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Predicting the Response of Insect Pests and Diseases of Arabica Coffee to Climate Change along an Altitudinal Gradient in Mt. Elgon Region, Uganda

Kagezi, H. Godfrey[1*], Kucel Patrick[1], Kobusinge Judith[1], Olango D. Nicholas[1]
Nakibuule Lilian[1,] & Wagoire, W. William[1].

Abstract

Recent studies have predicted an increase in temperature due to climate change which is likely to upsurge pressure from pests and diseases on Arabica coffee, *Coffea arabica*. Under the future climate change scenarios, elevation gradients can be used as analogues for global warming. Basing on this, we therefore determined the incidence and damage of Arabica coffee pests and diseases along an altitudinal gradient in Mt. Elgon region in order to predict their possible impact under these scenarios. Seven insect pest species were recorded - with the white coffee stem borers (WCSB) having the highest incidence of 13%. On the other hand, three diseases were recorded - with coffee leaf rust (CLR) having the highest mean severity of 1.9 on a 1-5 scale. Multiple regression analysis showed that the incidence of only WCSB decreased significantly ($p=0.0169$) with increasing altitude. This implies that under the future climate change scenarios, the impact of this insect pest on Arabica coffee will increase with increase in temperature. Therefore, adaptation mechanisms for climate adversaries such as inter-planting with shade trees should be advanced. However, these tree species should not compete with the coffee as well as promoting pests and diseases.

Key words: Altitudinal-gradient, diseases, climate-change, pests, shade-trees

1. Introduction

Coffee is currently the most important cash crop of Uganda (Musoli et al., 2001). The crop is grown by over 1.3 million households (a quarter of which are headed by females), who are spread out over several production zones (Hill, 2005). There are two main types of coffee grown by farmers in the country, Robusta coffee, *Coffea canephora* Pierre ex A. Foreigner which accounts for about 80% of the coffee and Arabica coffee, *Coffea arabica*, which occupies the remaining 20%. Robusta coffee is predominantly grown below 1200 meters above sea level (m.a.s.l), while Arabica dominates highland regions above 1500 m.a.s.l, particularly in the Mt. Elgon region located in the eastern part of the country (Musoli et al., 2001).

However, production of Arabica coffee in this region is constrained by a number of factors, with pests and diseases are paramount (Musoli et al., 2001; Matovu et al., 2013; Kucel et al., 2016; Liebig et al., 2016). The incidence and severity of these insect pests and diseases differ along the altitudinal gradient (Matovu et al., 2013; Kucel et al., 2016), due to variation in temperature and precipitation. Increase in altitude results into lower temperatures and higher precipitation (Ohmura, 2012). This in turn influences species richness and abundance of insect species as well as plant pathogens, and thus, the damage they cause to plants (Hodkinson, 2005; Deutsch et al., 2008; Matovu et al., 2013).

In Uganda, the growth of Arabica coffee is favoured by temperatures which range between 18-21^{o}C as compared to 22-30^{o}C for Robusta coffee (Musoli et al., 2001). Arabica coffee is therefore more heat sensitive (Bunn, 2015) and thus will be more vulnerable to climate change (Jaramillo et al., 2009; Läderach et al., 2017). Therefore, the suitability area for growing this type of coffee will drastically reduce in future compared to Robusta coffee (Jaramillo et al., 2009; Jassogne et al., 2013).

[1] National Coffee Research Institute (NaCORI)/National Agricultural Research Organisation (NARO), P.O. Box 185 Mukono, Uganda. [1*]Email : gkagezi@gmail.com

There will be a possible geographical shift by pests and diseases to higher altitudes due to global warming (Jaramillo et al., 2009), since elevation gradients can be used as analogues for global warming (Péré et al., 2013).

Rising temperatures have been reported to expand the altitudinal range of certain pests and diseases (Bongase, 2017). For example, the coffee berry borer (CBB), which has been having limited impact over 1500-1600 m.a.s.l in many countries (Baker and Hager, 2007; Jaramillo et al., 2009: Kyamanywa et al., 2012), has now been observed at altitudes more than 1800 m.a.s.l (Jaramillo et al., 2009; Kyamanywa et al., 2012; Agegnehu et al., 2015). Similarly, rising temperatures and rainfall have also been reported to have led to coffee leaf rust (CLR) becoming prevalent at higher altitudes than it used to be (Iscaro, 2014; Bebber et al., 2016).

Basing on the above backdrop, we therefore conducted a study along an altitudinal gradient in Mt. Elgon, eastern Uganda in November-December 2016 to determine (i) the most prevalent insect pests and diseases influencing the production of Arabica coffee, (ii) the variation of insect pests and diseases along the altitudinal gradient, and, (iii) the insect pests and diseases that are likely to become a threat to Arabica coffee production under the future climate change scenarios. This information is a prerequisite for developing sustainable pest and disease control strategies as well as making decision for rational management practices.

2. Materials and methods

2.1 Description of the study area

A biological survey of pests and diseases was conducted in 4 districts located in the Mt. Elgon Arabica coffee growing region of Uganda, namely, Bulambuli, Kapchorwa, Sironko and Mbale in November-December 2016. This area is located between latitude 0.893° and 1.084°, and longitude 34.056° and 34.384° in the WGS84 coordinates system. The elevation ranges between 1084 and 2455 m.a.s.l (Jiang et al., 2014). The mean annual air temperature is about 23°C with average minimum and maximum temperatures of 15°C and 28°C, respectively. This region has a weak bi-modal rainfall pattern with a mean annual value of around 1500 mm (Bamutaze et al., 2010). The soils are generally deep and derived from volcanic ash as a product of a single weathering cycle (NEMA, 1998).

2.2 Sample selection and data collection

Ten (10) coffee growing households were purposively selected in each district and their coffee fields evaluated for pest and disease occurrence, severity and damage. Within each field, 30 coffee trees were selected along a diagonal. The first 10 coffee trees were assessed for both pests and diseases, then the other 20 assessed for only diseases. Pests were assessed on the coffee trees, leaves, clusters and berries. Trees were assessed for the presence or absence of white coffee stem borer (WCSB) – evidenced by either entry hole and/or the powdery frass resulting from burrowing of the larvae into the coffee stem, root mealy bugs – evidenced by either ant activity up and down the coffee plant and/or whitish powdery-like materials around the collar region and/or coffee roots as well as antestia bugs – by physical visual observation of the bugs.

To select the coffee leaves, clusters and berries to be sampled, the bearing head was divided into 3 imaginary sections – the upper, middle and lower. One primary branch with berries was randomly selected from each section. Then the total number of leaves as well as those damaged by the coffee leaf miner (CLM), skeletonizers, and lace bugs were determined. The total number of coffee clusters as well as those infested with canopy mealy bugs, canopy scales, and berry moth was determined on the sampled primary branch. The middle cluster of the sampled primary branch was selected and the number of berries as well as those infested with coffee berry borer (CBB) was determined. For the diseases, the incidence (presence or absence) and severity (scored on a scale of 1-5 where; 1=absent, 2= 1-10%, 3= 11-25%, 4= 26-50% and 5=>50% of leaves and/or berries are infected) were determined for coffee berry disease (CBD), coffee leaf rust (CLR), red blister disease and Elgon dieback.

2.3 Data analysis

Data for pest as well as disease incidence and severity were summarized using descriptive statistics including means and percentages. In addition, multiple regressions were run to assess the relationship between altitude and Arabica coffee pests and disease in order to determine those pests and diseases that are likely to be a threat under the future climate change scenarios. All the analyses were done in SAS v. 9.1 for Windows (SAS, 2008).

3. Results and Discussion

This section presents the results obtained in the study as well as providing the discussion on the observed results.

3.1 Insect pests recorded on Arabica coffee in Mt. Elgon region

A total of seven insect species, namely, the white coffee stem borers (WCSB), root and canopy mealy bugs, coffee leaf miners (CLM), leaf skeletonizers, lace bugs and coffee berry borers (CBB) were recorded on Arabica coffee in the Mt. Elgon region of Uganda (Table 1). This finding corroborates with several studies in this region (Kyamanywa et al., 2006; Egonyu et al., 2015; Jonsson et al., 2015; Kucel et al., 2016; Liebig et al., 2016).

Table 1: Percentage of trees, leaves, cluster and berries infested by the various Arabica coffee pests in Mt. Elgon region of Uganda

District	Infested trees (%)		Infested leaves (%)			Infested clusters (%)	Infested berries (%)
	WCSB	RMB	LB	SKL	CLM	CMB	CBB
Bulambuli	27.3	16.4	5.9	3.5	0.4	2.8	0.7
Kapchorwa	0.0	0.0	2.2	0.0	0.7	0.0	1.6
Mbale	13.0	19.0	7.8	3.6	0.3	0.5	1.9
Sironko	10.0	7.0	2.0	6.5	0.3	0.3	2.1
Overall	12.6	10.6	4.5	3.5	0.4	1.0	1.5

WSB=White coffee stem borers, RMB=Root mealy bugs, LB=Lace bugs, SKL=Skeletonizers, CLM=Coffee leaf miners, CMB=Canopy mealy bugs, CBB=Coffee berry borer

WCSB was the most prominent insect pest recorded, scoring the highest incidence of 13%. The importance of this insect pest in this region has been reported in biological surveys (Kyamanywa et al., 2006; Egonyu et al., 2015; Kucel et al., 2016) as well as farmers' perceptions (Liebig et al., 2016). WCSB has also been observed to be a major problem to Arabica coffee production in the Kilimanjaro region of Tanzania (Magina et al., 2010) as well as in several Asian countries (Venkatesha and Dinesh, 2012). Damage by this pest species is caused by its larva boring into the stem of coffee, weakening it and leading to yellowing of the foliage (Le Pelley, 1968). Cumulative yield losses of more than 25% in coffee due to this pest have been reported in Zimbabwe (Kutywayo et al., 2013).

3.2 Diseases recorded on Arabica coffee in Mt. Elgon region

On the other hand, three diseases, namely: - brown eye spot (BES), coffee leaf rust (CLR) and coffee berry disease (CBD) were observed in the region (Table 2). These diseases have been reported to be dominating the disease spectrum in the region (UCDA, 2011; Matovu et al., 2013).

Table 2: Severity (on a 1-5 scale) of Arabica coffee diseases in the Mt. Elgon region, eastern Uganda

	Coffee leaf rust (CLR)	Brown eye spot disease (BES)	Coffee Berry Disease (CBD)
Bulambuli	1.8	1.5	1.2
Kapchorwa	1.7	1.4	1.8
Mbale	1.8	1.7	1.0
Sironko	2.2	1.9	1.0
Overall	1.9	1.6	1.2

CLR registered the highest severity scores of 1.9 on a 1-5 scale. The importance of this disease in Mt. Elgon region has been recognized by biological studies by Matovu et al. (2013) as well as farmers' perceptions (Luzinda et al., 2015; Liebig et al., 2016). Similarly, CLR is one of the most important diseases of coffee worldwide (Hindorf and Omondi, 2011). The disease is caused by the fungus, *Hemilea vastatrix* (Berkeley and Broome) and manifests itself as yellow pustules on the lower surface of leaves, turning them to orange-yellow. It causes defoliation, leading to loss of yield of 10-50% and quality of coffee (Kushalappa and Eskes, 1989; van der Vossen, 2001; Silva et al., 2006).

3.3 Variation of the incidence of Arabica coffee insect pests with altitude

Results showed that, altitude significantly ($p<0.05$) influenced the incidence of only WCSB and CLM among the insect pest species (Table 3). The incidence of WCSB decreased significantly ($p=0.0169$) with increasing altitude, a similar trend observed by Jonsson et al. (2015) in the Mt. Elgon area and elsewhere (Le Pelley, 1968; Wrigley, 1988; Waller et al., 2007).

Lawton et al. (1987) suggested four possible causes for this decrease in pest incidence and damage - reduced habitat area at high elevations, reduced resource diversity, increasingly unfavourable environments, and/or reduced primary productivity at higher altitudes.

Table 3: Relationship between Arabica coffee insect pests and altitude in Mt. Elgon region, eastern Uganda

Variable	Df	Parameter estimate	Standard error	t value	Pr> |t|
Intercept	1	1620.35424	68.81287	23.55	<.0001
White coffee stem borers (WCSB)	1	-4.7767	1.89169	-2.53	0.0169
Root mealy bugs (RMB)	1	1.06663	2.22415	0.48	0.6349
Coffee leaf miners (CLM)	1	123.37257	48.02125	2.57	0.0152
Leaf skeletonizers (LS)	1	-15.01215	9.02984	-1.66	0.1065
Lace bugs (LB)	1	-3.68124	6.53014	-0.56	0.5770
Canopy mealy bugs (CMB)	1	13.16578	10.39109	1.27	0.2146
Coffee berry borer (CBB)	1	-5.21794	29.90727	-0.17	0.8626

On the other hand, the incidence of CLM increased significantly (p=0.0152) with increasing altitude. Our finding agrees with studies by Lomelí-Flores et al. (2009) conducted in Mexico, but contradict results by Nestel et al. (1994) and Tuelher et al. (2003). The difference in CLM incidence and damage at different elevations may be explained in part by the variation of rainfall and ambient temperatures which affect the coffee plant and thus, the pest and its natural enemies (Nestel et al., 1994; Pereira et al., 2007; Lomelí-Flores et al., 2009).

3.4 Variation of the severity of Arabica coffee diseases with altitude

Table 4 shows that among the Arabica coffee diseases, the severity of only CBD varied significantly (p=0.0004) with increasing altitude (Table 4). This observation agrees with findings by Mulinge (1971), Zeru et al. (2009) and Matovu et al. (2013). This relationship could be due to varying temperatures and moisture conditions as altitude increases (Zeru et al., 2009; Hindorf and Omondi, 2011). This subsequently translates into successful spore dispersal, germination and colonization of the disease (Griffiths and Waller, 1971; Ntahimpera et al., 1999; MouenBedimo et al., 2012).

Table 4: Relationship between severity of Arabica coffee diseases and altitude in Mt. Elgon region, eastern Uganda

Variable	Df	Parameter estimate	Standard error	t value	Pr> |t|
Intercept	1	1677.59446	216.95591	7.73	<.0001
Brown eye spot (BES)	1	-240.81709	213.95077	-1.13	0.2678
Coffee leaf rust (CLR)	1	-82.42293	163.21746	-0.50	0.6166
Coffee berry disease (CBD)	1	374.99216	96.26465	3.90	0.0004

3.5 Insect pests and diseases that are likely to become a threat under the future climate change scenario

Our results showed that only the incidence of WCSB decreased significantly (p=0.0169) with increasing altitude (Table 3). Our finding is consistent with biological studies by Kyamanywa et al. (2006) and Jonsson et al. (2015) as well as farmers' perceptions by Liebig et al. (2016) in this region. Similarly, Kutywayo et al. (2013) observed that WCSB was more prevalent at low altitude and significantly increased with altitude in Zimbabwe. This implies that basing on the future climate change scenarios (Jassogne et al., 2013), this insect pest which is currently a problem at low altitudes is expected to extend its niche to higher altitudes with increase in temperatures (Jaramillo et al., 2009, 2011; Kutywayo et al., 2013; Ovalle-Rivera et al., 2015), since elevation gradients can be used as analogues for global warming (Péréet al., 2013).

Given this general increased risk from WCSB in the face of climate change, there is a need to develop adaptation strategies for minimizing its impact to the coffee crop. This should go hand in hand with the various stakeholders who derive their livelihood from the crop along the value chain (Jassogne et al., 2013; Kutywayo et al., 2013). One of the proven strategies for mitigating these impacts is the introduction of shade systems in the coffee gardens (Jaramillo et al., 2009, 2011; Morris et al., 2016; Vezy et al., 2016; Alemu and Dufera, 2017). Shade systems can reduce the temperatures in coffee gardens by 2-6^{o}C (Barradas and Fanjul, 1986) and solar radiation (Lin, 2007), thus, buffering the coffee plants from microclimate variability (Beer et al., 1998).

However, these tree species should offer limited competition to the coffee plants as well as not promoting pests and diseases (Beer et al., 1998; Kagezi et al., 2015; Netsere and Kufa, 2015; Likassa and Gure, 2017).

4. Conclusion

A total of seven insect pest species were observed on Arabica coffee in the Mt. Elgon region of Uganda - with the white coffee stem borers having the highest incidence of 13%. On the other hand, three diseases were observed – with CLR having the highest severity of 1.9. The incidence of WCSB and CLM as well as the severity of CBD varied significantly ($p<0.05$) with increasing altitude. However, it was only the incidence of WCSB that decreased significantly ($p=0.0169$) with increasing altitude, implying that this insect pest which is currently a major pest at low altitude will became a threat at higher altitudes under the future climate scenarios. Therefore, adaptation mechanisms for climate adversaries such as planting shade trees in coffee should be developed and promoted. However, these shade systems should offer limited competition to the coffee plant as well as not promote pests and diseases.

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