



Infestation Rate of the Coffee Berry Borer, *Hypothenemus hampei* (Ferrari) (Coleoptera: Curculionidae) in South India

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Abstract

The coffee berry borer (CBB), *Hypothenemus hampei*, is a monophagous insect pest that poses a major threat to coffee production worldwide, causing yield losses of up to 30-50%. India's coffee heartland in the south, responsible for over 90% of the national output, grapples with the threat of CBB infestations. Despite its economic importance and global spread, research on the ecology of CBB in India's traditional coffee-growing regions still needs to be completed. In this study, we investigated the infestation rate of CBB in *Coffea arabica* and *C. canephora* plantations at three designated locations at Chikkamagaluru (Karnataka), Thandigudi (Tamil Nadu) and Chundale (Kerala) from south India and samplings was done once a month during three fruiting periods between 2015 and 2018. The three sampled sites showed variable percentages of infestation rates across the sampling period between 4.61 ± 0.73 and 29.60 ± 2.28 , with the lowest and highest infestation rates in Thandigudi and Chikkamagaluru, respectively. The increase in CBB infestation towards harvest and variations in pre-brood, brood, and post-brood populations suggest the influence of different stages of fresh coffee berries, favorable agro-climatic conditions, and gaps in management strategies in the three sampled regions.

Keywords: Population, field survey, berry borer, coffee

Introduction

Coffee, one of the most consumed processed beverages globally, is produced in about 80 countries and is the second-largest traded commodity after petroleum. Out of 124 species under the Rubiaceae family, but only *Coffea arabica* Linnaeus and *C. canephora* Pierre ex A. Froehner are grown in tropical and subtropical regions that are known for trade and cup quality, representing 99% of the world market (Mussatto et al.,

2011; ICO, 2014). In southern states of India, *C. arabica* and *C. canephora* are grown on about 388,000 ha. The Karnataka state is a major producer of both *C. canephora* and *C. arabica* (71%), whereas Kerala predominantly produces *C. canephora* (21%) and Tamil Nadu produces *C. arabica* (5%), that making up over 90% of the national total (Kumar, 2000; ICO, 2002; Karunakaran, 2017; Anil Kumar et al., 2019).

Coffee berry borer (CBB), *Hypothenemus hampei* (Ferrari) (Coleoptera: Curculioni-

dae), is the most destructive pest of coffee worldwide and become the major threat to global coffee production. CBB attacks the coffee berries, reducing the quality of fragile, lighter, and discolored fruits. The attacks cause yield losses of 30-50%, with the potential for even greater damage if harvests are delayed (Lemma and Abewoy, 2021; Mubin et al., 2023). It was first reported in Gabon, West-Central Africa, in 1901. With the recent introductions to Hawaii and Puerto Rico, the invasive pest has spread globally to nearly all coffee-growing countries except Nepal and China (Agegnehu and Dawa, 2015; Vega et al., 2015; Infante, 2018). In India, CBB was first reported from Gudalur (Tamil Nadu) in 1990. After its introduction, the invasive pest has spread to almost all coffee-growing regions of the country (Singh and Ballal, 1991; ICO, 2002). Despite the increasing infestations in India, very few studies have attempted to study the dynamics of pest populations (Kumar et al. 1990; Samuel et al. 2008, 2011; Irulandi et al. 2007).

Knowledge of the biology and agroecology of the pest at locations classified with differing ecological conditions will help categorize site-specific management to reduce the population and prevent the spread. Generally, CBB biology is influenced by several factors, i.e., coffee phenology, elevation, harvesting strategies, and control measures employed. *C. arabica* is the best suited for high elevations, and conversely *C. canephora* for lower elevations (Vega et al. 2009, 2015). Low elevation levels with optimum temperatures provide an ideal condition for developing the borer populations (Baker et al. 1992a, 1992b; Baker, 1999; Ruiz-Cárdenas and Baker 2010). Further, it has also been observed that high temperatures and relative humidity in coffee plantations located at low altitudes are favorable for CBB development (Giraldo-

Jaramillo et al., 2018; Asfaw et al., 2019; Hamilton et al., 2019).

However, detailed studies on the insect population have not been conducted, especially in major coffee-growing areas in India, such as Karnataka, Tamil Nadu, and Kerala. Therefore, this study aimed to evaluate the spatiotemporal variation in the infestation rate of CBB in three selected traditional coffee-growing areas of south India (Karnataka, Tamil Nadu, and Kerala) through three fruiting periods between 2015 and 2018.

Methods

Coffee farms from traditional coffee-growing regions in three states of India viz. Karnataka, Tamil Nadu and Kerala were selected for the study. The three sites were the *C. arabica* plantations in Chikkamagaluru (13.3161°N, 75.7720°E, 1063 m above sea level) (Karnataka), Thandigudi (10.3093° N, 77.6435° E, 1299 m asl) (Tamil Nadu), and the *C. canephora* plantation in Chundale (11.5721°N, 76.0580°E, 840 m asl) (Kerala). Coffee farms selected in Chikkamagaluru, Thandigudi and Chundale have average annual temperatures ranging from 21 to 31°C.

Coffee Berry Development

Flowering periods are essential in coffee to predict harvest time. In the present study sites, the peak flowering period of *C. arabica* and *C. canephora* typically occurs in March – April and February, respectively. Fruit harvest will be from November to January. Coffee has a long fruiting season with variable phenology between *C. arabica* and *C. canephora* (Baker and Barrera, 1993). *C. canephora* takes about 40 weeks to ripen from flowering, whereas *C. arabica* takes 30 weeks. Thus, harvesting is early for *C. arabica* and late for *C. canephora* (ICO, 2002). Coffee berries generally attain a 20% dry weight between 120-150 days, and harvesting typically occurs after 200-250 days

after flowering (Baker, 1999; Ruiz-Cárdenas and Baker, 2010). However, the Thandigudi fruit harvest is delayed due to running blossom conditions (ICO, 2002).

Sampling

The phenology of CBB is correlated with coffee berry development. Infestation by *H. hampei* in the field typically occurs when coffee berries attain 20% dry weight. CBB female beetles prefer 150-240 days older coffee berries over younger berries for infestation (Baker, 1999; Ruiz-Cárdenas and Baker, 2010). Thus, the peak population of the pest will be during the harvesting time.

Therefore, the present study was conducted during three fruiting periods between 2015 and 2018. This period corresponds to the coffee fruiting period and harvest season in the study areas to keep track of the pest population according to the seasonality of each location. For both species of coffee, 50 coffee trees were chosen randomly in a zig-zag transect at each site. A total of 50 branches of different heights were selected randomly from each selected tree. The branches were selected based on the following requirements: most had mature berries and more than 3-5 fruiting nodes per branch (to ensure approximately more than 50 coffee berries).

Variable Observed

Infestation rate

The infestation rate was determined by calculating the percentage of berries infested by CBB using the method of Baker and Barrera (1993) and Mariño et al. (2017). Infested berries were identified based on the borer entrance pinhole showing a tunneled powder substance in the navel region, which indicates active tunneling and feeding within the berries.

CBB population per fruit was defined as the total number of individuals in all developmental stages (eggs, larvae, pupae,

and adults) in a single fruit. The pest population assessment was made once a month, i.e., from October to January for *C. arabica* and November to January for *C. canephora*. The number of berries infested by CBB and the total berries in the selected branch were counted.

Changes in *H. hampei* pre-brood, brood, and post-brood infested berries

Besides quantifying the pest population in the field, 50 infested berries were collected during the study to understand the stage of pest development. The infested berries collected from each site were dissected under a stereo-zoom microscope. They were classified into pre-brood (colonizing adult female with no immature stages), brood (colonizing adult female with life stages, i.e., egg, larva, prepupa, and pupa), and post-brood berries (colonizing adult female with progeny that has reached melanized/non-melanized adults).

Statistical Analysis

Statistical analysis was conducted using Statistical Package for Social Sciences (SPSS) software (SPSS, 2006). Results are expressed as mean $\pm$ SEM. The overall percentage of infestation between the months and years was assessed by repeated measure ANOVA. The statistical significance threshold was set at $P < 0.05$. Data from CBB pre-brood, brood, and post-brood berries were subjected to regression analysis using Microsoft Excel 2013 software.

Results

Infestation rate

CBB infestation rate fluctuated throughout the survey periods in all three locations. In general, the pest infestation increased steadily and peaked during harvesting i.e., December-January in all three locations. However, the infestation rate was

considerably different and was not uniform in all the locations.

Chikkamagaluru. The highest percentage of infestation 29.60 ± 2.28 (mean $\pm$ SE) was recorded in December 2016-2017. The percentage of CBB infestations was significantly different between years ($F=53.094$; $df=2, 398$; $P<0.0001$, Partial $\eta^2=0.211$), and between some months in a year (2015-2016: $F=2.665$; $df=3, 147$; $P<0.05$,

Partial $\eta^2=0.052$, 2016-2017: $F=13.890$; $df=3, 147$; $P<0.0001$, Partial $\eta^2=0.221$, 2017-18: $F=6.588$; $df=3, 147$; $P<0.05$, Partial $\eta^2=0.119$). No significant difference in CBB infestation was observed between months in the year 2015-2016. In 2016-2017 and 2017-2018, there was no significant difference between months except between October and December, and October and January in 2016-2017 and 2017-2018 (Figure 1).

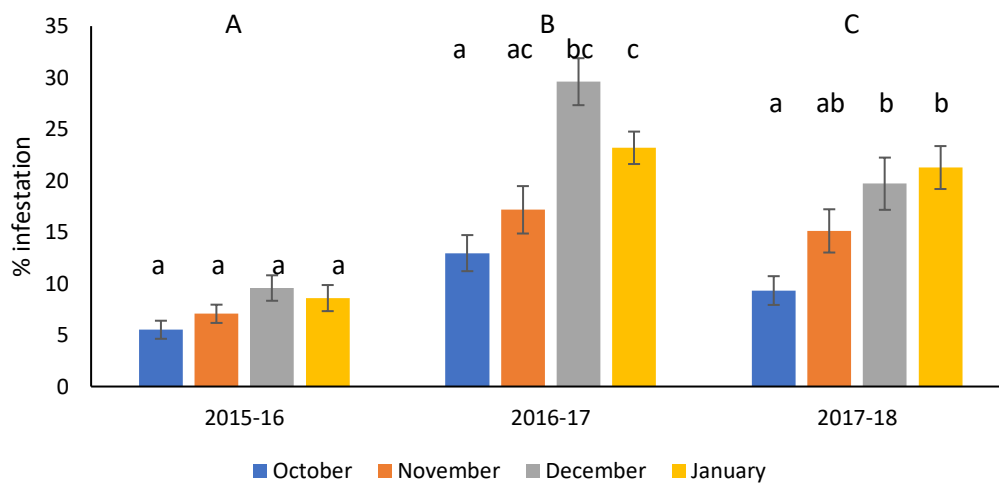


Figure 1. Percentage of *H. hampei* infestation in Chikkamagaluru during October-January 2015-2016, 2016-2017, and 2017-2018. Means with different letters indicate the significant difference in the percentage of *H. hampei* population between the years (capital letters) and months (small letters) at $P<0.05$ (ANOVA). The vertical lines indicate the SE mean percentage of *H. hampei* populations.

Thandigudi. The highest percentage of CBB infestation 14.03 ± 1.37 (mean $\pm$ SE) was recorded in January 2016-2017. The overall percentage of infestation during 2016-2017 was significantly different from 2015-2016 and 2017-2018 ($F=7.114$; $df=2, 398$; $P<0.05$, Partial $\eta^2=0.035$). The percentage of infestation was significantly different between some months in a year (2015-2016: $F=3.509$; $df=3, 147$; $P<0.05$, Partial $\eta^2=0.067$, 2016-17: $F=8.463$; $df=3, 147$; $P<0.0001$, Partial $\eta^2=0.147$, 2017-2018: $F=14.646$; $df=3, 147$; $P<0.0001$, Partial $\eta^2=0.230$). No significant difference was observed between October and December in 2015-2016, October and November, and December and January in

2016-2017, and October and November, and December and January in 2017-2018 (Figure 2).

Chundale. The percentage of CBB infestation only in 2015-16 was significantly different from 2016-17 whereas between other years it was not significant ($F=2.771$; $df=2, 898$; $P=0.067$, Partial $\eta^2=0.018$). There were no significant differences in the percentage of CBB infestation between months during 2015-16, 2016-2017 and 2017-2018 except between November and January ($F=4.186$; $df=1.75, 85.730$; $P<0.05$, Partial $\eta^2=0.079$; $F=5.272$; $df=1.690, 82.819$; $P<0.05$, Partial $\eta^2=0.097$; $F=6.588$; $df=1.728, 84.689$; $P<0.05$, Partial $\eta^2=0.095$) (Figure 3).

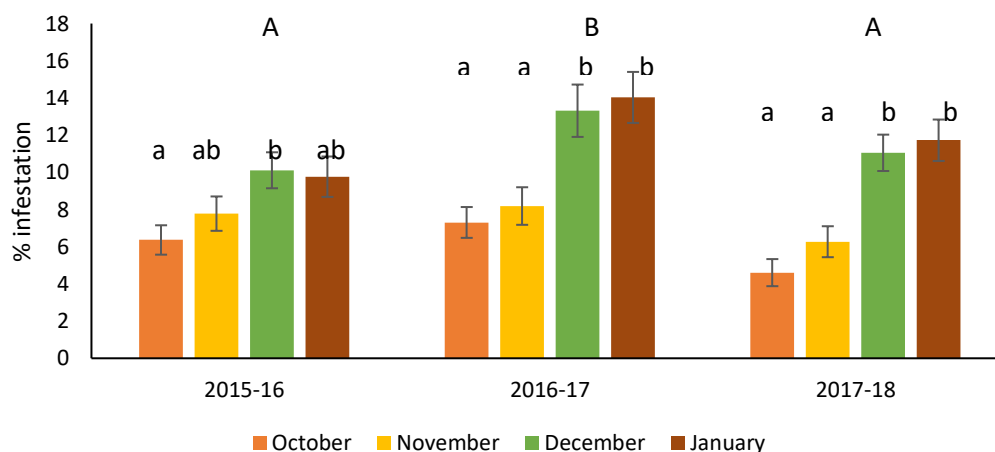


Figure 2. Percentage of *H. hampei* infestation in Thandigudi between October and January 2015-2016, 2016- 2017, and 2017- 2018. Means with different letters indicate the significant difference in the percentage of *H. hampei* population between the years (capital letters) and months (small letters) at $P < 0.05$ (ANOVA). The vertical lines indicate the SE mean percentage of *H. hampei* populations.

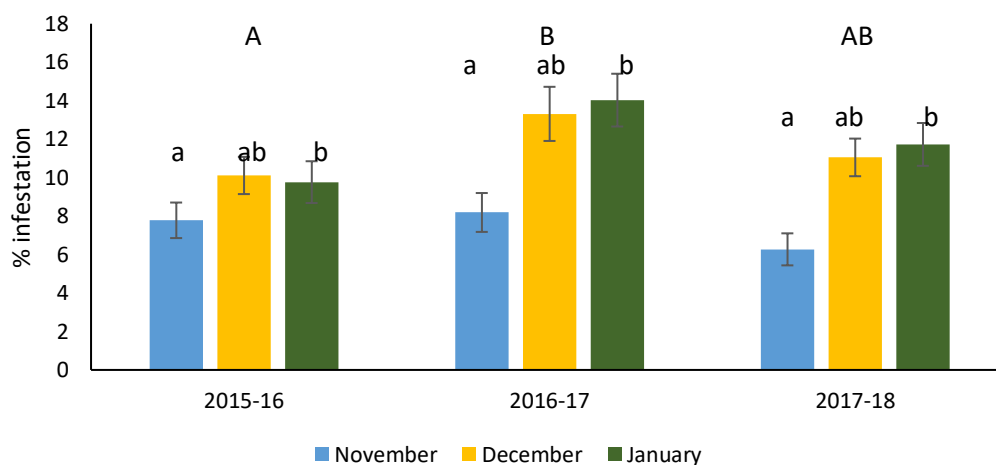


Figure 3. Percentage of *H. hampei* infestation in Chundale between November and January 2015-2016, 2016- 2017, and 2017- 2018. Means with different letters indicate the significant difference in the percentage of *H. hampei* population between the years (capital letters) and months (small letters) at $P < 0.05$ (ANOVA). The vertical lines indicate the SE mean percentage of *H. hampei* populations.

Changes in *H. hampei* pre-brood, brood, and post-brood infested berries

A considerable difference was observed in the abundance of CBB pre-brood, brood, and post-brood infested berries from the sampled locations. The average relative abundance of pre-brood, brood, and post-brood populations in berries from three locations were linearly correlated (Figures 4-

6). The abundance of the borer stages correlated with the availability of coffee berries for infestations. The value of the coefficient of determination (R^2) of pre-brood (0.8906, 0.9419, 0.9809), brood (0.8419, 0.6596, 0.9694), and post-brood (0.9113, 0.9888, 0.9758) borer infested berries in Chikkamagaluru, Thandigudi, and Chundale were linearly correlated.

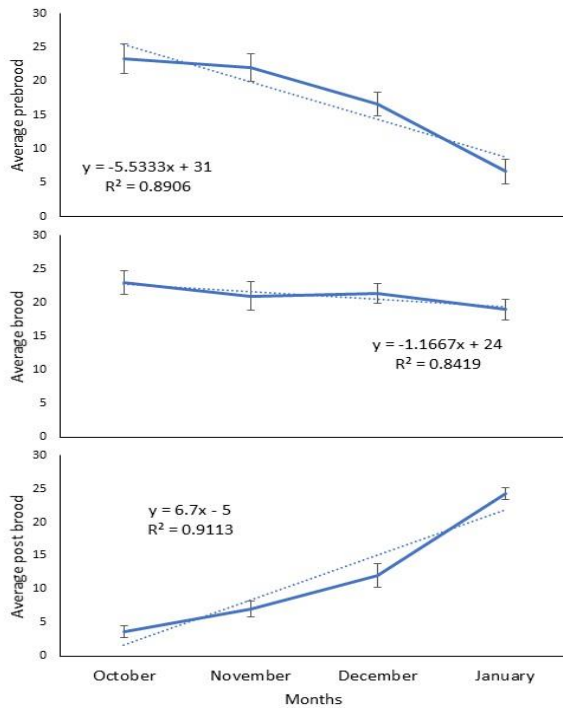


Figure 4. Changes in *H. hampei* pre-brood, brood, and post-brood infested berries during October - January 2015 - 2018 at Chikkamagaluru.

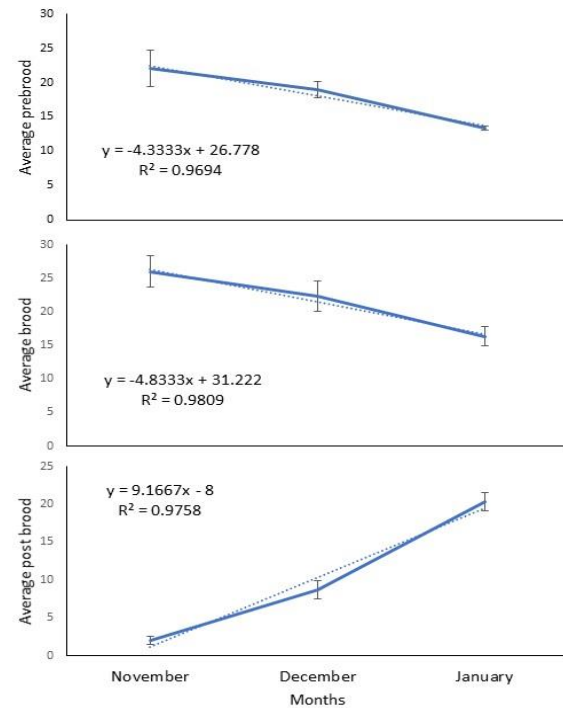


Figure 6. Changes in *H. hampei* pre-brood, brood, and post-brood infested berries during November - January 2015-2018 at Chundale.

Discussion

The three study sites showed variable percentages of CBB infestation rates, gradually increasing from October to January, with a slight decrease after December (Figures 1-3). The increase in the infestations could be due to the rise in developing berries and the dispersal of colonizing adult females (Kiran and Venkatesha, 2020). As the major harvesting takes place in December, a slight decrease in the borer population was observed after December, possibly due to the decline in the number of fresh berries for infestations.

The gradual increase in the infestations of the pest is correlated with the phenology of coffee berry development. According to Ruiz-Ca'rdenas and Baker (2010), infestation rates correlate with coffee berry development's phenology, regional conditions, and management practices. Meanwhile, the maturation of coffee berries typically depends on the

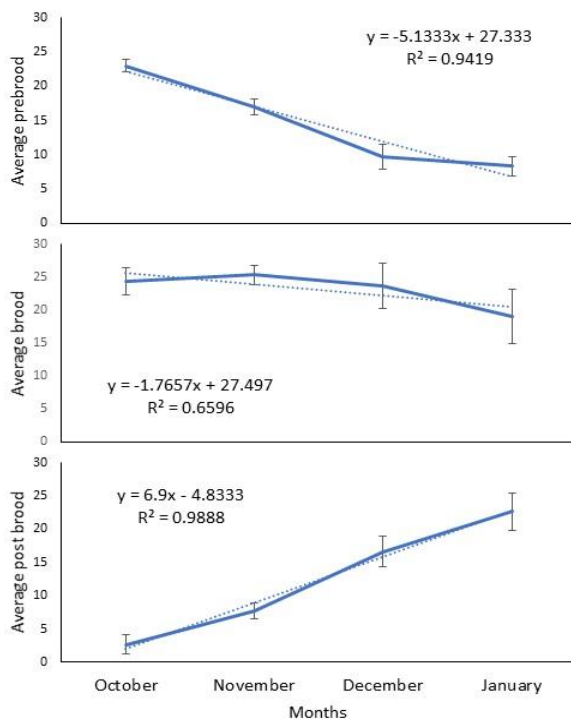


Figure 5. Changes in *H. hampei* pre-brood, brood, and post-brood infested berries during October - January 2015 - 2018 at Thandigudi.

temperature and elevation of the coffee plantations. A low elevation range with optimum temperature is ideal for pest development. The pest exploits the period corresponding to berry development between 120 and 250 days for reproduction, and multiple generations are completed before harvesting.

The developing coffee berries above 20% dry weight can be attacked by females colony for oviposition. Fresh infestation by CBB is linked to colonizing females from old berries to new berries for colonization. Previous studies reported that colonizing females' wing muscles are less developed, and most females fly a short distance to disperse from one node to another for colonization. The number of colonizing adult females caught barely affects the field populations when infestations are at the rate of millions per hectare (Gil et al., 2015; Green et al., 2015; Aristizábal et al., 2016).

The rate of CBB infestation in the three sites was considerably different due to differences in regional conditions and management practices. The risk of CBB infestation in the *C. arabica* plantation in Thandigudi was higher due to the favorable regional conditions. The difference in coffee berry development phenology due to multiple blossoms observed in Thandigudi was a major constraint for the timely harvesting of coffee berries. Furthermore, the highest infestation rate in Chikkamagaluru during 2016 might be due to the nearby plantations where the crop was left un-harvested in the previous year. Moreover, the lack of awareness among farmers about the pest and control measures resulted in a higher infestation rate. The term "gleaning" is used to remove/collect over-ripened, leftover, and dried berries after a major harvest (ICO, 2002).

Ripe and overripe berries left un-harvested on the trees and ground are

considered the primary source of CBB infestations for the subsequent coffee berry cycles. Similarly, abandoned or severely infested plantations nearby increase the chances of a higher rate of infestations. In old dry berries left after harvest, it is common to find more than 100 individuals (Baker, 1999).

The variation in the pre-brood, brood, and post-brood stages was synchronized to the maturation of berries. The borer pre-brood berries were highest in September and October, and brood populations almost remained inactive. The post-brood borer berries were highest during harvesting, i.e., December and January (Figures 4-6). Due to CBB being a synovigenic species, feeding coffee endosperm by colonizing adult females is critical for egg production. After successful penetration into the endosperm, the colonizing adult females lay eggs continuously for 20 days (Silva et al., 2012). Thus, infested berries contain all the developing stages due to the prolonged oviposition period.

The variation in the mean percentage of infestation among the locations, with Thandigudi exhibiting the lowest rate followed by Chundale and Chikkamagaluru, suggests a significant influence of environmental conditions and management practices at the individual sites, indicating differences in the prevalence of CBB. Among the three locations, Chikkamagaluru showed a greater rate of coefficient of variation and mean population, indicating considerable population variability. On the contrary, Chundale and Thandigudi exhibited lower coefficient of variation percentages, indicating more stable populations.

The altitude of *C. arabica* in Chikkamagaluru and Thandigudi and *C. canaphora* in Chundale are well below 1500 m asl and between 800-1300 m asl, a favorable range for the borer population growth. The average temperature 20-28°C in Chikkamagaluru, 22-

31°C in Thandigudi, and 21-28°C in Chundale was favorable for developing *H. hampei*. Previously, it was reported that *C. arabica* grown at an altitude of 1500 m asl and above was unsuitable for CBB infestations. However, it is now known that even in high altitudes, the increasing temperature has favored *H. hampei* infestations (Agegnehu and Dawa, 2015). According to the previous findings, temperature between 20 and 28°C was considered the most optimal range for developing *H. hampei* (Jaramillo et al., 2009, 2011; Azrag et al., 2020). The dry spell weather from December to February has significantly disadvantaged field applications in Chundale and Chikkamagaluru. Additionally, constraints with large-scale production of fungus, the timing of application, and acceptance by farmers are the reasons for limited success in India (ICO, 2002).

The major control recommended for CBB include attractants, natural enemies and cultural practices (Vega et al. 2009; Hollingsworth et al. 2013, Chain-Guadarrama et al. 2019; Escobar-Ramírez et al. 2019; Kiran and Venkatesha, 2022; Venkatesha and Kiran, 2023). A training for adequate cultural harvest was helpful in significantly reducing the CBB infestations (Aristizábal et al., 2012). Similar results were observed in Thandigudi and Chundale plantations, where workers were trained for meticulous cultural harvesting. The frequent re-picking practice after harvesting helped reduce the CBB infestation rate. In contrast, the shortage and retention of trained workers have been a major concern in Chikkamagaluru.

Conclusion

The three sampled sites showed variable percentages of infestation rates across the sampling period between 4.61 ± 0.73 and 29.60 ± 2.28 with the lowest and

highest infestation rates in Thandigudi and Chikkamagaluru, respectively. The increase in CBB infestation towards harvest and variations in pre-brood, brood, and post-brood populations suggest the influence of different stages of fresh coffee berries, favourable agro-climatic conditions, and gaps in management strategies in the three sampled regions.

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Declaration

Author contribution

Venkatesha is the main contributor and corresponding author for this paper. Kiran is the co-author. Both authors read and approved the final paper.

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Competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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