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HOST- PLANT AND INSECT- PEST COMPENSATIONS, AND MICROCLIMATE AS DRIVERS FOR INTENSITY OF *Toxoptera aurantii* (HEMIPTERA: APHIDIDAE) IN ARABICA COFFEE-BANANA FARMING SYSTEM OF MOUNT ELGON REGION, UGANDA

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ABSTRACT

Host-plants and insect-pests' compensational relationships are known to enable plants and insects to survive and adopt to changing environmental conditions. In the mount Elgon region of Uganda, exists a mosaical pattern of different coffee farming systems with increasing altitudes, and their combinations create differing microclimates, which influence host-plant and pest behaviors. The objective of this study was to determine the host-plant and *Toxoptera aurantii* compensations in Arabica coffee cropping systems of mount Elgon region in Uganda. A two-year study on the coffee leaf biomass, *T. aurantii* numbers on the leaf surface, and damage intensity of *T. aurantii*, was conducted using 72 Arabica coffee farms with mixed coffee polycultures (farming systems). Two independent factors were considered; altitude as a major factor and the farming system as the second factor. There was evidence of significant host-plant and insect-pest compensations; host-plant/ microclimates, and insect-pest /microclimates. Linear regression analysis revealed a **-** relationship (number of leaves /branch / *T. aurantii* numbers). A + relationship (number of leaves / branch infested by *T. aurantii* / *T. aurantii* abundance). Also *T. aurantii* abundance had a **+** relationship / RH or/ ambient temperature). The Arabica coffee leaves/ branch had a **–** relationship (ambient temperature or/ RH). While the *T. aurantii* infested leaves /branch only had a **+** relationship with RH. Regarding the soil variables it was only soil temperature which had a **+** relationship with the number of leaves / branch. The *T. aurantii* infested leaves /branch had a **+** relationship (soil temperature or/soil moisture).

Key Words: Leaf-biomass, microclimate, relative-humidity, temperature

RÉSUMÉ

Les relations de compensation entre les plantes hôtes et les insectes ravageurs sont connues pour permettre aux plantes et aux insectes de survivre et de s'adapter aux conditions environnementales changeantes. Dans la région du mont Elgon en Ouganda, il existe un modèle mosaïque de différents systèmes de culture du café avec des altitudes croissantes, et leurs combinaisons créent des microclimats différents, qui influencent les comportements des plantes hôtes et des ravageurs. L'objectif de cette étude était de déterminer les compensations de la plante hôte et de *Toxoptera aurantii* avec le microclimat dans le café Arabica dans des conditions d'altitudes et de systèmes de culture différents. Une étude de deux ans sur la biomasse des feuilles de caféier, le nombre de *T. aurantii* à la surface des feuilles et l'intensité des dégâts de *T. aurantii* a été menée dans 72 plantations de café Arabica avec polycultures de café mélangé (systèmes agricoles). Deux facteurs indépendants ont été considérés; l'altitude comme facteur majeur et le système agricole comme deuxième facteur. Il y avait des preuves de compensations importantes pour les plantes hôtes et les insectes nuisibles; plante hôte / microclimats; et insectes nuisibles / microclimats. Une analyse de régression linéaire a révélé une relation - (nombre de feuilles / branches / nombres de *T. aurantii*). Relation A + (nombre de feuilles / branches infestées par *T. aurantii* / *T. aurantii* abondance). L'abondance de *T. aurantii* avait également une relation + / RH ou / température ambiante). Les feuilles / branches de café Arabica avaient une relation - (température ambiante ou / RH). Alors que les feuilles / branches infestées par *T. aurantii* n'avaient qu'une relation + avec le RH. En ce qui concerne les variables du sol, seule la température du sol a une relation + avec le nombre de feuilles / branche. Les feuilles / branches infestées par *T. aurantii* avaient une relation + (température du sol ou / humidité du sol).

Mots Clés: Biomasse foliaire, microclimat, humidité relative, température

INTRODUCTION

Host- plants and insect-pest compensations with microclimate are very important enablers of plants and insect's survival; and acclimatising to changing environments (Hulle *et al.,* 2010; Pincebourde *et al.,* 2017; Dosta´lek *et al.*, 2018). These compensations impact on the host plants and insect- pests in different pathways, which may include changes in plant shoot biomass, and insect numbers and their damage intensities (Hulle *et al.*, 2010; Pincebourde *et al.,* 2017; Dosta´lek *et al.*, 2018). Factors at the cropping environment notably; soil moisture, frost, relative humidity, temperature, sunshine and tree shade inclusions, can trigger off physical and biochemical responses in plants (Tomar, 2010; Hameed *et al.*, 2018; Piron *et al.*, 2019). Low and high extreme temperatures on the coffee plant physiology, causes desperate situations, depressed growth, yellowing of leaves and growth of tumors; and these predispose the plant to biotic stress (Da Matta and Ramalho, 2006). Additionally, the relative humidity impacts on the vegetative growth of the coffee trees variably (Coste, 1992; Dosta´lek *et al.* (2018).

Different coffee genotypes are known to response with different survival mechanism against abiotic and biotic stresses; notably higher or lower leaf mass area, greater leaf thickness, increased depth and changed composition of the waxy cuticle, altered size of resin ducts and reduced intercellular airspace in the leaf mesophyll (Hulle *et al.*, 2010; Chemura *et al.*, 2014; Pincebourde *et al.,* 2017; Dosta´lek *et al.*, 2018). Under moderate humid conditions, coffee trees flourish continuously by activating their dormant buds, which causes overlaps in the minor and major coffee production cycles. These may lead to the continuous appearance of fresh leaves, and flowers (Waller *et al.,* 2007; Jassogne *et al.*, 2013; Coltri *et al.*, 2019).

The insects may compensate with rapid rates of development, use of local micro-environment, and adjustments to body temperature (Willmer, 1982; Clissold1 *et al.,* 2013). The probability of a leaf being eaten by an insect depends on a complex suite of plant and herbivore traits (Agrawal, 2011; Carmona *et al*., 2011; Pincebourde *et al*., 2017).

Aphids have showed high preference for warmer conditions and their continued presence on crops contributes to high crop losses (Rathore, 1995; Ogunrinde and Adebanjo, 2007). They live in association with ants, which interfere with the efficacy of biological control, especially by their natural enemies, the parasitoids; hence exacerbating other pest situations (Ogunrinde and Adebanjo, 2007; Abedeta *et al*., 2011).

Moreover, *T. aurantii* is an important pest of coffee in the tropics and subtropics (Deng *et al*., 2019) as it sucks sap from leaves, stems, flowers and fruits of coffee; and eventual fall of leaves and flowers (Ogunrinde and Adebanjo, 2007). Besides sap feeding, it injects toxic saliva into the plant tissue, causing phytotoxicity and stunting in seedlings (Guidolin and Consoli, 2018). The pest also secretes honeydew when sap-feeding, and sooty molds frequently grow on the honeydew, which hinders photosynthetic activity (Sevim *et al*., 2012). *Toxoptera aurantii* existence in the mount Elgon Arabica coffee was reported by Karungi *et al.* (2015). It is also known to thrive on various alternative crops in the absence of favourable coffee conditions; notably Rutaceae, Proteaceae, Theaceae, Anacardiaceae, and Lythraceae, Ficeae and Asteracea (Carver, 1978; Deng *et al*., 2019).

Mount Elgon regions hosts mosaical patterns of Arabica coffee farming systems in Uganda. Arabica coffee (*Coffea arabica*) in the mount Elgon region harbours a greater number of herbivores, claiming over 13% of its yields as losses (Karungi *et al.,* 2015; Liebig *et al*., 2016; Ijala *et al*., 2019). Understanding host-plant choice by herbivores in Arabica coffee, and interpreting the effects of changing environmental conditions on insect-plant interactions, require a wider knowledge of various pathways acting in a unit area. Looking at host-plant insect-pest and microclimate compensational context may capture the depth of understanding of pest and host behaviors at altitudinal level. The objective of this study was to determine the host- plant and *T. aurantii* compensations with microclimate in Arabica coffee under conditions of different altitudes and farming system of mount Elgon region in Eastern Uganda.

MATERIALS AND METHODS

Study site description. The study was conducted in the districts of Kapchorwa and Sironko, the major mount Elgon coffee growing zone of Eastern Uganda. These are naturally fertile and highly productive areas, with high human occupation, and blotches of semi-natural vegetation (Kachorwa District local Government, 2011). The Arabica coffee production farms exist in the altitudinal range of 1,300 - 2,500 m.a.s.l (Kachorwa District local Government, 2011), and within 1°8'43''N-1°23'04''N and 34°22'26''E-34°26'29''E. The area receives two rainfall seasons annually, achieving precipitation ranges of 1200 - 2200 mm (NEMA, 2010). The mean annual temperature ranges stand at 13.2° C (minimum) to 23.2° C (maximum), as at Buginyanya local weather station. The soils were classified as Nitisols (IUSS Working Group, 2007), developed on basaltic outflows (De Bauw *et al*., 2016).

The farming system is mixed coffee polycultures, with tree inclusions in the coffee (Arabica) and banana (Plantain); and followed by the annual crops (*Zea mays*, *Solanum tuberosum*, *Phaseolus vulgaris*, *Arachis hypogaea*) (Liebig *et al*., 2016; Sudiono *et al*., 2017; Karungi *et al*., 2018).

Treatments and design. Treatments included altitude and farming system. Altitude was a major factor categorised in three altitude levels; namely lower (1400-1499 m.a.s.l), mid (1500-1679) and high (1680-2100). The farming system was categorised into four, namely coffee polycultures, that is, coffee monocrop (C), coffee+annual crop (C+A), coffee+banana (C+B), and coffee+banana+ shade trees (C+B+T); following the procedures of Liebig *et al*. (2016) and Karungi *et al*. (2018). A total of 72 sites, each with a land area of about 4000 M^2, estimated with a help of GIS 3.2/ GPS, were used following the procedures by Diekotter e*t al*. (2010). We allocated 36 study sites for each district; 12 to each altitude level, and 4 to each farming systems (coffee polycultures), and including 3 replicates for each coffee polyculture (making 72 study sites).

Data on host-plant (Arabica coffee leaf biomass) and *Toxoptera aurantii*. Five coffee trees, spaced 10 m away from each other, were randomly selected for this purpose. For each selected tree, 3 coffee branches positioned at low, middle and top were randomly selected for leaf count and examination for *T. aurantii* occurrence. The study trees and branches were tagged using ribbons. The total number of leaves on each branch aphid-infested leaves (discoloured and with aphids) were counted. The number of aphids on each of the infested leaf were recorded with an aid of a magnifying lens, following the procedures of Sudiono *et al*. (2017).

Data were collected in 12 rounds, in two years, covering the major and minor coffee production cycles (5 trees x 3 branches x 4 coffee farming systems x 3 altitude levels x 12 rounds= 2160). Proportions for pest infestation intensity were calculated in each data collection round, following Sudiono *et al*. (2017).

Microclimate variables. Data on microclimatic variables at farm level were recorded at midday on every sampling day, along the diagonal and three readings were obtained for each. For the percentage relative humidity (readings±3%) and ambient temperature (reading ±0.6°C); a thermo-hygrometer pen (Model 3402) was used, following the techniques of Spectrum Technologies, Inc. (2009). For soil parameters, measurements were taken from a soil depth of 0 - 15 cm. Data on soil temperature (± 1°C), and soil moisture (± 3% VWC), were taken using Procheck sensor (GS3 model) following the technology of Wadsworth (2015). The microclimate data was later used in linear regressions as predictors.

Data analysis. The data collected were analysed in the Generalised Linear Mixed Models (GLMM) of GenStat 13, with a farm as a random factor and dispersion of 1 for fixed factors. We used the logarithmic link because the data were non normal. For the data on leaf damage intensity, we used binomial distribution, and logit link since the data were on proportions.

The means and Wald test were generated for all data illustrations (figures and tables) and the means were separated using Fischer's protected LSD at 5%.

The data on compensational relationship of host-plant and *Toxoptera aurantii*; host- plant and microclimate; and *Toxoptera aurantii* with microclimate were analysed using linear regression. The data were first tested for linearity and the collinearity. In the relationship of host plant and *T. aurantii*, the host plant variables were used as predictors and *T. aurantii* numbers as a dependent variable. For the relationship of host-plant/*T. aurantii* and microclimate, the host-plant/*T. aurantii* were used as dependent variables and the microclimate variables as predictors. The microclimate variables, which had an autocorrelation, were dropped off the model with stepwise generalised linear regression model.

RESULTS

Host-plant and *T. aurantii* compensation. Linear regression analysis revealed a significant negative relationship for the number of leaves per branch and *T. aurantii* numbers (Table 1). A significant positive relationship was realised when the number of leaves per branch infested by *T. aurantii* were used against *T. aurantii* numbers as the dependent variable (Table 1).

Host-plant and *T. aurantii* microclimate compensations. *Toxoptera aurantii* population density had a significant positive relationship with relative humidity and ambient temperature (Table 2). The leaves per branch had a negatively significant relationship the ambient temperature and relative humidity. The *Toxoptera aurantii* infested leaves per branch only had a significant positive relationship with relative humidity (Table 2).

Regarding the soil variables relationships with the host-plant, it was only soil temperature which had a significant and positive relationship with the number of leaves per branch (Table 2). The *T. aurantii* infested leaves per branch had a significant positive relationship with the soil temperature and moisture.

Arabica coffee leaf biomass and number of *T. aurantii*. The Generalised Linear Mixed Model analysis (GLMM) indicated highly significant effects of altitude and farming system, and their interaction on the numbers of *T. aurantii,* leaves per branch and leaves infested by *T. aurantii* (Table 3). The leaf damage intensity was highly significant with the altitude and farming system, but not for their interaction (Table 3).

Toxoptera aurantii numbers were highest in the mid altitude across the farming systems, except in the coffee+banana. The highest number of *T. aurantii* was recorded in the coffee+banana+shade tree coffee farming system (Fig. 1).

TABLE 1. T statistic, T significance value, its coefficients for the compensational relationship of dependent variables and the predictors in the mount Elgon coffee-banana farms in Uganda

Predictors	Unstandardised coefficients		Standardised coefficients	T statistic	Significance
	B	Std. Error	Beta		
(Constant)	.686	.132		5.211	.000
Number of coffee leaves/ branch	-.116	.039	-.044	-2.946	.003
Number of *Toxoptera aurantii* infested Arabica coffee leaves /branch	2.799	.057	.726	49.019	.000

*** Sig. at <0.001, ** Sig. at <0.01, * Sig. at <0.05

TABLE 2. T statistic, T significance value, and its coefficients for the compensational relationship of dependent variables and the predictors in the mount Elgon coffee- banana farms in Uganda

Dependent variable	Predictors	Unstandardised coefficients		Standardised coefficients	T statistic	Significance
		B	Std. Error	Beta		
Toxoptera aurantii	(Constant)	-130.49	54.926		-2.376	0.02
	Temperature	2.676	1.317	0.33	2.032	0.046
	Relative humidity	1.271	0.43	0.48	2.954	0.004
Arabica coffee leaves/branch	(Constant)	96.006	16.856		5.696	.000
	Ambient temperature	-1.750	.404	-.630	-4.331	.000
	Relative humidity	-.686	.132	-.756	-5.192	.000
Toxoptera aurantii infested leaves/branch	(Constant)	-.406	.532		-.763	.448
	RH	.022	.009	.294	2.570	.012
Arabica coffee leaves/branch	(Constant)	7.362	1.092		6.740	.000
	Soil moisture	-.206	1.505	-.017	-.137	.892
	Soil temperature	-.165	.033	-.551	-4.981	.000
Toxoptera aurantii infested leaves/branch	(Constant)	-2.600	1.248		-2.083	.041
	Soil moisture	4.764	1.720	.354	2.770	.007
	Soil temperature	.095	.038	.292	2.512	.014

*** Sig. at <0.001, ** Sig. at <0.01, * Sig. at <0.05

TABLE 3. F statistics and Wald statistic with F probability by altitude and different farming system on the pest abundance of *Toxoptera aurantii,* coffee leaves per branch*, Toxoptera aurantii* affected coffee leaves on Arabica coffee farms in the mount Elgon region in Uganda

Fixed term	Waldn. statistic	d.f.	F statistic	d.d.f.	F pr
Coffee leaves/ branch					
Altitude	3663.64	2	1831.82	2146	<0.001
Farming system	63.64	3	21.21	2146	<0.001
Altitude. Farming system	469.6	6	78.27	2146	<0.001
***Toxoptera aurantii* abundance on coffee tree leaves**					
Altitude	9313.98	2	4656.99	2146	<0.001
Farming system	4024.8	3	1341.6	2146	<0.001
Altitude. Farming system	2074.54	6	345.76	2146	<0.001
***Toxoptera aurantii* infested coffee leaves**					
Altitude	156.22	2	78.11	2146	<0.001
Farming system	296.89	3	98.96	2146	<0.001
Altitude. Farming system	66.56	6	11.09	2146	<0.001
Proportional leaf damage					
Altitude	68.7	2	34.35	2118	<0.001
Farming system	47.55	3	15.85	2118	<0.001
Altitude. Farming system	7.66	6	1.28	2118	0.264

*** Sig. at <0.001, ** Sig. at <0.01, * Sig. at <0.05

The number of leaves per branch was higher across the high altitudes, with the most recorded in the coffee+ annual crop farming (Fig. 2). Also, the number of *T. aurantii* infested leaves per branch was higher in the mid altitude across three farming system, except the monocropping where they were more in the high altitude areas (Fig. 3).

The proportional leaf damage intensity of Arabica coffee, by *T. aurantii*, was lowest in the coffee monocrop faming system (Fig 4a). It was also recorded lowest in the high altitude areas (Fig. 4b).

The microclimate variables. The microclimate variables recorded generally higher relative humidity in the coffee+ banana+shade tree, farming systems across all the altitudes (Fig. 5a). Lower temperatures were recorded in the coffee+banana+shade tree farming systems across all the altitudes (Fig. 5b). Soil moisture was greatest at high altitude (0.43%) and coffee monocropping (0.44%). Soil temperature was highest at mid altitude (26 ^{o}C) and (24.4 ^{o}C) coffee+banana+ shade tree (Table 4).

DISCUSSION

Host- plant and *T. aurantii* compensation. The positive relationship of *T. aurantii* with the number of *T. aurantii* infested coffee leaves per branch, could mean that in cases where the number of infested leaves per branch increased by 1 unit, the number of *T. aurantii* could have increased by 0.726. Here, *T. aurantii* compensated positively and boosted up its numbers which infested more leaves per

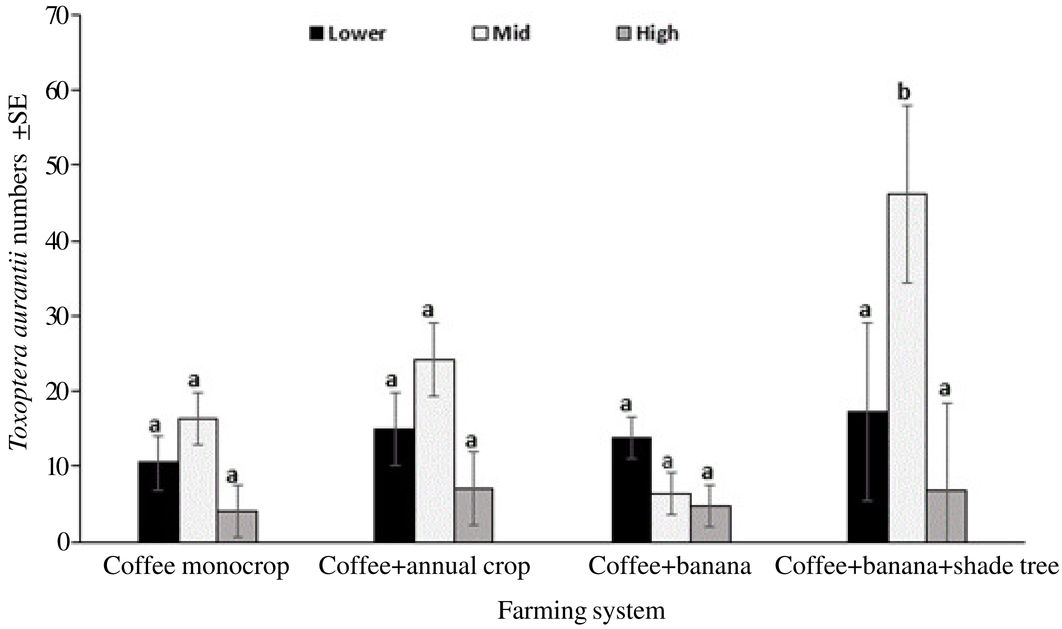

Figure 1. Number of *Toxoptera aurantii* at different altitude and Arabica coffee farming system of mount Elgon coffee- banana farms of Uganda.

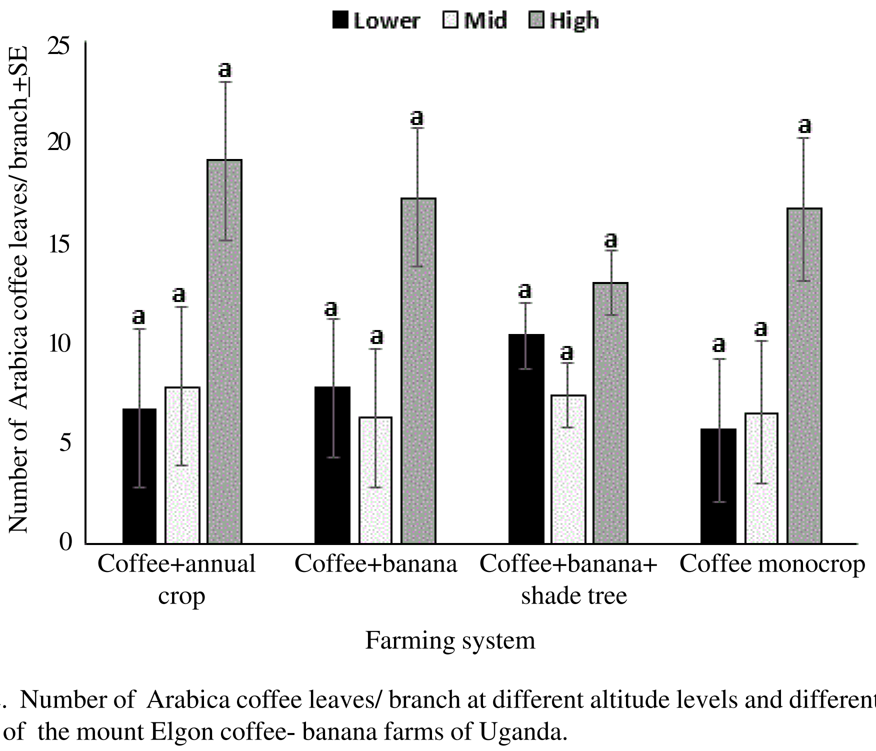

Figure 2. Number of Arabica coffee leaves/ branch at different altitude levels and different farming systems of the mount Elgon coffee- banana farms of Uganda.

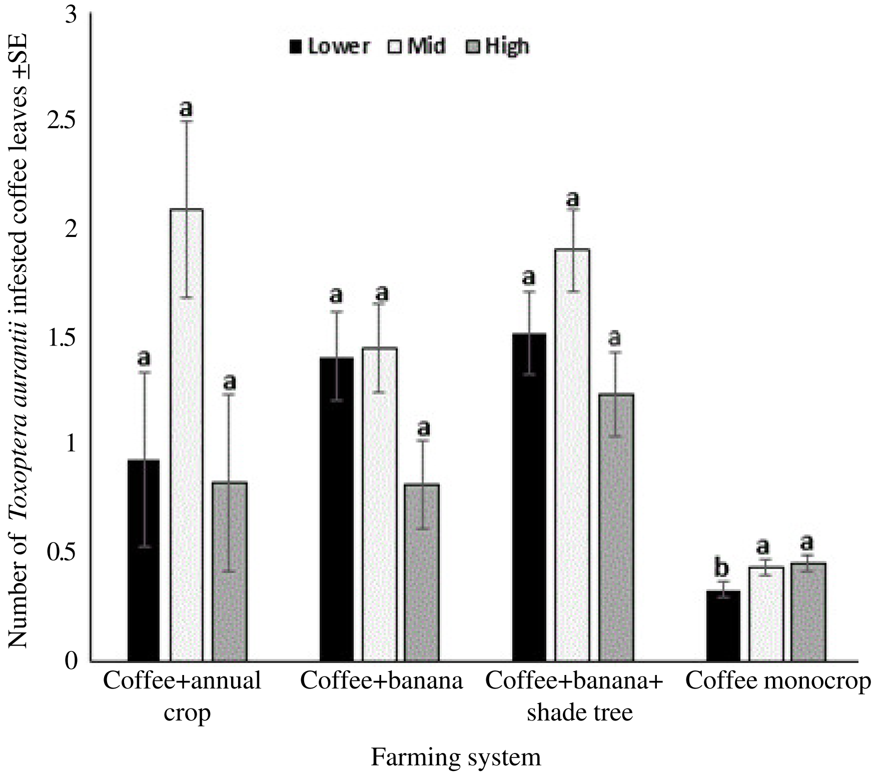

Figure 3. Number of *Toxoptera aurantii* infested Arabica coffee leaves/ branch at different altitude levels and different farming systems of the mount Elgon coffee- banana farms of Uganda.

branch. This was in line with the results at mid altitude, where higher numbers of *T. aurantii* (mean=18.6) and (mean =17.67, in the coffee+banana+shade tree, farming system) were highest. Also, *T. aurantii* infested leaves at the same altitude level were higher (mean=1.2) and in the same farming system (mean =1.5). The highest leaf damage intensity (mean =21.7 %) in the same altitude and same farming system (mean=19%) were also recorded in this study. These results could be perceived as a failure of the host plant resistance to counter the pest compensations.

Conversely, the negative relationship of *T. aurantii* population density with the coffee leaves per branch (host plant), a 1 unit increase in the number of coffee leaves per branch could compensate for the numbers of *T. aurantii* (pest) by a factor of -0.044. Here, the host-plant was able to maintain the highest number of leaves per branch and a minimum number of *T. aurantii* with minimum leaf damage intensity. This was in line with the greater number of coffee leaves per branch in the high altitude (mean = 16.3) and (mean= 2.0 in the coffee+ annual cropping) compared to the lower number of *T. aurantii* at the same altitude level (mean = 13.8) and same farming system (mean = 13.81). At the same altitude, a lower damage intensity was recorded (mean =6%) and mean for the farming system (mean= 17%). The coffee trees without tree shade, especially at high altitude may have been triggered under such abiotic conditions to produce a complex set of compounds which could have enhanced the plant defensive mechanism to repel the infestations by *T. aurantii*. Carver (2007) reported the possibility of enormous chemical and physiological differences existing between the young and

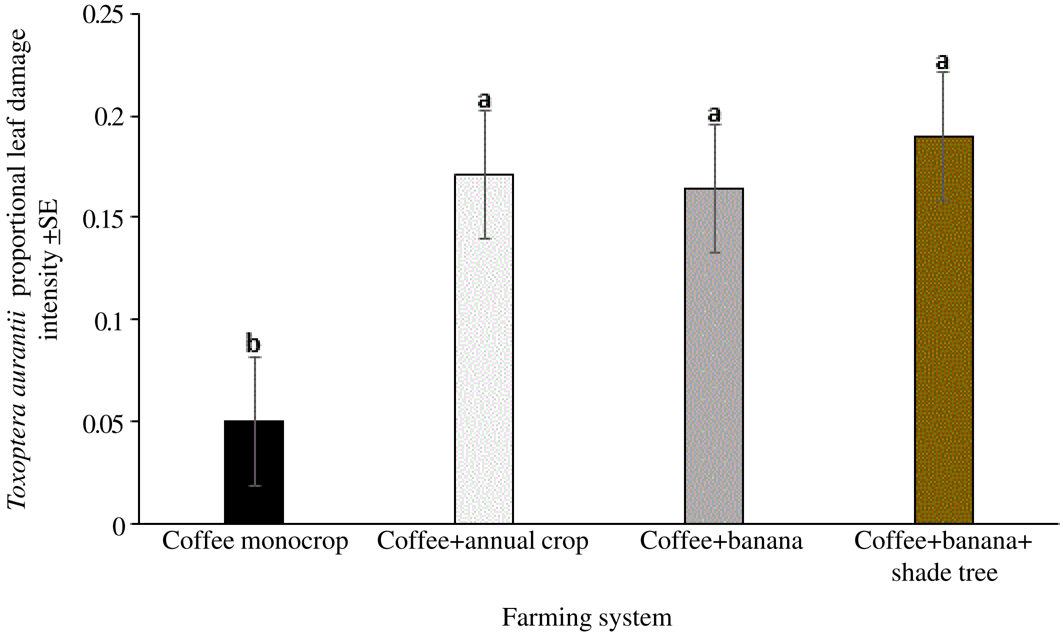

Figure 4a. Proportional leaf damage/farm of Arabica coffee by *Toxoptera aurantii* with different farming system in the mount Elgon coffee- banana farms.

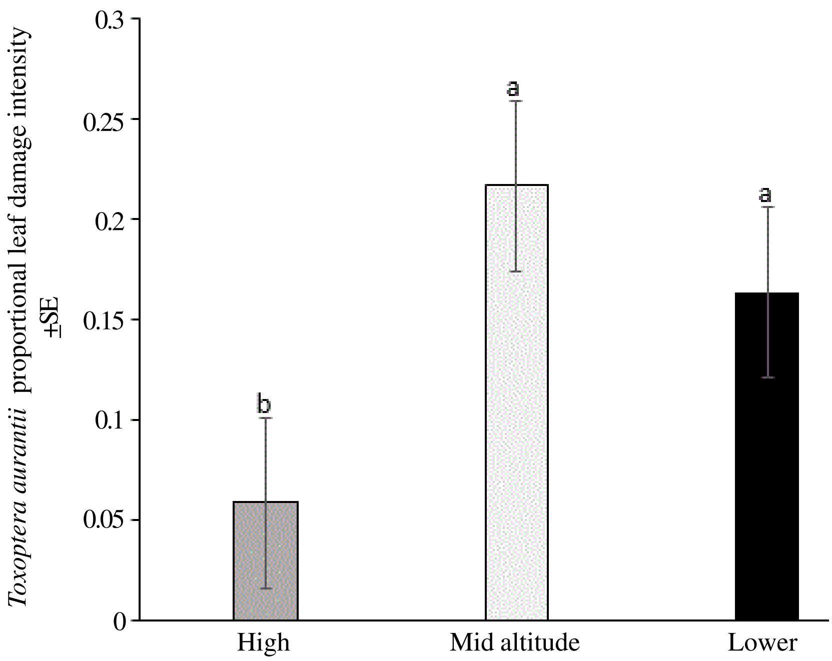

Figure 4b. Proportional leaf damage/ farm of Arabica coffee by *Toxoptera aurantii* at different altitudes in the mount Elgon coffee- banana farms.

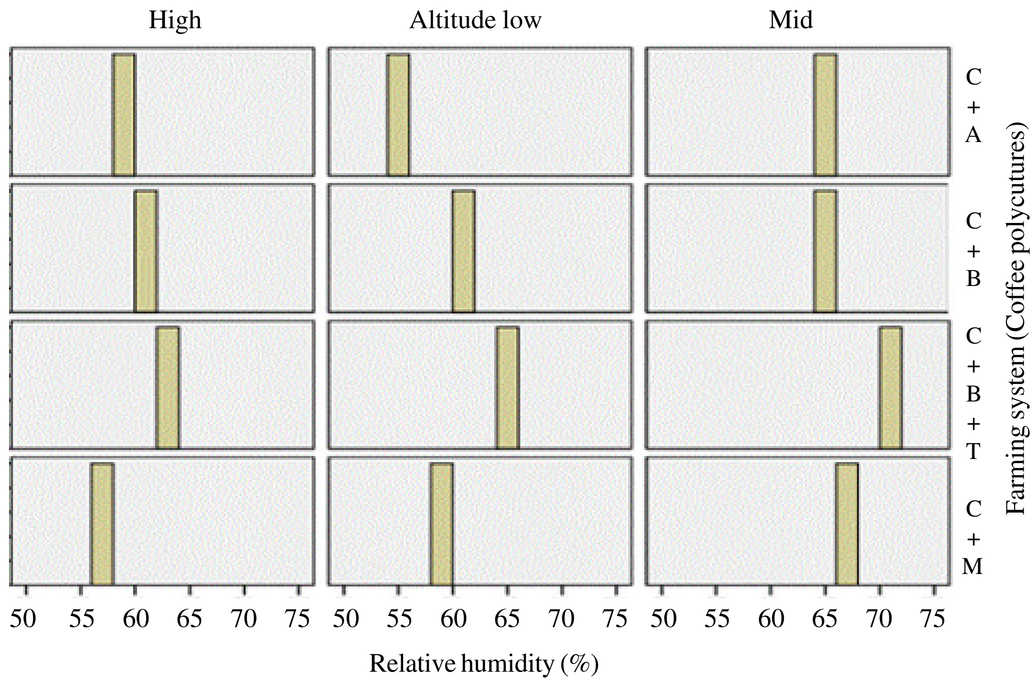

Figure 5a. Changes in relative humidity by increasing altitudes and different farming system, coffee monocrop (C+M), coffee+annual crop (C+A), coffee+banana (C+B), and coffee+banana+shade trees (C+B+T).

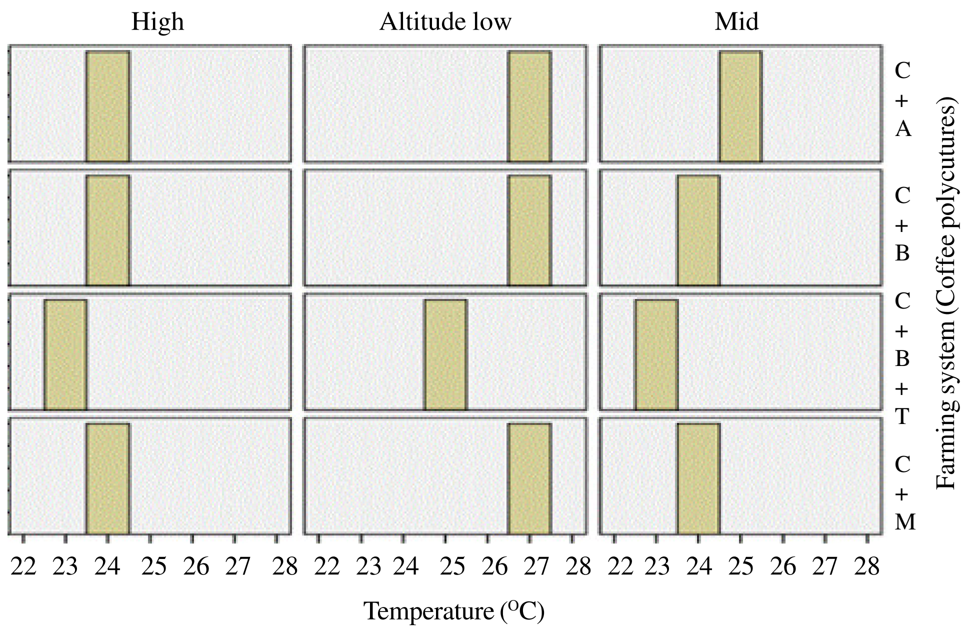

Figure 5b. Changes in temperature by increasing altitudes and different farming system, coffee monocrop (C+M), coffee+annual crop (C+A), coffee+banana (C+B), and coffee+banana+shade trees (C+B+T).

TABLE 4. Autos elected soil variables in the mount Elgon coffee- banana farms in Uganda by altitude and farming system

Fixed factor	Dependent variables	
Altitude	Soil moisture (%)	Soil temperature (^{0}C)
Lower	0.39	24.51
Mid	0.41	25.73
High	0.45	21.87
Farming system		
Coffee monocrop	0.44	23.85
Coffee+annual crop	0.41	23.67
Coffee+banana	0.44	24.29
Coffee+banana+ shade tree	0.39	24.34

mature foliage that could impact on a two-way front: either by an intense sink of amino-acids, proteins and sugars, or a carbohydrate store and a complex of secondary repellent compounds.

The studies of Hodkinson (2005) and Stenseth and Mysterud, (2002) reported mismatches due to the influence of altitude on biotic forms to enable compensations by nature at altitudinal level. Such mismatches are capable of causing negative synchronies, leading to low numbers of *T. aurantii* and possibly lower damage intensities. The interventions on possible control of *T. aurantii* can make use of studies that explore the possibility of harnessing such repellants to induce mismatches for host plant resistance against *T. aurantii*. Studies of Sase *et al.* (1998), Suzuki (1998) and Hengxiao *et al.* (1999) highlighted the changes and composition of the plant phenology to have pronounced effects on the herbivore at altitudinal level.

Host-plant and *T. aurantii* microclimate compensations. With the significant positive relationship of relative humidity with number of *Toxoptera aurantii,* a 1unit increase in relative humidity caused an increase in *T. aurantii* by a factor of 0.480. The highest number of *T. aurantii* existed in the mid altitude farming system with the coffee+banana+shade, a system and level which recorded the highest relative humidity (Mean = 69.98% compared to the altitude average of 66.64 % within the same altitude). Here, the pest possibly compensate for high relative humidity. This is in agreement with the fact that the number of leaves infested by *T. aurantii* was positively related to the relative humidity. In this study, 1 unit increase in relative humidity caused an increase in the number of leaves infested by a factor of 0.294. Tomar (2010) suggested that microclimate elements such as relative humidity play a key role in aphids' physiological development.

In contrast, a negative relationship of relative humidity with the number of leaves could mean reduction of leaves by a factor of -756, with one percentage increase in relative humidity. This study has highlighted that the number of Arabica coffee leaves per branch in the mid altitude were lowest (mean = 7); a level which recorded the highest average relative humidity. Increasing relative humidity could be delaying the opening of leaf buds to warrant tolerance (Waller *et al.,* 2007; Coltri *et al.*, 2019). Arabica coffee sensitivity to relative humidity was earlier on highlighted by the work of Coste (1992), and attributed it to changes in altitude. In the present case, moderate relative humidity could maintain high leaf biomass, implying that extreme levels of relative humidity can affect the growth of Arabica coffee leaves.

With respect to temperature, the significant positive relationship of *T. aurantii* population density against ambient temperature, could mean that 1 unit increase in temperature results in an increase of *T. aurantii* population by a factor of 0.330. This could hold in line with the situations in the lower altitudes, where the higher ambient temperatures of up to 27.3 °C were recorded compared to the average within the same altitude of 26.4 °C at the same level. The altitude which recorded the second best with more numbers of *T. aurantii* (mean =14.1) and (mean =13.8, in coffee+ annual cropping farming system) could have had an influence of higher temperatures on the aphid multiplication. At this altitude, *T. aurantii* was able to compensate for advances in ambient temperature by enabling multiplication of its numbers by a factor of 0.330 per degree change in temperature. Studies of Piron *et al.* (2019) indicated that the rising temperatures in Europe and other temperate areas enabled *T. aurantii* to rather easily adapt to such regions, thus warmer conditions could promote aphid accumulation.

The negative relationship between the number of Arabica coffee leaves with ambient temperature could mean that a 1 unit increase in the ambient temperature could cause a reduction in leaves by a factor of -630. This could hold on for situations at the lower altitude, especially in the coffee+annual farming system where temperatures were highest (27.3 °C). The number of leaves per branch was lower (mean =6.7) than (mean=19.1) in high altitude areas with a similar farming system. Also, the number of Arabica coffee leaves per branch was negatively related with soil temperature (-5.51). The increasing soil temperatures which could have resulted from increasing ambient temperatures, may affect the available soil moisture, and this could impact negatively on the plant physiological systems. Under low host-plant compensations, the host-plant may hold on to a maximum limit, beyond which, stress sets in and with the accumulation of biotic stress, the host-plant may succumb to leaf desiccation. The number of infested leaves increased with increasing soil temperature by a factor of 0.292. The increasing soil temperatures could have exacerbated the effects of biotic factors on the Arabica coffee plant. The studies of Da Matta and Ramalho (2006) indicated seriously high consequences of low and extreme temperatures on the coffee physiology, including causing desperate situations predisposing the plant to biotic stress.

The significant positive relationship of the number of *T. aurantii* infested Arabica coffee leaves with soil moisture by a factor of 0.354, could mean that higher levels of soil moisture could also worsen the biotic stress due to aphids on the Arabica coffee plant. Chemura *et al.* (2014) indicated a variable response of Arabica coffee to soil moisture levels.

Regarding the host-plant and *T. aurantii* compensations with microclimate in the mount Elgon Arabica coffee-banana farming system of Uganda, the study indicates variable results at different altitude and farming systems.

CONCLUSION

The study recorded hosts-plant and insect pest compensations; and insect-pest/host-plant compensations with microclimate which were variable by altitude and farming system on mount Elgon in Uganda. In the hosts-plant and insect-pest compensations, the increase in the number of infested leaves by one, the number of *T. aurantii* increased by a factor of 0.726, and these were clear situations in the mid altitude with coffee+banana+shade tree farming systems. In the negative relationship, increase in the number of coffee leaves by one, *T. aurantii* numbers reduced by -0.044, a situation much favored by high-altitude coffee+ annual cropping system.

As regards the insect-pest/host-plant compensations with microclimate, a one percent increase in relative humidity, *T. aurantii* increased by the factor of 0 .480. A situation which was common to mid altitude coffee+banana+shade trees. While for leaf biomass, a one percent increase in relative humidity, the number of leaves reduced by -756 and this was much pronounced in the mid-altitude situations.

A one degree increase in temperature, *T. aurantii* numbers increased by 0.330, a situation which was much created by the lower altitudes combinations with coffee+annual farming system. In the negative relationship, a one degree increase in the ambient temperature caused a reduction in leaf biomass by -630 especially in the farming systems with combination of coffee+annual farming with low altitudes. The situations of low soil moistures and high soil temperatures could only exacerbate the host plant stress due to *T. aurantii* feeding. The recommendations on aphid control could make use of repelling environments on the leaf surface to induce mismatches for host plant resistance against *T. aurantii*.

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