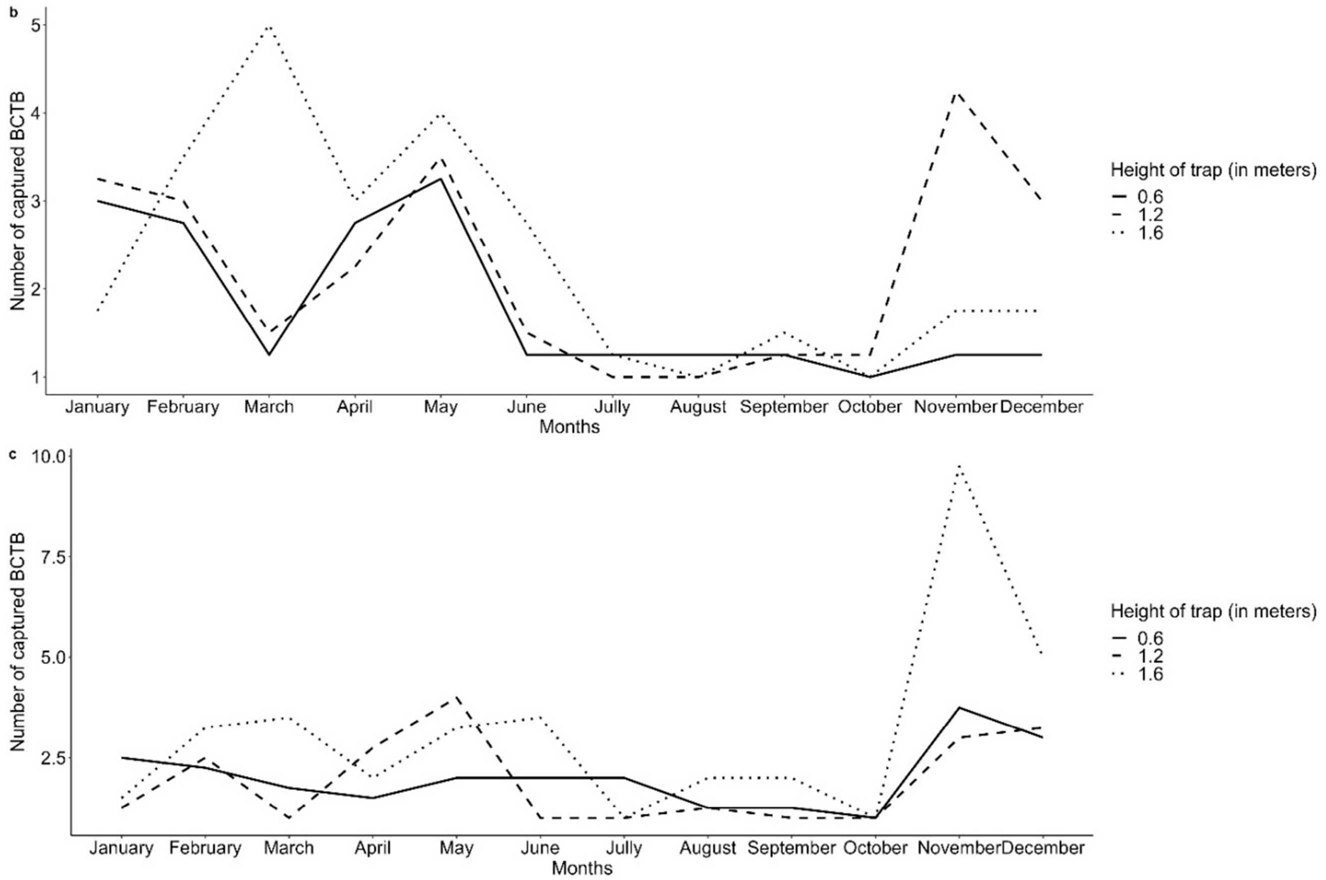


__Figure 5.__ The Number of Captured BCTB in Each Month at Different Trap Heights (in meters) at (a) 5 m (b) 10 m and (c) 15 m Spacing Throughout the Study Period (12 months).

3.4. Implication of Weather Variables on the Population of Captured Coffee Berry Borer (CBB)

The monthly mean temperature, rainfall, relative humidity, and solar radiation in the site where an experiment was conducted are presented in Table 1. The results showed that rainfall and relative humidity (Table 2) had a significant positive correlation with captured CBB (r^2=0.175, p<0.001) and (r^2=0.135, p<0.01) respectively.

__Table 1.__ Summary of Weather Variables Information during the Study Period of 2022, Source: North Zone Tanzania Coffee Research Institute, Lyamungu Meteorological Station).

Months	Temperature	Rainfall (mm)	Relative humidity (%)	Solar radiation
January	22.12	51.30	66.00	21.28
February	21.87	139.70	76.00	18.33
March	22.24	29.90	69.00	21.19
April	21.40	310.40	81.00	14.87
May	19.70	219.80	83.00	11.99
June	19.04	209.00	84.00	8.48
July	17.86	57.00	79.00	11.18
August	21.81	16.70	68.00	13.04
September	19.03	3.60	74.00	13.75
October	20.80	20.80	67.00	16.68
November	21.70	21.70	63.00	23.27
December	22.12	52.10	77.00	16.88

__Table 2.__ Pearson Correlation Coefficient (r^2) of the Relationship between Environmental Conditions and the Number of Captured adult coffee berry borer (CBB) during the Study Period of One Year.

Captured coffee pests	Environmental/or weather variables			
	Temperature	Rainfall	Relative humidity	Solar radiation
CBB	0.093	0.175***	0.135**	0.053

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

4. Discussion

4.1. Effect of Height on Trapping Efficiency

The height of the trap affects the number of CBB populations caught in the trap that can be placed. From the findings, our result revealed that plastic bottle-baited traps placed at a height of 1.2 m above the ground were observed to capture more CBB than those placed at 0.6 and 1.6 m heights from the ground. Therefore, the height at which each trap is placed is crucial; our results establish a significant difference among the plastic bottle-baited trap heights. It was the height of 1.2 m above the ground that captured the highest numbers of adults CBB. This might have been associated with the nature of flying height of CBBs and presence of food (fruit berries) in the coffee tree, where most of the berries in the coffee tree branches were present near that height from the ground as more CBB were captured in the period of green fruit present in the coffee farm, also this height is near with attractant or trap flying height which is preferred by the pests during the mating period. Similar observations were made by [30] who realized that placing a BROCAP® trap at a 1.2 m height capture rate was three times better than that for a position near ground level. Contrary to Ruiz-Diaz *et al.* [27] who found that placing a trap at this 0.5 m height captures more CBBs. Furthermore, [21] reported that during migration periods, colonizing female populations leave residual fruits in enormous numbers and take flight this is the time when are captured more. Therefore, would suggest that the best captures can be achieved with the trap placed at 1.2 m from the ground. Also, most of the flying heights of this insect beetle are from one meter to two-meter height vertically, therefore it is possible to be captured within the range of flying height, especially during the period of searching for food. Therefore, the insect flies to the nearest attractant or trap as per migration cost based on the concept which says that “Insects will fly to the nearest source of food-conserved energy” as reported by [31]. Furthermore, [32] reported the height of CBB flies in the absence of berries is higher than those in the reproductive period of the coffee planting which could also affect this insect pest's chemical and or visual response to the trap.

Regardless of their long and widespread use of baiting traps, there are considerable discrepancies between different research about the optimum capture of CBB. Probably, the condition under which coffee is grown (climate, spacing, shade, cultivar, plant age, wind direction, speed height of the trap, etc) may affect trapping efficiency [33]. This can bring some discrepancy in the results involving the capture of CBB in response to semiochemicals, which may interact with other factors.

4.2. Effect of Spacing on Trapping Efficiency

However, the trap collected CBBs at all three distances during the entire studied period with significant differences between the three distances over time was 10m in May. This might be associated with suitable food which accelerates the addition and increases the number of pests. May is the time when there's a lot of food for the insects as berries are numerous and green in colour which is further preferred by the pest. Also, the results endorse that the utmost of the adult CBB population has preferred insects of short or low flight. The CBBs that lived in the dry berries (raisins) on the ground, when they fly again and are subject to the vacuity of an attractant, will first populate berries in branches closer to the flying distance. Likewise, the variation between the number of CBBs captured at the first installation and the end of the trial may have been caused by the condition of the CBB population in the field. The largest population that passed when the traps were first installed, also dropped sluggishly, as numerous insects had been caught in the traps. The other reason was that the factual CBB population in the field was small due to limited food because utmost coffee berries were still at the pinhead experimental stage and weren't yet fit as food for the insects.

The height of CBB flies in the absence of berries is more advanced than those in the reproductive period. Thus, the use of plastic baited traps to capture CBBs also can induce a chart of CBB infestation in the area that exposes the extremely overran trees or hotspots near the traps. The chart can help CBB control at each point potentially indicating the necessity for an early crop of the coffee factory located around the traps (subject to the fruit development) to avoid the CBB population from reaching too grandly a position. This approach would lead to cost reduction in coffee ranch operation.

4.3. Seasonal Variation in Trap Catches

The results of observations of other types of insect pests captured in the Plastic baited bottles trap for one year in the coffee field plantation was only Black coffee twig borer (*Xylosandrus compactus)*. The trap’s capturing of BCTB showed significant variation by height over time and spacing over time also, as by the interaction effect of height and spacing. The adult BCTBs were more captured at a spacing of 15 m in November, both at a height of 1.6 m. This might be associated with the coffee farm infested by the pest near the site where the trial was established. Therefore, the area of the experiment which was close to a Coffee plantation about 20 m, had some spot infestation with the pest, hence might have migrated from the other tree although they didn’t infest the trial and were surrounded by the forest. Furthermore, a few beetles flew at a height of up to 2 m and those beetles also pose a threat to trees. Whether that beetle was flying at those heights naturally or attracted to them by the methylated spirit and water lures. This result is slightly similar to the findings of [34] who reported that most BCTB are captured at 1.5m by using methanol and ethanol 3:1 lure and the reasons behind this might be the nature of attacking damage of the pest which always attacks the twig of the coffee branches as only female beetles cause damage to the plants by tedious into the tissue of the host. They bore through the xylem into the twig pitch and having reached, the pitch they masticate along the axis of the twig to make a common brood cavity for the eggs. It is presumably because the insect has an interest in volatile compounds similar to the sex pheromones contained in the coffee bean extract and pericarp According to [23]. Moreover, insects' attraction to plants can be influenced by kairomones and plant colour, among other factors. The result showed that the BCTB beetle also responded to the vertical distribution of the baited traps used in the experiment, especially when the three heights were used, but captures concentrated in the trap placed at a height of 1.6m.

The mixture of methylated spirit and water at a ratio of (1:1) attracts the black coffee twig borer into the traps and it gets killed by water instead of costly synthetic pesticides. The study has found the black coffee twig borer can be contained ecologically or through integrated pest management with minimal chemical use. Using a trap for BCTB might not be eliminated it but you combine it with other pest management methods. Therefore early warning networks by using baited traps should be permanently active in the coffee field.

4.4. Implication of Weather Variables on the Population of Captured Coffee Berry Borer (CBB)

The Coffee berry borer (CBB) distribution and crop damage are related to several environmental factors. Regarding the environmental variables analyses, we noticed a significant positive correlation between the rain and relative humidity events in relationship to the total CBB captured in the coffee field trial. This is in line with the findings of numerous studies that reported rainfall and relative humidity as the main abiotic factor positively influencing CBBs beetle captures [4, 13] The use of weather variables at this experimental site increases the accuracy of the relationship between CBB capture and the considered environmental variables (RH, temperature, and rain events). When there is an increase in the number of CBB captures in the traps reported in successive samplings care should be paid to the CBB infestation level in the berries which will certainly increase as well. Early flowering, stimulated by early rainfall offered an extended period of available ripe coffee berries for H. *hampei* and was therefore the single most important environmental aspect accountable for the economic damage caused by this pest. Humidity is regularly mentioned as a key factor determining infestation level and it's a generally held view that H. *hampei* survives for longer and reproduces better in humid, shade conditions as reported by [4]. The pest and its brood are endangered from humidity instability inside the maturing berry, but ambient humidity can become critical during the inter-harvest period when coffee berries become black and dry. Equally, extreme humidity during the post-harvest period may cause enhanced decaying of coffee berries in the ground, reducing the food. The continued accession and use of data throughout the seasons and different locations will potentially allow us to build better predictive patterns of CBB outbreaks and understand their relationship to environmental variables. The correlation we found between CBB captured in the trap and rainfall and relative humidity, can help to specify the pest status in the field and is a valuable tool for monitoring the level of CBB infestation.

Although the current study aimed to analyse the efficiency of the trap in capturing CBB, it is worth emphasizing that the trap was also more efficient in capturing the individual in other species of adult BCTB. This outcome advocates that the adoption of traps to produce entomological traps can be an efficient strategy to capture other insect groups. We have shown that the use of plastic bottle-baited traps with methylated spirit and water at the ratio of 1:1 is efficient in attracting CBBs and consequently enables infestation levels in the coffee fields to be predicted. This prediction with traps can be a tool for monitoring CBB movement within the coffee growing area as CBB females start to colonize other coffee berries from February.

5. Conclusions and Recommendations

The study found that a plastic bottle-baited trap is a useful tool in indicating CBB viscosity and population distribution by height and spacing. Traps placed at a 1.2m height always maintained the highest capture of CBB throughout the study period. Under the environmental situations of this study, the traps with the maximum capacity to capture the CBB throughout the evaluation periods were those placed at 1.2 m from the ground. Further studies on spacing (distance) trapping design should be conducted to optimize and explore their use as a proper pest operation tool. This study emphasizes the use of Plastic baited traps (methylated spirit & water) should be enforced as a part of integrated pest management of CBB to reduce the use of chemical insecticides.

The information generated in this study concerning the appropriate position for placing the traps can be used as a cost-effective management strategy to control this coffee pest by farmer.

Data Availability

The datasets used and/or analysed during the current study are available from the corresponding author upon reasonable request.

Competing Interests

The authors declare no competing interests.

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