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Research Article

Coffee Berry Borer Infestation and Population per Fruit Relationship with Coffee Variety, Shade Level, and Altitude on Specialty Coffee Farms in Peru

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Although the coffee berry borer (CBB) is the most important coffee pest worldwide, controversies remain regarding basic aspects of its behavior, such as how this is influenced by abiotic factors of the coffee agroecosystem. In this study, we compared the level of infestation and total population per fruit under three different levels of shade (full sun, up to 40%, and >40%), for two varieties of coffee (Caturra and Catimor) and at two different altitudes (1200 to 1700 m above sea level) in Rodríguez de Mendoza, Peru. We found that the infestation percentage increases with the shade levels of the plot. The average percentages of infestation according to shade levels were 10.52% for coffee in full sun, 12.56% with up to 40% shade, and 17.99% for coffee growing in more than 40% shade; however, maximum infestation values of 68.421%, 84.127%, and 95.238% were obtained for coffee plantations in full sun, up to 40% shade, and more than 40% shade, respectively. The Catimor variety was found to be more susceptible to CBB infestation than Caturra. In addition, CBB infestation per fruit was found to decrease with increasing altitude.

1. Introduction

In many countries, coffee production is seriously threatened by different pests [1, 2], and the main global pest is the scolytid *Hypothenemus hampei*, the coffee berry borer (CBB) [2–4]. Typically, they cause significant losses in crop yields ranging from 5% to 24% in Costa Rica [5], in Uganda, infestation ranged 21 from to 78% [6], but can damage up to 90% of production and even total losses in many countries [7–9].

The CBB was first reported in Peru in 1962 [10]. It is now found in all coffee-producing areas of the country and multiple studies have been developed to improve integrated control techniques using artisanal traps and entomopathogens [3, 8, 11, 12]. Despite this, infestation levels of over 5% have been reportedbetween 8% and 23% in Tingo María in 2013 [3], 13%–35% in Chanchamayo in 2007 [13], and 45%–90% in Rodríguez de Mendoza in organic coffee plantations [8], which demonstrate the severity of the problem.

Due to the severity of the problem, academics, institutions, and producers worldwide are working on developing practical, low-cost, and environmentally friendly alternatives that can contribute to controlling the main pest of coffee [14–16]; however, establishing an integrated management program for CBB requires knowledge about their biology, ecology, and behavior within a specific region [4].

The use of shade on coffee plantations provides coffee farmers around the world with many benefits, including increased diversity of the agricultural ecosystem which favors the development of beneficial insects [6] and maintains the balance of the ecosystem [17–19]. Studies have confirmed that the use of shade improves the quality of coffee beans [20]. In Peru, most coffee plantations are managed in agroforestry arrangements and have some type of shade [3, 8, 12, 13, 21].

However, studies have reported that high levels of shade favor the reproduction and dispersion of the CBB in plots

[22–26] because this pest evolved in forest environments under shade in Africa [27]. Thus, the spatial distribution of the coffee berry borer is characterized by aggregates, and foci are observed in areas of high humidity favored by high levels of shade since it is the initial colonizer that attracts other females [28, 29]. As the CBB population increases, the population distribution becomes more homogeneous [4]. Altitude is another factor to affect the CBB, in the example, the physiology of the coffee plant which is linked with the pest cycles will vary across altitudes and locations [4].

The effect of coffee variety was not yet compared between varieties into the same species, however, some authors have evaluated the resistance of different species (*C. Arabica*, *C. canephora*, etc), and varieties separately [13, 21, 30, 31], demonstrating the importance of CBB resistance for an effective integrated control program [32, 33].

Hence, to understand the ecology of the pest and to develop and implement effective control methods, in this study, we aimed to review the effects of the shade levels, altitude, and coffee variety on the CBB infestation and adult CBB population per fruit in the Omia district-Rodríguez de Mendoza-Amazonas.

2. Materials and Methods

2.1. Trials, Sites Descriptions, and Experimental Designs. The study of CBB infestations per tree and per fruit according to shade and variety factors was conducted on four farms producing special coffee in the Omia district (Amazonas, Peru)F1 (6°37′03.7243″ S, 77°14′05.6122″ W), F2 (6°37′03.7263″ S, 89°14′05.1566″ W), F3 (6°36′44.2075″ S, 89°14′11.0243″ W), and F4 (6°37′5 3.2158″ S, 89°13′37.6515″ W). These plots are specifically located in Líbano village. The district of Omia, representative of coffee production in the area, is located between 1200 and 1300 m above sea level (m.a.s.l.). In each location, six plots were selectedthree plots of coffee of the Caturra variety and three plots of the yellow Catimor variety. For each plot, we selected areas corresponding to either full sun, a shade of up to 40% (1–40%), or shade greater than 40%. The shade was generally provided by Inga edulis (guava), *Erythrina* sp., *Eucalyptus saligna*, *Citrus* spp., and *Pouteria caimito*. Due to the impossibility of obtaining specialized equipment, the percentage of shade in shaded plots was calculated using the occlusion method proposed by Somarriba [34]. In this method, the percentage of shade is calculated based on the occlusion of each tree, the diameter of the canopy, and the population density of plants in the canopy. To measure the combined effect of the shade factors and coffee variety, a trial was constructed adopting a randomized complete block design with four repetitions in a bifactorial arrangement ($3A \times 2B$), where A is the level of shade in the plots and B is the studied varieties. Considering the interaction of these factors, 6 interactions were obtained, as detailed in Table 1. Each experimental plot had an area of 100 m^2, with a total of 36 plants per plot. Free space of at least 10 m was left between plots. In each plot, 11 trees were selected at random, rejecting the trees located at the borders of each plot, and data were collected as explained in the previous paragraph.

Table 1: Description of generated interactions. The interactions were between shade levels (high ≥ 40% shade, med = up to 40% shade, no shade = full sun) and coffee variety (Caturra and Catimor).

Interaction	Description
T1	No shade × var. Catimor
T2	No shade × var. Caturra
T3	Medium shade × var. Catimor
T4	Medium shade × var. Caturra
T5	High shade × var. Catimor
T6	High shade × var. Caturra

The study of CBB infestations per tree and per fruit according to altitude was conducted in three districts in the province of Rodríguez de Mendoza. Three farms were selected for each district, for a total of nine study sitesS1 (6°28′13.6205″ S, 77°22′48.1654″ W), S2 (6°32′18.8491″ S, 77°24′26.9244″ W), S3 (6°25′28.9071″ S, 77°32′50.0357″ W), S4 (6°25′28.0496″ S, 77°32′58.8779″ W), S5 (6°32′36.2399″ S, 77°24′16.8893″ W), S6 (6°28′08.9724″ S, 77°22′33.2120″ W), S7 (6°25′26.6592″ S, 77°32′15.5817″ W), S8 (6°28′21.6624″ S, 77°22′51.0007″ W), and S9 (6°32′28.3884″ S, 77°24′15.0949″ W). The altitude in this area ranges from 1200 to 1700 m.a.s.l., which includes the lowest and highest areas where coffee is produced in the specialty coffee production area of Rodríguez de Mendoza. In the case of this study, we established a completely randomized design with three levels of altitude (1200–1399, 1400–1600, and >1600 m).

Rodríguez de Mendoza is a zone of warm temperate climate, with an annual average temperature of 18–22°C, and a relative humidity of 40 to 50% annual average. The annual rainfall is 1400–1600 mm, with a marked difference between a rainy season during the first months of the year until April (750 mm approx.) and a less rainy season between June and September (300 mm approx.).

2.2. Agronomical Conditions. Every selected farm has a sowing density of 3333 plants per hectare, all of which are managed under an organic production approach, and deficiencies in crop management were observed (inefficient pruning management, low fertilization level, inopportune weeding, low or null pest, and disease control). Hence, before starting the study, weeding was conducted once in the selected plots to facilitate sampling work. Notably, these plots were of different ages, varying from two years of sowing to more than eight years of production. The dynamics of fruiting in the Rodríguez de Mendoza area is highly complex, having fruit most of the year. The following phenological periods can be differentiated in the crop, between the months of December and January the flowering begins as a result of the beginning of the rainy period, between the months of February and May the fruits are in development and there is a total absence of crops between the months of March and May. Towards the end of May, the progressive harvests begin and extend until the end of the year, the highest peak of harvests occurs between June and August.

2.3. Measurement of Climate Factors. The temperature and relative humidity were measured from May to September 2017 using WatchDog A150 A-Series Data Loggers (Spectrum Technologies Inc., Aurora, IL, USA). Two data loggers were placed on each plot, hung from a coffee plant 1.5 meters aboveground, and distributed to best represent the conditions that occur in the plot. The measurements were taken every minute, and the average of 30 minutes was automatically recorded. The climate factors were measured in the plots where the effect of shade and variety was studied.

2.4. Sampling Methods. The effect of shade and variety on the infestation was measured from May to September 2017, running for 120–150 days after flowering until the end of harvest. The percentage of infestation was evaluated with the 30-tree sampling method [35], in which 30 trees were randomly selected throughout each plot, and from each tree, a single branch was selected randomly from the central zone of the trees. The total number of berries and the total number of infested berries per branch were counted, including all stages of berry development. Berry infestation was determined through a visual inspection of the apical disc to check for berry perforation. In the first sample, the infested fruits were marked. The percentage of infestation was evaluated every 30 days on the same branches of the trees as marked. The effect of plot altitude was evaluated using the same sampling methodology, infestation measurements were recorded from May to August 2018.

In both trials, the population of CBB adults was determined through the fruit collection technique for dissection [36]. All infested fruits were collected from the same plants selected for the incidence assessment, with the exception of those on the branches selected for infestation measurement, and the collected fruits were taken to the laboratory in plastic bags to be dissected with a scalpel, and the number of adult CBBs were quantified for each fruit. Infested fruits were harvested at the same times, and therefore, frequently as the infestation assessments.

2.5. Statistical Analysis. In the study of CBB infestations per tree and per fruit according to shade and variety factors, for statistical analysis, the following CBB descriptors were considered response variablesCBB infestation and total CBB adult per fruit. The explanatory variables were shade levels (sunup to 40%, >40%), coffee variety (Caturra and Catimor), farm location (F1, F2, F3, and F4), and sampling dates. Infestation data and total population per fruit were analyzed separately using generalized linear mixed models (GLMM) to measure the effect of the variety and the level of shade. Variables, shade level, coffee variety, and sampling dates were added as fixed effects with plots as random effects. Binomial and Poisson error distributions were used for infestation and adult population by fruit, respectively. One-way ANOVAs were performed to determine the significance of differences in mean temperature and mean relative humidity between three shade levels. The combined effect of shade and variety on CBB infestation was analyzed by GLMMs, and the interactions explained in Table 1 were used as fixed effects and the farms as the random effect. Tukey's multiple comparisons tests ($p < 0.05$) were performed to establish the differences between the means of infestation per interaction on each evaluation date.

In the study of CBB infestations per tree and per fruit according to the plot altitude, we established a completely randomized design with three levels of altitude (1200–1399, 1400–1600, and >1600 m). For the statistical analysis, we considered the level of infestation of the CBB and total population per fruit as response variables, whereas the explanatory variables were plot altitude, plantation age, farm location, and sampling dates. Infestation data and total population per fruit were analyzed separately using a mixed-effects model. The altitude and sampling dates were added as fixed effects and farms as random effects. Multiple Tukey comparisons ($p < 0.05$) were performed to establish the differences between the means of infestation. In addition, Spearman correlation analysis was performed.

All statistical analyses were performed using Minitab 19 statistical software (Minitab, State College, PA, USA).

3. Results and Discussion

The estimated probability of infestation was significantly higher in areas with greater than 40% shade compared with coffee plantations in full sun. We observed that the infestation level increases as the plot shade level increases (Tables 2 and 3). We also found that the variety of coffee grown significantly determined the level of infestationthe level of infestation in the Catimor variety (18.22%) was much higher than for the Caturra variety (9.16%) (Tables 2 and 3). The sampling date also had a significant effect (Table 2); the percentage of infestation peaked during the second sampling in June, then decreased in the following samples (Figure 1). The same occurred for varietythe CBB per fruit in coffee crops of the Catimor variety (8.45) was significantly higher than in coffee plantations of the Caturra variety (4.29) (Tables 2 and 3). The correlation analysis showed an inverse correlation between altitude and CBB infestation ($r = -0.76$).

3.1. Environmental Characteristics of Plots from CBB Infestations According to Shade and Variety Trial. Observed that three shade levels differed significantly in all temperature and humidity variables evaluated. Sun plots were characterized by higher maximum temperatures (33.8°C) and lower maximum humidity (56%) compared with shade plots that reach 29.75°C of temperature and 78% of HR (Table 4). In general, when shade levels increase humidity increases.

3.2. Effect of Shade Levels on CBB Infestation and Total Number of CBB per Fruit. The estimated probability of infestation was significantly higher in areas with greater than 40% shade compared with coffee plantations in full sun. We observed that the infestation level increases as the plot shade level increases (Tables 2 and 3). The average infestation levels according to shade were 10.52% for coffee plantations in full sun, 12.56% with up to 40% shade, and 17.99% with more

Table 2: Generalized linear mixed model (GLMM) estimates for infestation of the total number of individuals of coffee berry borer (CBB) fruit according to shade levels, coffee varieties, and sampling dates.

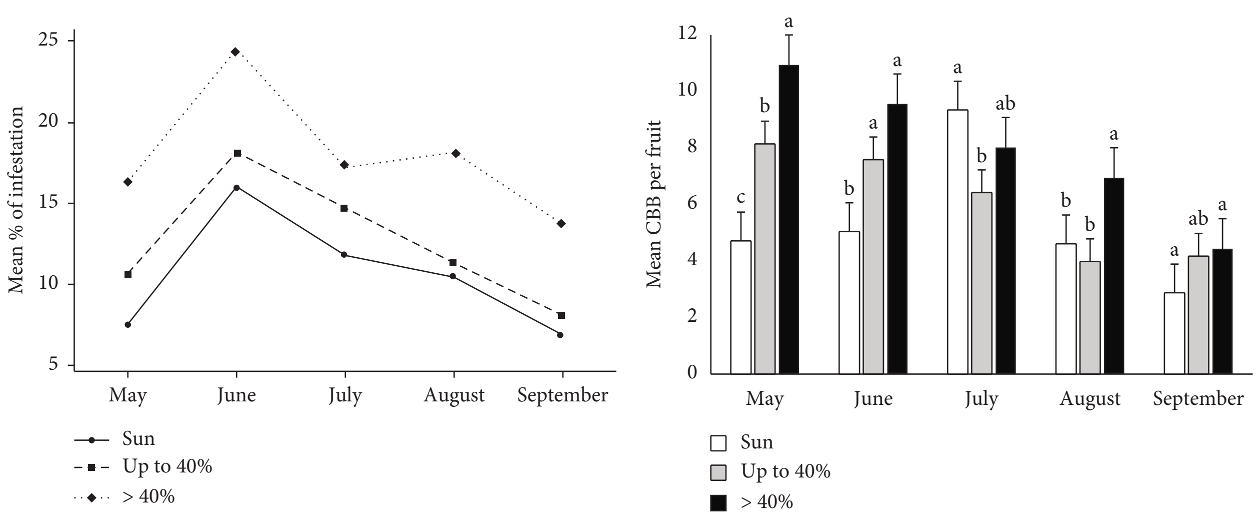
Model variable	CBB infestation		The population of CBB per fruit	
	F	*p* value	*F*	*p* value
Shade levels	49.810	<0.001***	25.482	<0.001***
Variety	205.810	<0.001***	175.898	<0.001***
Sampling dates	28.700	<0.001***	27.831	<0.001***

Asterisks indicate a significant effect of a model variable on the abundance of CBB infestation and adult individuals. Generalized linear mixed models:*** = $p < 0.001$, ** = $p < 0.01$, * = $p < 0.05$, and ns = $p > 0.1$.

Table 3: Mean ± standard error (SE) of infestation and the adult population of CBB per fruit according to the shade levels and coffee variety. Data from all farms and sampling dates combined.

Variable		Mean ± SE of % infestation per plot	Mean ± SE of total no. CBB per fruit	Min infestation (%)	Max infestation (%)
Shade levels	Sun	10.518 ± 0.518	5.239 ± 0.268	<1	68.421
	Up to 40%	12.559 ± 0.562	5.982 ± 0.310	<1	84.127
	>40%	17.991 ± 0.763	7.893 ± 0.327	<1	95.238
Coffee variety	Catimor	18.222 ± 0.590	8.448 ± 0.284	<1	95.238
	Caturra	9.157 ± 0.370	4.294 ± 0.179	<1	71.429
Altitude (m a.s.l.)	1200–1399	23.01 ± 2.1	11.72 ± 1.15	3.04	46.55
	1400–1600	6.21 ± 0.76	2.85 ± 0.31	0.5	18.68
	>1600	5.71 ± 0.88	3.26 ± 0.52	<1	17.33

Note. The mean is the result of the combination of all plots and sampling dates according to shade levels, coffee variability, and altitude.



(a) (b)

Figure 1: Monthly changes in (a) infestation and (b) CBB per fruit according to shade levels. The letters above bars indicate statistical differences between CBB per fruit means (means separations test are independent for each month).

than 40% shade; however, maximum values were 68.421%, 84.127%, and 95.238% for coffee plantations in full sun, up to 40% shade, and more than 40% shade, respectively (Table 3). These levels of infestation were compared with previous studies and found to be similar to those found by Mariño [37] in Puerto Rico, who reported infestation rates of 2%–68% in coffee plantations under shade and 3%–29% in coffee plantations in full sun, some differences in values can attribute to the agroclimatic conditions of the region where the trial was carried out. The use of shade in coffee plots influences humidity and ambient temperature [38–40], such that the plots under shade maintained stable temperatures and high relative humidity, creating adequate conditions required for a CBB attack [41, 42].

Figure 1 depicts the monthly percentage of infestation and the tendency for an infestation to be higher under high shade levels was maintained throughout the study. However, we observed that, in general, the infestation peaked in June,

TABLE 4: Environmental variables measured in the study plots for the three coffee agroecosystems (sun, shade up to 40%, and shade > 40%). Mean ± S. E. are given for temperature and relative humidity. Statistics based *on* differences between agroecosystems.

Coffee agroecosystem		Temperature			Humidity		
		Mean ± S. E.	Min	Max	Mean ± S. E.	Min	Max
Sun	Farm 1	28.01 ± 1.37	24.45	33.8	50.5 ± 1.54	46.5	56.5
	Farm 2	26.7 ± 0.232	25.95	27.4	52.63 ± 1.01	50	57
	Farm 3	26.012 ± 0.356	25	27.05	54.25 ± 0.726	52.5	57.5
	Farm 4	25.856 ± 0.486	23.65	27.45	51 ± 0.964	47.5	56
Shade 1–40%	Farm 1	26.05 ± 0.69	23.5	28.45	53.75 ± 1.35	50.5	59.5
	Farm 2	25.131 ± 0.64	23.75	27.9	54.375 ± 0.849	52	57.55
	Farm 3	25.075 ± 0.452	23.2	26.3	57.38 ± 1.42	51	60.5
	Farm 4	23.962 ± 0.355	22.5	25.2	57.5 ± 2.22	47.5	62.5
Shade > 40%	Farm 1	25.375 ± 0.817	23	29.75	72 ± 1.25	68	77
	Farm 2	24.225 ± 0.392	22.65	25.55	72.63 ± 1.34	67.5	77.5
	Farm 3	23.975 ± 0.535	22	26	73.25 ± 0.688	71	75.5
	Farm 4	22.838 ± 0.467	21.15	25.05	71.25 ± 2.1	61	78
Statistics		$F = 17.32$ $p < 0.001$			$F = 248.21$ $p < 0.001$		

which coincides with the time of the massive emergence of female CBB to infest new fruits. In our case, this occurred in June, the month in which coffee beans have reached 20% dry weight mostly. This state is reached 120 days after flowering [15]. In Puerto Rico, Mariño et al. [43] reported that the CBB infestation continued to increase until it peaked in November. The difference in months could be due to the location of the study since Puerto Rico is in the opposite hemisphere and farther from the equator, which would lead to different behaviors in the phenological cycle of coffee. It can be expressed, however, that the highest CBB infestations correspond to ripening and harvesting cycles in the coffee plots.

The total number of CBB adults per fruit was also influenced by shade levels. Similar to the percentage of infestation (Table 2), the number of CBB individuals per fruit increases as shade levels increase. Tukey's mean comparisons test ($p < 0.05$) showed that no significant difference exists in the number of individuals found per fruit in coffee plantations in full sun (5.24) and up to 40% shade (5.98), but in coffee plantations with shade greater than 40%, the number of CBB per fruit is significantly higher (7.89) (Tables 2 and 3). These results are similar to those reported by Sanchez et al. [44, 45] and Féliz et al. [25]. Again, the shade affects the biotic and abiotic characteristics of the plot buffering the temperature and relative humidity [37, 43, 46]. As such, the plots in full sun have higher temperatures that exceed the optimal limit for CBB reproduction, Jaramillo et al. [47] reported that the minimum fecundity rate has 30°C, whereas plots with some level of the shade create temperature and relative humidity (RH) conditions that are more stable and optimal for CBB reproduction [48]. However, our results are controversial with the results of Mariño et al. [43] who measured the total population of the CBB, and the number of individuals per fruit was higher in full sun than in shaded plots. In addition to the different environmental conditions that can arise from the different latitudes in which the Mariño study takes place, the differences are in their study they counted all stages of the insect, while we only counted the adults.

3.3. Effect of Variety on CBB Infestation and Total Number of CBB per Fruit. The infestation (Figure 2) maintains a behavior similar to that observed when the effect of the shade levels was evaluated. Infestation peaked in June which, regardless of the variety, could be due to the reproductive cycle of the insect, since mass emergence occurs at this time, which coincides with the largest number of individuals per fruit reported (Figure 2). Significantly higher infestation values were recorded in plots grown with the Catimor variety compared to those with the Caturra variety (Tables 2 and 3). The Catimor variety is considered susceptible to CBB attack [21] because it emits volatiles, mainly ethanol, esters, and other alcohols, that increase its attractiveness to CBB. CBB is attracted to certain volatiles specific to coffee plants, which are released between 120 and 150 days after flowering, which is when their period of increased susceptibility begins, which then further increases as the berries ripen [49–51]. Catimor has longer and earlier flowering [52], so there is more time for CBB to infest its fruits. Some studies compare resistance to CBB among coffee species [53], and some have tested the resistance or susceptibility of varieties or genotypes of Coffea arabica, but so far, no study has been published comparing the susceptibility of different varieties of Coffea Arabica. However, many authors considered that incomplete or complete resistance to CBB infestation is an important integrated control strategy [32, 54] to reduce the devastating effect of this pest on coffee plantations around the world.

Additionally, Caturra is a compact variety with a plant density of 4000–5000 per hectare, while Catimor is 3000–4000 plants per hectare [55]. This condition might suggest that with Caturra better yields can be achieved with less CBB damage.

3.4. Combined Effect of Shade Level and Variety on CBB Infestation. Table 5 and Figure 3 present the results of the

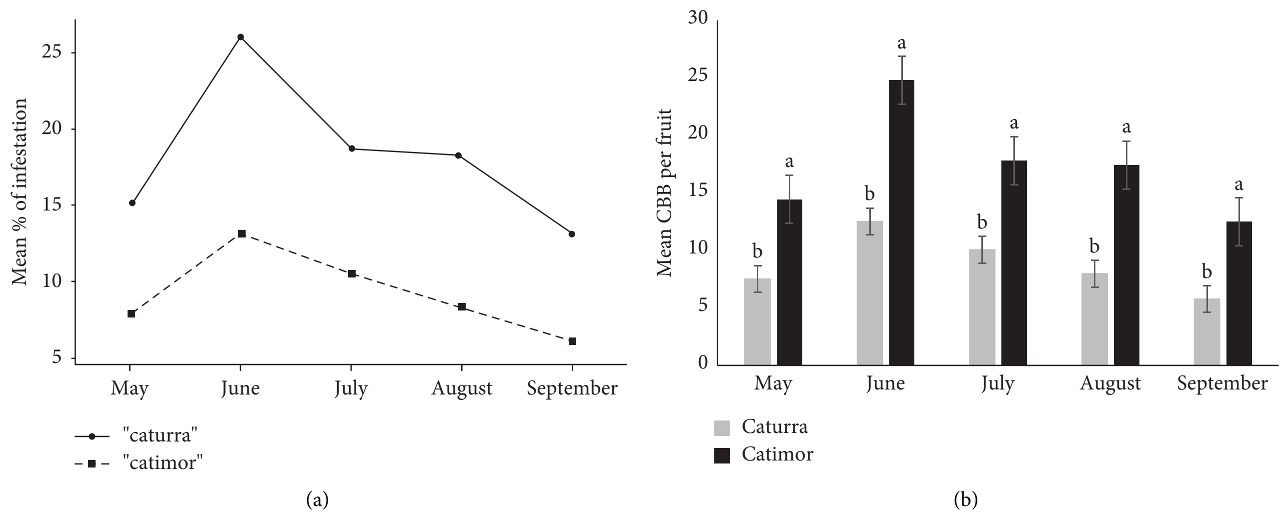


Figure 2: Monthly changes in (a) infestation and (b) CBB per fruit according to coffee variety. Letters above bars indicates statistical differences between CBB per fruit means (means separations test are independent for each month).

GLMM estimates applied to the CBB infestation percentage values found during the study.

The results of the variance analysis of CBB infestation (Table 5) showed that differences between the treatments were highly significant in all evaluations. Tukey's test ($p < 0.05$) showed that the T5 (High shade × var. Catimor) interaction resulted in the highest levels of CBB attack damage in all evaluations. Notably, the same test showed that the T2 (No shade × var. Caturra) interaction resulted in the lowest levels of incidence in all evaluations, except one evaluation in September, in which a lower infestation was observed for T4 (Medium shade × var.Caturra), although it was statistically equal to T2 (No shade × var. Caturra). This result suggests that no-shaded plots reduce conditions for CBB infestations.

Figure 3 shows that all interactions maintained a similar trend, also demonstrating the differences between treatments. All treatments displayed a peak of infestation, and interactions T5, T3, T1, and T6 maintained incidence levels above 10% throughout the evaluations, with T5 maintaining the highest levels throughout the study period. In general, the obtained results reflect similar values to those reported when variables were studied separately. The T5 interaction represents the Catimor variety and shade levels above 40%, confirming that these factors most favor CBB infestation, with Catimor being a susceptible variety [21] and high levels of shade favoring the development of CBB [26, 37, 43]. These factors would converge to favor a more severe attack by CBB.

3.5. Effect of Plot Altitude on CBB Infestation and Total Number of CBB per Fruit. We observed that as the altitude gradient rises, the number of CBB per fruit decreases. The estimated probability of infestation was observed to decrease as the altitude of the coffee-producing areas sampled increased (Table 3). Plot altitude had significant effects on infestation ($p < 0.001$) and number of CBB per fruit ($p < 0.001$); sampling date had no significant effect on these two variables. The number of CBB per fruit was also affected by the altitude of the plot ($p < 0.001$) but not by the sampling date ($p = 0.542$). Tukey's mean comparison test ($p < 0.05$) indicated that at altitude levels lower than 1600 m.a.s.l., the average infestation was significantly greater (23.01% combined mean of all data); however, at altitudes above 1600 m.a.s.l., no significant differences were observed. The number of CBB per fruit showed the same trend. Previous studies confirmed this relationship between altitude and infestation at different altitude gradients [31, 42, 48, 56, 57]. This correlation would be strongly linked to temperature, considering that unfailingly, if we go higher in the altitudinal gradient, the temperature will tend to decrease and inversely [31]. The optimal range for CBB survival is between 15 and 32°C, with faster development at 27–30°C [48]. Hence, at sites with lower temperatures CBB development time is longer relative to sites with high temperatures [58]. The correlation between CBB per fruit and altitude has rarely been investigated, though studies such as by Mariño et al. [31], and Asfaw et al. [57] have shown that altitude is negatively correlated with infestation.

Table 5: GLMM estimates for CBB infestation according to the interaction between shade levels and coffee variety.

Sampling month	CBB infestation		
	F	p value	Major/minor[z]
May	12.425***	<0.0001	5//2
June	14.601***	<0.0001	5//2
July	7.6***	<0.0001	5//2
August	14.023***	<0.0001	5//2, 4
September	20.995***	<0.0001	5//2, 4

Asterisks indicate a significant effect of interaction on the CBB infestation. Generalized linear mixed models:*** = $p < 0.001$, ** = $p < 0.01$, * = $p < 0.05$, and ns = $p > 0.1$. [z]Treatment with major and minor mean.

Figure 4 depicts the monthly trend in infestation; at low altitudes below 1400 m.a.s.l., high infestation levels were maintained throughout the sampling period. During the months of July and August, the average number of CBB per fruit increased at altitudes below 1600 m.a.s.l.; however, they did not

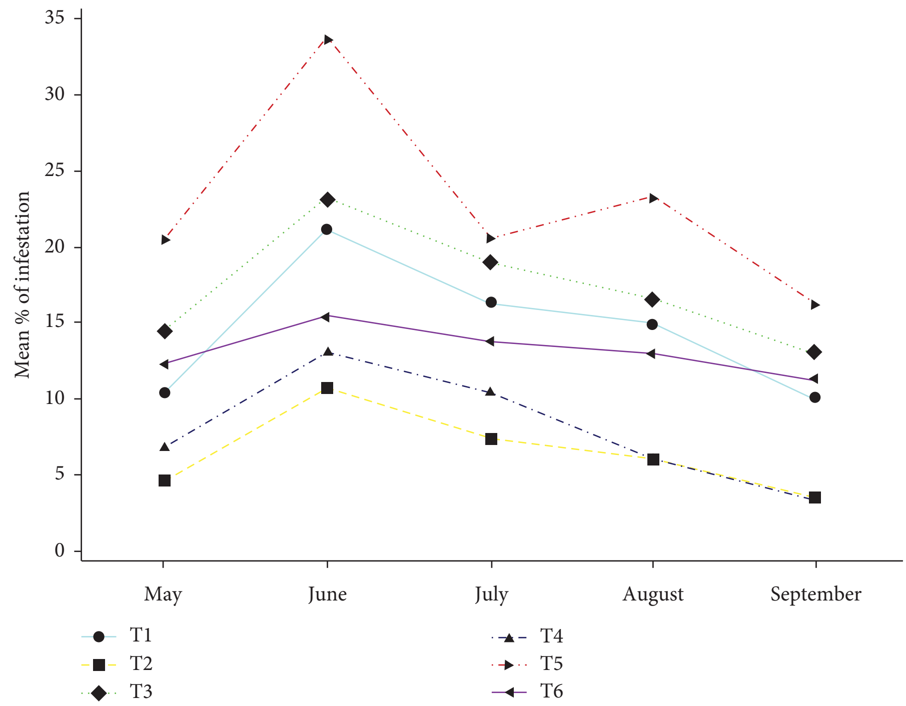


Figure 3: Monthly changes in the infestation of *Hypothenemus hampei* according to the interaction between shade levels and coffee variety. (T1no shade × var. Catimor, T2no shade × var. Caturra, T3medium shade × var. Catimor, T4medium shade × var. Caturra, T5high shade × var. Catimor, and T6high shade × var. Caturra).

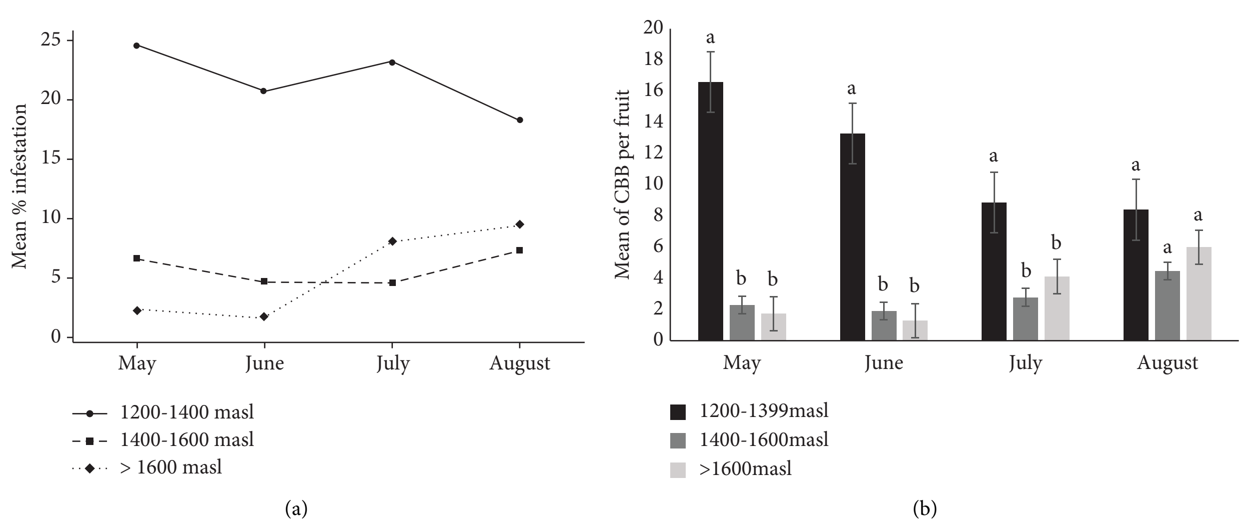


Figure 4: Monthly changes in (a) infestation and (b) CBB per fruit according to altitude. The letters above bars indicate statistical differences between CBB per fruit means (means separations test are independent for each month).

reach the average numbers of CBB per fruit in areas above 1600 m.a.s.l., which were higher, on average, throughout the study.

4. Conclusions

Our study shows that coffee variety, altitude, and shade influence the behavior of CBB in the agroecosystems of coffee plantations in the study area, and applies to other areas in Peru and worldwide.

We observed that the Caturra variety has a lower infestation of CBB than the Catimor variety, which is resistant to rust and has the largest area of cultivation within the study area. In the study area, more than 80% of the coffee farms are of the Catimor variety, its expansion was only because it is tolerant to rust but not considering other criteria such as cup quality and susceptibility to CBB. With this study, it is demonstrated that in future projects of renovation of coffee plantations or plans of expansion, other varieties should be considered as it is the case of the Caturra since studies demonstrate that besides demonstrating major resistance to CBB, with good management it has major quality in the cup and good yield, for what it is constituted as an alternative for the farmer.

On the other hand, the tests indicated higher proportions of CBB infestation at altitudes below 1400 m.a.s.l; these results are very encouraging for the study area since we are talking about rainforest brow ecosystems, whose altitudes of the coffee zones range from 800 to 1800 m.a.s.l., although there are areas with lower altitudes but these are used for other types of crops such as rice and cocoa. If the infestation of CBB decreases as the altitude increases, this is a good result, especially when talking about specialty coffees or high-altitude coffees that today are the most commercialized in international markets, due to their high quality in the cup, being very encouraging for coffee growers dedicated to the production of high-altitude coffee.

Shaded farms with more than 40% show higher percentages of CBB infestation. To minimize this damage, tree species that provide shade within the farm must be selected according to a good arrangement of shade and leaf type, among other characteristics. On the other hand, trees must be adequately distributed throughout the farm with adequate spacing to provide adequate shade for increased production and reduce CBB infestation. Based on these results, coffee producers are urged to adequately manage the shade within the coffee plantations, using adequate spacing according to the forest species, using species according to the contribution that they can make to the system (for wood, nitrogen fixation, biomass contribution, etc.), and finally species of rapid growth and preferably species native to the area.

Also based on this study, considering the Caturra variety, higher altitudes, and shade of less than 40% with appropriate tree species and with an adequate use of control methods such as biological (Beauveria sp), ethological control (traps), and cultural control (selective harvesting), can significantly increase the yield and quality of the cup and this means increasing the economic income of the coffee producer, and therefore this will contribute to raising the standard of living.

Data Availability

All data presented in this study are available in the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

S.L and M.O. were responsible for conceptualization; L.G.B., D.M, S.L., M.O., and K.B.R. were involved in methodology; K.B.R. performed the formal analysis; D.C., L.G.B., and J.C. were involved in the investigation of the study; K.B.R. was involved in data curation; K.B.R. was responsible for writing and preparing the original draft; S.L. and K.B.R. were responsible for writing, reviewing, and editing the manuscript; M.O. was involved in the supervision of the study; M.O. was involved in project administration; and S.L., M.O., and L.G.B were responsible for funding acquisition.

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