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Options for managing *Antestiopsis thunbergii* (Hemiptera: Pentatomidae) and the relationship of bug density to the occurrence of potato taste defect in coffee

Joseph Bigirimana[1,], Andrew Gerard[2], David Mota-Sanchez[1], and Larry J. Gut[1]*

Abstract

Potato taste defect is a potato-like smell found in green and roasted coffee beans. Potato taste defect reduces the flavor experience of finished coffee and causes it to be rejected by consumers. The presence of potato taste defect has been associated with insect damage, especially damage from the Antestia bug, *Antestiopsis thunbergii* (Gremlin) (Hemiptera: Pentatomidae). A 2-yr study was conducted to evaluate the effectiveness of integrated pest management using pruning alone or in combination with several commercially available insecticides to control a field population of Antestia bug and to assess the relationship between these treatments and the occurrence of potato taste defect in coffee using laboratory and field tests. Field trials were conducted in 3 major coffee growing regions of Rwanda: Rubona, Gakenke, and Kirehe. In laboratory bioassays, significant differences were found between insecticides on the percentage mortality of adult bugs. The percent mortality was higher for pyrethroid, Fastac (Alpha-cypermethrin), and pyrethrins (Pyrethrum 5EW, Pyrethrum EWC + Sesame and Agroblaster) than for the neonicotinoid, imidacloprid. Mortality from imidacloprid increased over time, providing a lower mortality than Pyrethrum 5EW and Agroblaster 12 h post-treatment. In the field, the highest mean mortality was achieved with Pyrethrum 5EW, Fastac, and Pyrethrum EWC applied to pruned coffee trees. Additionally, pruning alone registered a statistically higher mean insect mortality than unpruned coffee trees without insecticides application. Multiple logistic regression analysis indicated that potato taste defect was positively associated with the bug density and the extent of damage caused by Antestia bug. The study suggests that pruning combined with insecticide application, especially Fastac, provides better control of Antestia bug and significantly reduces potato taste defect compared to either pruning or insecticide application alone.

Key Words: Antestia bug; pruning; pyrethroid; Integrated Pest Management

Resumen

El defecto del sabor de la papa es un olor similar a la papa que se encuentra en los granos de café tostados y verdes. El defecto del sabor de la papa reduce la calidad del sabor del café procesado y hace que los consumidores lo rechacen. La presencia de del sabor de la papa se ha asociado con daño por insectos, especialmente daño por el chinche Antestia, *Antestiopsis thunbergii* (Gremlin) (Hemiptera: Pentatomidae). Se realizó un estudio de dos años para evaluar la efectividad del manejo integrado de plagas usando solamente la poda o en combinación con varios insecticidas disponibles comercialmente contra una población del chinche Antestia en el campo y para evaluar la relación entre estos tratamientos y la ocurrencia de del sabor de la papa en el café usando el laboratorio y pruebas de campo. Se realizaron ensayos de campo en tres de las principales regiones productoras de café de Ruanda: Rubona, Gakenke, y Kirehe. En bioensayos de laboratorio, se encontraron diferencias significativas entre los insecticidas en el porcentaje de mortalidad de insectos adultos. El porcentaje de mortalidad fue mayor para los piretroides, Fastac (alfa-cipermetrina) y las piretrinas (Pyrethrum 5EW, Pyrethrum EWC + Sesame y Agroblaster) que para el neonicotinoide, imidacloprid. La mortalidad por imidacloprid aumentó con el tiempo, proporcionando una mortalidad menor que Pyrethrum 5EW y Agroblaster 12 horas después del tratamiento. En el campo, el promedio más alto de mortalidad se logró con Pyrethrum 5EW, Fastac y Pyrethrum EWC aplicado a los cafetos podados. Además, la poda sola registró un promedio de mortalidad de insectos estadísticamente más alta que los árboles de café no podados sin aplicación de insecticidas. El análisis de regresión logística múltiple indicó que del sabor de la papa se asoció positivamente con la densidad de los chinches y la magnitud del daño causado por Antestia. El estudio sugiere que la poda combinada con la aplicación de insecticidas, especialmente Fastac, proporciona un mejor control del chinche Antestia y reduce significativamente la del sabor de la papa en comparación con solamente la poda o la aplicación de insecticida.

Palabras Clave: chinche Antestia; poda; piretroides; Manejo Integrado de Plagas

Coffee is an important export crop and a major foreign exchange earner for many countries in Africa, Asia, and Latin America. It is estimated that coffee cultivation, processing, trading, transportation, and marketing provide employment for millions of people worldwide (Phiri et al. 2009). Particularly for Rwanda, coffee accounts for a significant proportion of the country's total annual agricultural export and is an important source of direct cash income for about a half million families (Moss et al. 2017). As most of the coffee in the country is cultivated on smallholdings, it impacts a much higher percentage of the population than all other cash crops in the country.

Despite its importance, coffee suffers yield loss from several factors including insect pests and diseases, amongst which Antestia bug,

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Antestiopsis thunbergii (Gmelin) (Hemiptera: Pentatomidae) is the most important (Gesmalla et al. 2016). Antestia bug feeds on various parts of the coffee plants ranging from flower buds, berries at different stages of development and maturation, and green shoots and leaves (Kirkpatrick 1937). Cilas et al. (1998) reported that Antestia bug moves throughout the coffee plantations and sometimes has an aggregative distribution possibly due to its reproductive behavior. Feeding on flower buds results in browning or blackening of buds that impairs fruit set (Le Pelley 1968; Mugo 1994). When high infestation by Antestia bug occurs during the onset of rains, loss of flowers may be significant and severe infestation may prevent the tree from flowering (Waller et al. 2007). It is estimated that the yield loss due to Antestia bug averages 30%, but can be as high as 38% if the insect population reaches 15 bugs per tree (Gesmalla et al. 2016). Antestia bug is native to Africa, but also has spread to other coffee growing countries of Asia such as Pakistan, India, Myanmar, Sri Lanka, and southern China (Rider et al. 2002).

Antestia bug also is suspected to facilitate the entry of microbes that are associated with potato taste defect in coffee (Bouyjou et al. 1993). Potato taste defect is a potato-like smell found in green and roasted coffee beans, and also in roasted coffee beans after brewing (Gueule et al. 2015). The smell is believed to be caused by a bacterium of the family *Enterobacteriaceae* that develops in coffee beans and produces isopropyl-2-methoxyl-3-pyrazine (IPMP) and 2-isobutyl-3-methoxypyrazine (IBMP), the compounds that are responsible for the off-flavor (Becker et al. 1988; Gueule et al. 2013, 2015). It is also possible that one of the off-flavor compounds, IPMP, is produced by the plant itself as a stress response to Antestia damage (Jackels et al. 2014). Notwithstanding, it has been reported that protection of coffee plantations to control Antestia bug decreases the occurrence of potato taste defect in roasted beans (Bouyjou et al. 1999).

In studies conducted by Jackels et al. (2014), Bressanello et al. (2017), and Iwasa et al. (2015), the coffee quality was evaluated using the Cupping Protocol of the Specialty Coffee Association of America. Experienced Licensed Q Graders evaluated the cup qualities of samples including the defects, and assigned scores that provided international standards for cup evaluation that were consistent with other analytical techniques, such as Gas Chromatography-Mass Spectrometry, Headspace-Solid phase micro extraction, and Liquid Chromatography-Mass Spectrometry (Jackels et al. 2014; Bressanello et al. 2017; Iwasa et al. 2015). The aim of the current study was twofold: (1) to examine the effectiveness of integrated pest management tactics including pruning and the use of several commercially available insecticides to control field populations of Antestia bug, and (2) to evaluate the relationships between these treatments and the occurrence of potato taste defect in coffee.

Materials and Methods

LABORATORY BIOASSAYS

Adult Antestia bugs were field collected from coffee trees by handpicking in the principal Coffee Research Station situated in Rubona (02.4842°S, 29.7661°E), at altitude 1,673 masl, and held in a 3 L plastic container with holes on all sides to facilitate air entry and circulation. Identity of *Antestiopsis thunbergii* was confirmed by comparing collected insects with preserved specimen of this species. Five insecticides were used in the experiment: (1) Confidor (17.8% imidacloprid, Bayer East Africa, Nairobi, Kenya); (2) Fastac (10% alpha-cypermethrin, BASF Corporation, Nairobi sub-office; Nairobi, Kenya); (3) Pyrethrum 5EW (5% pyrethrins, Agropy Ltd, Kigali, Rwanda; (4) Pyrethrum EWC (2.19% pyrethrins and 10% sesame, Agropy Ltd, Kigali, Rwanda); and (5) Agroblaster (8% pyrethrins, SOPYRWA, Musanze, Rwanda). All of the insecticides were diluted as 1:1,000 except imidacloprid, where the dilution was 133 ppm to match the recommended concentration and serve as a positive control. Collected adult bugs were sprayed with insecticides or water only as a control on the same day they were collected from the field. Treatments were applied topically to groups of 15 adult bugs placed in a Petri dish using a hand sprayer (Multi-Purpose 1 L Hand Pump Sprayer, Hudson #79142, Zoro, Chicago, Illinois, USA) at the above concentrations. Each treatment was replicated 3 times in a completely randomized experimental design. Insects were counted as dead if they could not move their wings, stand, and fly. Mortality of Antestia bug was assessed at 5 min, 1 h, and 12 h after spraying.

FIELD TRIALS

Field trials were conducted in Rwanda from 2015 to 2016. Pruning, an agricultural practice used to shape the tree canopy, facilitates field operations and satisfies the needs of crop production and fruit quality (Jiménez-Brenes et al. 2017), and used either alone or in combination with insecticides, was evaluated for the control of Antestia bug. Pruning was carried out 1 mo prior to insecticide sprays. Trials were established in the 3 principal coffee growing regions of Rwanda: Rubona, Gakenke, and Kirehe. Rubona, already referred to earlier, is located in the southern province of Rwanda. Gakenke is in the northern province (01.6908°S, 29.7955°E) and at an elevation of 1,792 masl, whereas Kirehe is in the eastern province (2.2633°N, 30.6413°E) and at an altitude of 1,530 masl. These 3 sites were located in different agroecologies where high populations of Antestia bug were reported (Bigirimana et al. 2012). In all 3 sites, the variety used was Bourbon Mayaguez 139 (BM 139) and the coffee plantations were between 6 to 8 yr old. There were 2 criteria for farm selection: the farm was not sprayed with insecticides for at least 1 yr prior to the experiment, and was large enough to accommodate all the treatments. Treatments consisted of (i) control (plots were not pruned and not treated with insecticides); (ii) pruning only; (iii) pruning plus Fastac sprays; (iv) pruning plus sprays with Pyrethrum 5EW; (v) pruning plus sprays with Pyrethrum EWC; (vi) pruning plus sprays with Agroblaster; and (vii) pruning plus sprays with imidacloprid. In addition, all of the insecticides were diluted as 1:1,000 except imidacloprid where the dilution was 133 ppm because it was a recommended concentration. Control options were evaluated in a randomized complete block design with 7 treatments replicated 3 times each in the 3 production regions. The experimental plot in each region was comprised of 42 coffee trees, 7 rows by 6 trees per row. The coffee trees were spaced 2 m between rows and 2 m within rows. Experimental plots were isolated from each other by 5 m. The 6 central trees (2 rows of 3 trees) in each plot of 42 trees were used for data collection to provide a 2-tree buffer on all sides of the sampled trees. Before insecticides were applied, plastic sheeting was used to cover the ground to facilitate catching Antestia bugs that fell out of the canopy following the spray. Similar to the laboratory bioassays, bugs were considered dead if they were not able to move their wings, stand, and fly. Sprays were applied 2 wk after flowering using a knapsack sprayer (Cooper Pegler Sprayers, Gandhinagar, Gujarat, India), where a plot was sprayed with 15 L of insecticides and water for the control. We sprayed once, 2 wk after flowering, because the crop was in a most susceptible stage and the period when Antestia bug was most vulnerable (Le Pelley 1942). Dead insects including nymphs and adults were counted 5 min after sprays, then after 1 h, and 12 h post-treatment. On the day of harvest, cherry infestation by Antestia bug was determined by selecting 3 bearing branches (1 at the bottom, 1 in the middle, and the last at the top) of the 6 central trees used for data collection, counting the number of infested and clean berries, and calculating the percent infested.

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TESTING SAMPLES FROM THE STUDY

Three kg of ripe cherries were collected from each test plot 6 mo after spraying. The cherries were collected weekly over a 1 mo period and hand pulped at the washing station of the principal Coffee Research Station in Rubona. These coffee beans were wet processed and dried. Each sample (500 g of green coffee) was roasted using a laboratory-scale roaster (Suntory Laboratory and Suncafe Laboratory, Kanagawa, Japan). The roasting degree was adjusted to a luminosity (L, brightness) value of 22 to 23 for all samples. Cupping of the samples was performed in accordance with the Specialty Coffee Association of America cupping protocol (Iwasa et al. 2015). All evaluations were conducted by experienced Licensed Q graders, certified by the Coffee Quality Institute. Cupping was arranged in such a way that 15 cups per treatment were tested. Three Licensed Q graders cupped all the samples, and each grader was considered as a replicate. Every grader performed a standard session cupping of all the samples in a randomized order as blind analyses. The cupping objective was not to give the overall cupping score, but to detect whether the sample had or did not have the potato taste defect. The percentage of cups with potato taste defect was calculated for each treatment and then averaged across replicates.

STATISTICAL ANALYSES

Data from laboratory bioassays were corrected for mortality using Abbott's formula (Abbott 1925). Data were arcsine square root transformed to fit normality and homogeneity of variance assumptions prior to being subjected to the repeated measurements analysis of variance (ANOVA) test. Field data were log transformed (x + 1) and also were subjected to repeated measurements ANOVA test. A combined analysis of 3 sites and 7 treatments over time was conducted. For both laboratory bioassays and field experiments, treatment means were separated using the Tukey's test. In addition, the percent occurrence of potato taste defect was calculated for each treatment, and was tested for normality using the Shapiro Wilk test and equality of variance using Brown and Forsythe's Test. This data then was subjected to 1-way ANOVA, followed by Tukey's multiple comparison procedure at $P = 0.05$. The multiple logistic regression analysis was used to assess the relationship between the bug density, the berry density, and the effect of pruning to the occurrence of potato taste defect, a response variable modelled as present or absent. The multiple logistic regression model used can be written as:

$$Logit\ (p) = \log\left[\frac{p}{1-p}\right]$$

Or

$$Logit\ (p) = \alpha + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3$$

where p is the probability that potato taste defect occurs; α, the intercept; β_1, the coefficient of bug density (X_1); β_2, the coefficient of berry damage density, i.e., the percentage of damaged cherries ($X2$); and β_3, the coefficient of pruning ($X3$) (Rosner 2011). In this study, independent explanatory variables were Antestia bug density, and the percentage of cherries damaged by Antestia bug. Pruning was a binary variable, because plots were either pruned and the variable was coded 1, or unpruned and the variable was coded 0.

The probability value was thus estimated as:

$$p = \frac{\exp(\alpha + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3)}{1 + \exp(\alpha + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3)}$$

Odds ratio was used to facilitate model interpretation. Odds ratio indicates how much likely or unlikely potato taste defect will occur for a set of values of independent variables (Rosner 2011). To fit the model, we used the stepwise regression technique and the model with the smallest Akaike's Information Criterion was selected (Aho et al. 2014). All statistical analyses were conducted using SAS software (Version 9.4, SAS Institute, Cary, North Carolina, USA).

Results

LABORATORY BIOASSAYS

There were significant differences in percent mortality of Antestia bug following treatments with insecticides ($F = 163.48$; df = 4,12; $P < 0.0001$). Five min after sprays, Fastac and all the pyrethrins (Pyrethrum 5EW, Pyrethrum EWC, and Agroblaster) caused a higher percent mortality of Antestia bug than that of the neonicotinoid insecticide, imidacloprid (Table 1). The highest percent mortality was observed with Agroblaster and Fastac, 83 and 86%, respectively. The same trend was recorded 1 h after spraying except that the percent mortality due to imidacloprid sprays increased from 0 to > 26%. Twelve h after treatment, Fastac and Pyrethrum EWC provided 100% mortality and significantly greater mortality than imidacloprid. Antestia bug mortality rates of 94% and 90% were recorded in the Pyrethrum 5EW and Agroblaster treatments, respectively, which was statistically different than the 71% mortality provided by the imidacloprid treatment.

INSECTICIDES EFFECTIVENESS UNDER FIELD CONDITIONS

Analysis of variance did not show significant effects of sites on the bug mortality ($F = 1.16$; df = 2,36; $P > 0.05$); hence, all sites were combined in the analysis of efficacy. Significant differences in mortality of Antestia bug following pruning and the various insecticide treatments under field conditions were observed ($F = 100.2$; df = 6,36; $P < 0.0001$). Time effects also were significant ($F = 66.73$; df = 2,36; $P < 0.0001$). Five min after treatment, pruning, and all treatments combining pruning plus an insecticide provided significantly higher mortality than the no pruning and no pesticide treatment (Table 2). Across all time intervals, the highest mean mortality was recorded in plots that were pruned and treated with Pyrethrum 5EW. This treatment provided significantly greater mortality compared to all other treatments. Pruning plus application of Fastac or Pyrethrum EWC resulted in significantly higher mortality than all other treatments except pruning plus Pyrethrum 5EW treatment. A lower level of mortality was recorded in plots that were not pruned and not treated with insecticide. Plots that were pruned and not treated with insecticide had a mean mortality of Antestia bug equivalent to that of plots that were pruned and treated with imidacloprid or Agroblaster. Although mortality increased slightly across all treatments at 1 h and 12 h after sprays, the relative effectiveness of the various treatments was the same as that recorded 5 min after treatment.

Table 1. Mean* (± SEM) percent mortality of Antestia bug in laboratory bioassays at 5 min, 1 h, and 12 h after spray following insecticide sprays.

	Time after spray		
Treatment	5 min	1 h	12 h
Fastac	86.1 ± 2.7 a	83.3 ± 2.7 a	100.0 ± 0.0 a
Pyrethrum 5EW	58.3 ± 2.7 a	58.3 ± 3.7 a	94.4 ± 3.8 ab
Pyrethrum EWC + Sesame	68.1 ± 2.6 a	73.6 ± 3.6 a	100.0 ± 0.0 ab
Agroblaster	86.1 ± 2.7 a	86.1 ± 2.6 a	90.3 ± 3.9 ab
Imidacloprid	0 .0 ± 0.0 b	26.4 ± 2.6 b	70.8 ± 2.7 b

*Means in a column followed by the same lowercase letters are not statistically different ($P \leq 0.05$, ANOVA and Tukey's test)

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Table 2. Mean* (± SEM) mortality of Antestia bug in field trials at 5 min, 1 h and 12 h following insecticide sprays.

Time after spray			
Treatments	5 min	1 h	12 h
Pruning & Pyrethrum 5EW	13.1 ± 1.7 a	14.4 ± 1.5 a	15.8 ± 1.5 a
Pruning & Fastac	12.3 ± 1.3 a	13.7 ± 0.9 a	15.0 ± 1.2 a
Pruning & Pyrethrum EWC	8.7 ± 1.7 b	10.0 ± 1.6 b	11.6 ± 2.3 b
Pruning & Agroblaster	5.2 ± 2.2 c	6.4 ± 2.2 c	8.1 ± 1.8 c
Pruning & Imidacloprid	2.1 ± 0.8 d	4.6 ± 1.3 c	6.9 ± 1.6 c
Pruning & No Pesticide	3.1 ± 1.9 cd	4.9 ± 1.9 c	6.2 ± 1.2 c
No Pruning & No Pesticide	0.3 ± 0.8 e	1.4 ± 0.8 d	2.7 ± 0.8 d

*Means in a column followed by the same lowercase letters are not statistically different ($P \leq 0.05$, ANOVA and Tukey's test)

OCCURRENCE OF POTATO TASTE DEFECT IN TESTED SAMPLES

There were significant differences between treatments on the occurrence of potato taste defect in coffee ($F = 261.06$; df = 6,14; $P < 0.0001$). Treatment with Fastac in pruned coffee trees resulted in the lowest potato taste defect, and the control had the highest incidence (about 12 × Fastac spraying in pruned plots) (Fig. 1). Pruned plots treated with Fastac or Pyrethrum 5EW had the lowest potato taste defect incidence on average, but plots sprayed with Pyrethrum 5EW had twice the potato taste defect incidence than those treated with Fastac. Additionally, the control had twice the potato taste defect incidence than pruning alone, which had the same potato taste defect incidence as pruned plots treated with imidacloprid. Overall, occurrence of potato taste defect in all tested samples was about 6%, i.e., about 6% of the tested samples had potato taste defect. Multiple logistic regression analysis showed that each of the variables were significantly related with the incidence of potato taste defect in coffee (Table 3). The odds in favor of potato taste defect incidence for unpruned plots were 1.48 × (i.e., $e^{0.39} = 1.48$) as great as for pruned plots, holding all other variables constant. The odds ratio for Antestia bug density was 2.1 ($e^{0.74} = 2.1$), which indicated that for 2 plots that were 1 unit apart on Antestia bug density and were comparable on all other variables, the odds in favor of potato taste defect incidence for the plot with higher Antestia bug population were 2.1 × as great as the plot with lower bug population. Similarly, the odds ratio for berry damage density were 1.36 (i.e., $e^{0.31} = 1.36$) indicating that for 2 samples that were 1% berry damage density apart, the odds in favor of the potato taste defect incidence were 1.36 × as great as for a sample with a higher berry damage compared with a sample with a lower berry damage density. The mean percent infested berries ranged from 13.1% in pruned plots sprayed with Pyrethrum 5EW to 47.15% in unpruned plots without insecticide sprays (Table 4). It is worth noting that all the variables tested in the analysis were significantly related to potato taste defect occurrence.

Discussion

Overall, pruning and all treatments combining pruning and insecticide application provided a higher mortality of Antestia bug compared to pruning alone, no pruning, and no pesticide application. Combining insecticide application and cultural practices is fundamental to Inte-

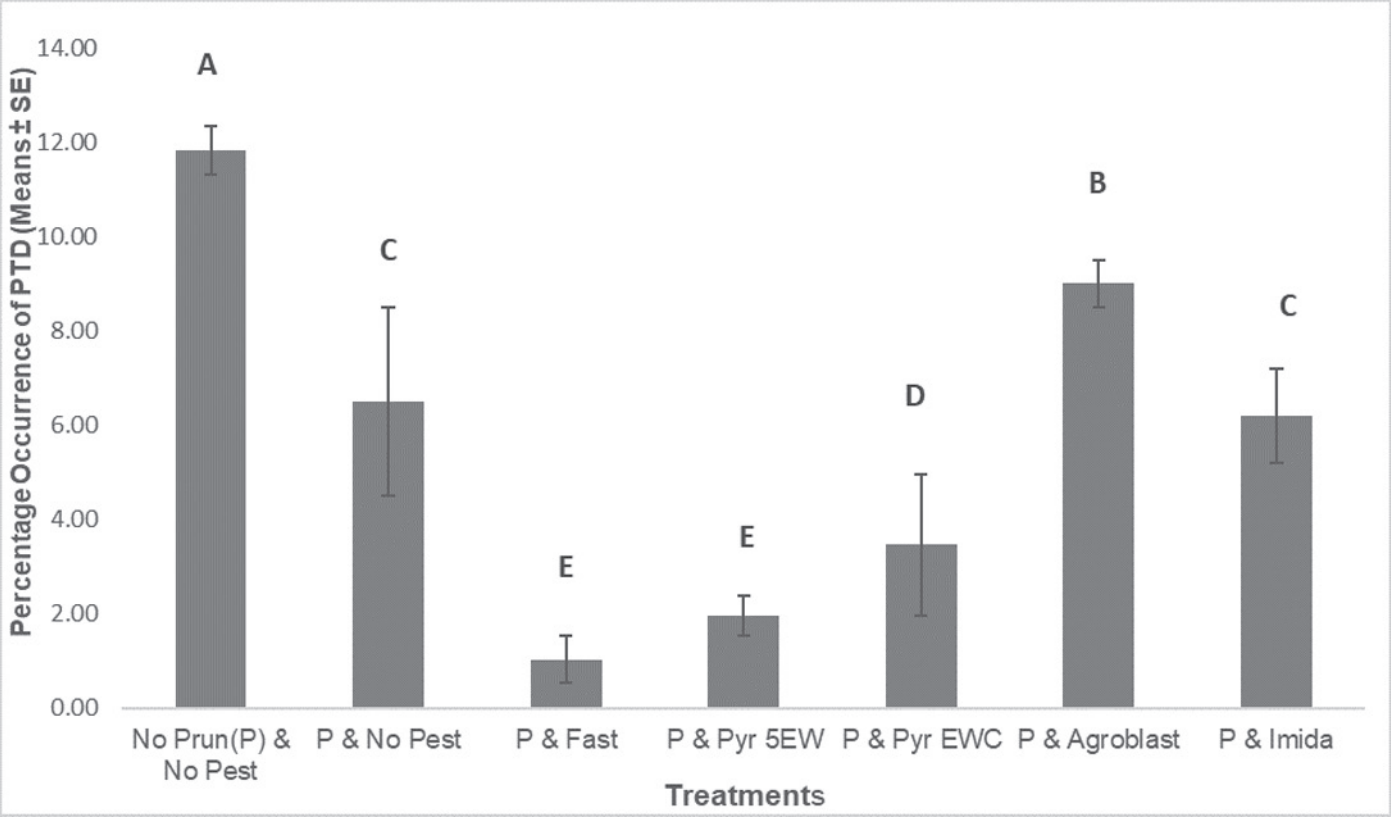


Fig. 1. Effects of pest management tactics on the occurrence of potato taste defect in coffee. No Prun(P) & No Pest (No Pruning and No Pesticide), P & No Pest (Pruning and No Pesticide), P & Fastac (Pruning and Fastac), P & Pyr 5EW (Pruning and Pyrethrum 5EW), P & Pyr EWC (Pruning & Pyrethrum EWC), P & Agroblast (Pruning and Agroblast), and P & Imida (Pruning and Imidacloprid). Fastac sprayed in pruned plots had the lowest levels of potato taste defect whereas the control had the highest. Bars represent the standard error of means. Means followed with the same letter are not statistically different ($P \leq 0.05$, ANOVA and Tukey's test).

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Table 3. Stepwise multiple logistic regression analysis using Antestia bug density, berry damage density, and pruning as predictors for occurrence of potato taste defect in coffee.

Variables/Units	Estimates	Standard error	*P* > ChSq	Odds ratio	95% Wald Confidence Limits
Intercept	−1.78	0.47	< 0.001		
Antestia bug density(number of bugs per plot)	0.74	0.18	< 0.01	2.10	1.47–2.98
Berry damage density (% of damaged cherries)	0.31	0.09	< 0.01	1.36	1.14–1.63
Pruning (Pruned versus unpruned plots)	−0.39	0.17	0.04	1.48	1.02–2.14

Model likelihood ratio: $\chi^2 = 14.5851$, df = 4, Pr > $\chi^2 = 0.0056$; AIC = 241.216; Pseudo – $R^2 = 0.329$. All variables tested in the study (Antestia bug density, berry damage density, and pruning) were significantly related with the occurrence of potato taste defect in coffee ($P < 0.05$).

grated Pest Management programs of many agricultural pests (Alyokhin 2009; Larson et al. 2017). This strategy not only facilitates insecticide sprays, increases insecticide control efficacy, and reduces the cost of insecticide application, but also helps in reducing the dependency on chemical insecticides, thereby slowing down the development of insecticide resistance and in preventing negative effects on humans and the environment (Freitas et al. 2011). The highest mortality of Antestia bug was recorded in plots that were pruned and treated with pyrethrins, such as Pyrethrum 5EW with a mean of 15.8 ± 1.5 bugs compared to plots sprayed with imidacloprid with a mean of 6.9 ± 1.6 bugs at 12 h post-treatment. On average, spraying with Pyrethrum 5EW provided greater mortality of the bug than all other treatments, including imidacloprid, with a mean mortality of 15.8 ± 1.5 and 6.9 ± 1.6 bugs for Pyrethrum 5EW and imidacloprid, respectively. In addition, pruning combined with Fastac or Pyrethrum EWC sprays caused significantly higher mortality of the bug than all other treatments except pruning plus Pyrethum 5EW. Pruned plots not treated with insecticides had a mean mortality of Antestia bug equivalent to those that were pruned and treated with imidacloprid, with a mean mortality of 6.9 ± 1.6 and 6.2 ± 1.2 Antestia bugs for pruned plots treated with imidacloprid and pruning plots not sprayed with insecticide, respectively. As shown in this study, pyrethrins provided greater mortality of the bug; however, they are reported to break down quickly, and are thus less toxic to the environment, especially when they are exposed to UV light and other weather conditions (Cecchinelli et al. 2012). However, pyrethrins also kill other non-target organisms. In this study, we did not evaluate the potential impact of pyrethrins and pyrethroids on non-target organisms.

This study also showed that the results of the laboratory bioassays were consistent with those of the field efficacy trial. Bruck et al. (2011) observed that insecticides that performed well in the laboratory bioassays also performed well in the field, an indication that laboratory screening of new pesticides is a worthwhile activity. An exception to this was Agroblaster, which performed well in the laboratory bioassays but failed to give satisfactory results in the field. This could be attributed to its degradation due to the environmental conditions, but given the lack of published documentation of degradation, this would require further investigation. In addition, results indicated that mortality due to imidacroprid sprays increased gradually over time, and this may be attributed to its slow rate of inducing mortality. Imidacloprid belongs to the neonicotinoid group of insecticides, which are systemic in nature, and with a high potential for long-term protection to control major insect pests (Mota-Sanchez et al. 2009; Simon-Delso et al. 2015).

Table 4. Mean percentage of infested berries in plots that received application of various treatments.

Treatment	N	Percentage infested berries* (Mean ± SE)
Pruning & Pyrethrum 5EW	3	13.12 ± 1.02 e
Pruning & Fastac	3	24.62 ± 2.33 d
Pruning & Pyrethrum EWC	3	25.68 ± 1.59 cd
Pruning & Imidacloprid	3	29.86 ± 0.87 cd
Pruning & No Insecticide	3	31.44 ± 0.89 c
Pruning & Agloblaster	3	39.16 ± 0.57 b
No Pruning & No Pesticide	3	47.15 ± 1.19 a

*Means in a column followed by the same lowercase letters are not statistically different ($P \leq 0.05$, ANOVA, and Tukey's test).

Our results also showed that pruning alone provided a significant increase in the mean mortality over plots not pruned. These results agree with Bigirimana et al. (2012), where it was reported that pruning opens up the coffee bushes and, thus, creates unfavorable conditions for the bug, while also improving pesticide penetration and efficacy. Additionally, Kirkpatrick (1937) confirmed that Antestia bug rarely can be found on exposed parts of unshaded bushes because it prefers warm conditions, especially when the outer parts of the coffee bush are warmer than the interior. Additionally, Hargreaves (1936), when conducting his research in Uganda, observed that shade was probably responsible for attracting Antestia and that with the removal of shade conditions, the pest disappears. More recently in Kenya, Mugo et al. (2013) confirmed that severity of Antestia spp. on coffee was significantly higher under shade conditions compared to coffee grown in the open. The above evidence suggests that pruning should be considered as an important component for an effective IPM program of perennial high value coffee trees. It is worth noting that in this study, pruning was carried out 1 mo prior to pesticide sprays.

This study indicated that about 6% of all tested samples had potato taste defect. It is worth noting that harvested cherries were not subjected to sorting at either the field or coffee washing station level. We also did not subject the coffee cherries to flotation. The effects of sorting or floating coffee cherries on the occurrence of potato taste defect needs further investigation.

Additionally, the study revealed that the higher the density of Antestia bug in some plots, the higher were the chances of detecting potato taste defect in samples obtained from such plots. Potato taste defect was positively associated with bug density and berry damage, with a significant association. Jackels et al. (2014), while investigating the manifestation of potato taste defect using chemical volatiles, found that coffee having visible insect damage exhibited both a potato taste defect surface volatile profile and 3-isopropyl-2-methoxypyrazine in interior volatiles. Jackels et al. (2014) concluded that Antestia bug feeding activity is associated with the occurrence of potato taste defect in coffee. In another study conducted in East Africa, specifically in Burundi, Bouyjou et al. (1993) reported that protection of coffee plantations to control insect pests decreases the occurrence of potato taste defect in coffee. He did not indicate to what extent the pest population should be reduced to eliminate the defect.

Our results also showed the odds in favor of potato taste defect incidence were 1.48 × greater for unpruned plots compared to pruned plots, holding all other variables constant. This should be expected be-

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cause both the Antestia bug population and the damage were higher in unpruned coffee bushes than in pruned coffee trees. Bouyjou et al. (1999) also observed that coffee plots that received up to 7 annual applications of insecticides could produce beans with less than 1% potato taste defect-contaminated cups, and that with proper processing and sorting of damaged beans could significantly reduce the incidence of potato taste defect in coffee beans.

To conclude, given that Antestia bug is widely distributed in various coffee producing countries and causes huge losses in terms of yield and quality, managing this insect pest is of critical importance. Pruning creates unfavorable conditions for Antestia bug and improves pesticide penetration and, therefore, efficacy, and it should be an integral part of Integrated Pest Management programs. Where only imidacloprid is being used continually to control Antestia bug in coffee plantations, it should be alternated with other contact insecticides because as a systemic insecticide, the likelihood for the bug to develop resistance is high (Prabhaker et al. 1997). Pyrethrins currently offer the best alternative because they are inexpensive and are produced locally in the eastern African region, and as documented in this study, they are fairly effective. Alpha-cypermethrin (Fastac) provides excellent control of the Antestia bug. However, pyrethroid activity on non-target organisms should be evaluated if one would like to make a sustainable recommendation of pyrethroids in coffee farming. Finally, as coffee coming from the African Great Lakes Region is among the best in the world (Gueule et al. 2013), and yet the place where potato taste defect has been reported, the distribution and the severity of this defect as well as the other factors that may be responsible for the occurrence of this defect should be fully investigated. Additionally, efforts should be made to understand the mechanisms of potato taste defect infection in order to eliminate it in coffee.

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