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Incidence, abundance and damage by the sweet potato butterfly (*Acraea acerata* Hew. and the African sweet potato weevils (*Cylas* spp.) across an altitude gradient in Kabale district, Uganda

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ABSTRACT
It is increasingly becoming important to understand relationships between temperature (manifested at different altitude levels) and sweet potato insect pest characteristics in light of temperature changes as a result of global warming. Field surveys were conducted in Kabale district of Uganda along an altitude gradient to study the effects of temperature on incidence, abundance and level of damage by main sweet potato insect pests, the sweet potato butterfly (*Acraea acerata* Hew.) and the African sweet potato weevils (*Cylas puncticollis* Boheman and *Cylas brunneus* F.), respectively. *A. acerata* and *Cylas* spp. occurred up to an altitude of >2400 m but infestation rate was significantly highest (77% for *Cylas* spp. and 45% for *A. acerata*) at low altitudes (1422-1814 m a.s.l.), and lowest (23% for *Cylas* species and 3% for *A. acerata*) at altitudes (1992-2438 m a.s.l.). Mean *A. acerata* density/counts were statistically different across altitudes being highest at the low altitude (4.3 larvae per plant) than at mid and high altitudes. Plant defoliation was highest (3.7%) at low altitude. The highest average number of *A. acerata* and mean defoliation rates of sweet potato plants recorded in this study was 35 larvae per plant and 27.5% defoliation, respectively. Mean root yield loss by *Cylas* spp. was significantly higher at low altitude (28.5%) than at mid (6.5%) and high (3.9%) altitudes. All pest damage characteristics significantly decreased with increasing altitude. Insights on the effects of temperature variation on insect pest damage characteristics gained in the present study suggest a possible geographical shift by the pests to higher altitudes due to global warming.

Keywords: *Altitude, Cylas puncticollis, C. brunneus, global warming, insect ecology, pest severity, Uganda*

INTRODUCTION
Sweet potato (*Ipomoea batatus* (L.) Lam.) is an important food crop in Eastern Africa with an annual production of 11.83 million tons cultivated on an area of 1.84 million ha (FAO, 2011). It is a staple and co-staple food crop contributing to households' food and income security, and a rich source of Vitamin A (Andrade *et al.,* 2009). On-farm sweet potato root yields have however kept low i.e. 4.2 t/ha (FAO, 2010; Tumwegamire *et al*., 2003) compared to 10 to 38 t/ha obtained on-station experiments (Mubiru, 2000 in Tumwegamire *et al.,* 2003). Many factors have been attributed to the low on-farm yields including socioeconomic, biotic and abiotic factors. The major factors include insect pests, viruses, prolonged

drought, low soil fertility, shortage of improved varieties, and shortage of planting materials (Armes *et al.*, 1996; Bua *et al.*, 2005; Mukasa *et al.*, 2003). Insect pests have been recognised by farmers in Eastern Africa to be among the most important constraints to sweet potato production (Ebregt *et al.*, 2005; Fuglie, 2007; Nderitu *et al.*, 2009; Smit, 1997). Caterpillars of the sweet potato butterfly *Acraea acerata* Hew. (Lepidoptera: Nymphalidae) and sweet potato weevils *Cylas brunneus* F. and *C. puncticollis* Boheman are the key problems to sweet potato production (Azerefegne *et al.*, 2001; Bashaasha *et al.*, 1995; Smit, 1997; Smit *et al.*, 1997).

Adult *Cylas* spp. feed on leaves whilst larvae feed on stems and storage roots. Stem damage is thought to be the main reason for yield loss, although damage to the vascular system caused by feeding, larval tunneling and secondary rots substantially reduce storage root yields (Sorensen, 2009). *Cylas* spp. are known to cause crop yield losses of up to 100% (Ebregt *et al.*, 2005; Fuglie, 2007; Nderitu *et al.*, 2009; Smit, 1997). *Cylas* spp. have been reported as a major pest in Uganda (Muyinza *et al.*, 2007; Mwanga *et al.*, 2009; Smit, 1997), Kenya (Nderitu *et al.*, 2009; Smit and Matengo, 1995), Nigeria (Tewe *et al.*, 2003) and are also present within 20 other countries in Africa (CAB International, 2005). The nature of attack and cryptic feeding habit by *Cylas* spp. reduces the effectiveness to control them by chemical and biological insecticides or natural enemies (Smit *et al.*, 2001). Despite years of intensive conventional plant breeding research, no varieties with resistance to *Cylas* spp. have been found until now (Stevenson *et al.*, 2009).

Besides *Cylas* spp., caterpillars of the sweet potato butterfly *A. acerata* have also been reported to be a pest in Uganda (Ebregt *et al.*, 2004; Lugojja *et al.*, 2001), Ethiopia (Azerefegne *et al.*, 2001; Girma, 1994), Rwanda (Smit *et al.*, 1997), Kenya (Nderitu *et al.*, 2009; Smit and Matengo 1995) and occur in 11 other African countries where they cause severe crop losses due to defoliation (Azerefegne and Solbreck, 2010; Ebreg *et al.*, 2004; Lugojja *et al.*, 2001; Smit *et al.*, 1997). Complete defoliation in young plants results into plant establishment failure which in turn leads to reduced storage root yields (Ames *et al.*, 1996; Hill, 1983; Smit *et al.*, 1997). Outbreaks of *A. acerata* normally occur during the dry season (Lugojja *et al.*, 2001). Management practices include the traditional method of handpicking and destroying young caterpillars, use of contact insecticides, intercropping sweet potato with onion, *Allium cepa* L. and/or silverleaf desmodium, *Desmodium uncinatum* Desv. supported by natural control provided from parasitoids, predatory ants and entomopathogenic fungi (Azerefegne *et al.*, 2001; Lugojja *et al.*, 2001; Rwomushana *et al.*, 2005; Smit *et al.*, 1997).

Higher temperatures may lead to increase in insects' population growth rates, number of generations per year, risk of invasion by migrant pests and could also increase the severity of insect outbreaks hence altering species geographical distribution (Gomi *et al.*, 2007; Karban and Strauss, 2004; Ladányi and Hufnagel, 2006). Mean annual temperature is predicted to increase between 0.7 ºC and 1.5 ºC by the 2020's and between 1.3 ºC and 4.3 ºC by the 2080's as a result of global warming in Uganda as elsewhere in the world (IPCC, 2007). Increases in temperature may be responsible for the increased population of coffee berry borer, *Hypothenemus hampei* Ferrari and nematode pests, expansion of the tsetse fly, *Glossina* spp. Wiedemann, and mosquito, *Anopheles* spp. geographical distribution that have become rampant in Uganda in the last 20 years (GoU, 2007). Logan (2003) noted that greater changes in pest distribution, severity and frequency of outbreaks will be experienced at high altitudes than at low altitudes. Recently, it could be demonstrated through phenology modeling and risk mapping that the potato tuber moth, *Phthorimaea operculella* (Zeller), will likely expand to higher altitudes in tropical cropping systems as well as expand its distribution to the northern hemisphere (Kroschel *et al*., 2013). The economic and ecological impacts of insect pests will therefore undoubtedly be amplified by the aforementioned changes in pest characteristics.

Observing the response of insect pests along an altitude gradient under natural conditions has been said to be the best approach of studying the impact of climate change on insects, because it's possible to directly observe response of individual species (Logan, 2003). Since insects species vary in their response to elevation (Fleishman, 2001), there is therefore need to study the variation of pest damage characteristics of *A. acerata* and *Cylas* spp. along an altitudinal gradient where temperature is also believed to vary. This will probably provide clues to the likely response of insect pest species to global warming at any one point over time.

Although the African sweet potato weevils and the sweet potato butterfly are key pests in African agriculture, very little information is available on how severity of these pests varies with temperature and agro-ecology. As part of a project to predict climate change-induced vulnerability of African agricultural systems to major insect pests, a study was carried out to assess the interrelationships between altitudes and levels of abundance and damage of *A. acerata and Cylas* spp. in farmers' sweet potato fields. This information is useful for designing Integrated Pest Management (IPM) strategies for *A. acerata* and *Cylas* spp. and for preparing the adaptation to climate change.

MATERIALS AND METHODS

Study area

Kabale district is located in the southwestern highlands of Uganda and is characterized by montane vegetation, mostly volcanic rich soils, high elevations (1300-3900 m a.s.l.) and comparatively cool temperate temperatures between 11-25 °C at mid elevations (Fig. 1). Two distinct rainy seasons occur from March to May and September to December. The district receives over 1400 mm of rainfall and practices rainfed mixed farming involving mostly stall fed livestock and vegetable production. Sweet potato is a staple food in addition to banana, *Musa* spp., Sorghum, *Sorghum bicolor* L., and potato, *Solanum tuberosum* L. Arabica coffee, *Coffea arabica* L. is grown at elevations above 1600 m. Some temperate crops like common wheat, *Triticum aestivum* L. and barley, *Hordeum vulgare* L. are also grown. High population intensities and intensive agriculture are the norm because of small land holdings of about 1.5 hectares per household (Kashaija and Wagoire, 2008).

Field survey

Field surveys were conducted at the end of two cropping seasons in 2012 i.e. between February and March for the first cropping season and between July and August for the second cropping season. Based on altitude and possible differences in temperature regimes, three different altitude ranges (low, mid and high altitudes) within Kabale district, Uganda were selected. Young fields (2-3 months after planting) were surveyed for *A. acerata* while older fields (3-12 months after planting) ready for root harvesting were surveyed for *Cylas* spp.; however, no differences were made between *C. puncticollis* and *C. brunneus*.

A total number of 240 fields were surveyed (20 per locality x 2 seasons x 2 pests x 3 altitude levels). Location of the fields was referenced to the Global Positioning System (GPS). Fields were selected at 1 to 5 km intervals and/or when a sweet potato field was found along major and feeder roads traversing the districts. To get a good representation of each field, ten plant stands/hills were randomly selected along two diagonal transects across each field and the following data was recorded;

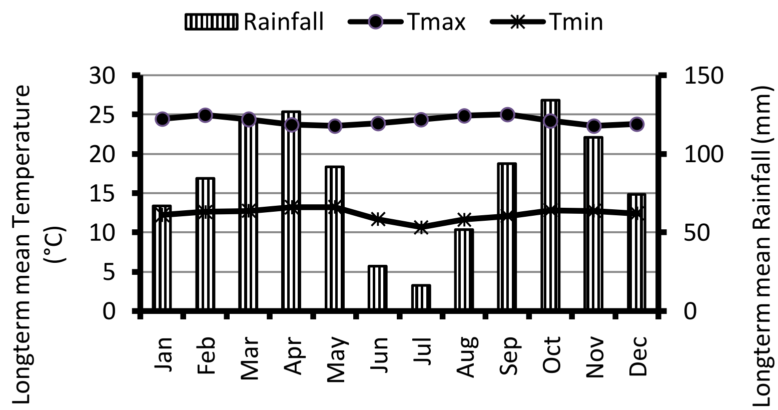

Fig.1: Long-term monthly mean temperature and rainfall at Kabale (1867 m a.s.l.), Uganda.

a) **Sweet potato vine defoliation rates by *A. acerata* larvae:** Defoliation on the vines was rated using a scale of 1 to 5 where 1=No detectable defoliation (0%), 2=Very little defoliation (1-25%), 3=Moderate defoliation (26-50%), 4=Considerable defoliation (51-75%), and 5=Severe defoliation (76-100%).

b) **Infestation rate and abundance of *A. acerata* and *Cylas* spp.:** Infestation rate (percentage of sweet potato fields where a pest was present) was recorded. The plant stands/hills were searched for presence of eggs, larvae, pupae and adults of *A. acerata* and their numbers recorded.

c) **Vine and root yield loss by *Cylas* spp.:** One vine per plant was randomly selected. A basal segment (10-20 cm from the crown) of each vine was cut off and visually inspected and scored for external physical weevil damage using a scale of 1 to 5, where 1 represented 0% basal segment damaged and 5 represented 76-100% basal segment damage (Stathers *et al*., 2003). Thereafter, each piece was split lengthwise to reveal internal physical weevil damage which was also assessed using the same scale as external weevil damage. Roots from 10 sweet potato hills were carefully dug-up, collected, and their weights recorded. The harvested roots were sorted into clean and weevil infested/damaged roots. A root was considered damaged if it had characteristic scarred spots on the root surface (Stathers *et al*., 2003) and clean if no surface damage was seen. Percentage root yield loss due to the weevil was measured as a ratio of weight of infested roots to the total weight of the roots

$$\text{Percent yield loss} = \frac{\text{Infested Root Weight}}{\text{Total Root Weight}} x100$$

Total root weight is the total weight of roots harvested from ten randomly selected plants in a field. Infested root weight is the total weight of roots that were damaged by or infested with weevils.

Data analysis

All data were analyzed using the SAS® statistical analysis program (release 9.2 for Windows) (SAS Institute Inc., 2008). Vine damage severity data (ranks) were square root transformed, percentage defoliation due to *A. acerata* and percentage root yield loss due to *Cylas* spp. were arcsine transformed while number of *A. acerata* per plant were log (x+1) transformed (Bland, 2000). Data for pest abundance, damage level and percent yield loss were subjected to analysis of variance (ANOVA). Mean values of both pest damage characteristics were determined at the three altitude levels and separated using the Fisher's LSD test. Spearman's correlation coefficients were calculated between elevation and pest characteristics.

RESULTS

Prevalence of *Acraea acerata* and *Cylas* spp.

Acraea acerata and *Cylas* spp. occurred at the three elevations surveyed in Kabale district. The highest number of fields infested with *Cylas* spp. (77%) and with *A. acerata* (45%) was at the low elevation. Similarly, the lowest number of field infestation (23 % with *Cylas* species and 3% with *A. acerata*) was recorded at the high elevations (Fig. 2).

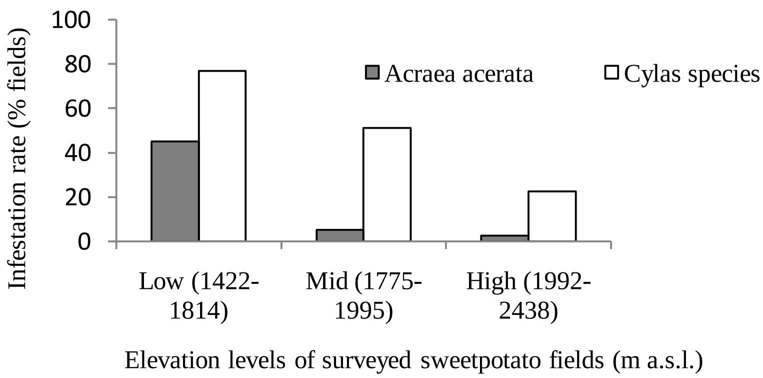

Fig. 2: Infestation rate by *A. acerata* and *Cylas* spp. at different elevations in Kabale district, Uganda.

Abundance and damage by *Acraea acerata*

Mean *A. acerata* abundances were not significantly different between the two seasons and were generally low between 1.4 to 2.3 larvae per plant (Tab. 2). Mean defoliation rates of sweet potato plants by *A. acerata* larvae were also not significantly different between the two seasons. Mean *A. acerata* densities were statistically different across altitudes being highest at the lowest altitude ranges (4.3 larvae per plant) and lowest at the mid and high altitudes (Tab. 3). At the lowest altitude occurred also the highest plant defoliation (3.7 %). The highest average number of *A. acerata* recorded in this study was 35 larvae per plant while the highest mean defoliation rates of sweet potato plants was 27.5%.

Vine damage and yield loss by *Cylas* spp.

External and internal vine damage by *Cylas* spp. did not significantly vary between seasons and were generally low (1.1 to 1.2) (Tab. 4). Season also had no effect on root yield loss due to *Cylas* spp. damage. Mean external and internal vine damage by *Cylas* spp. was significantly higher at the lowest altitude (1.3 and 1.4) than at mid and high altitudes (Tab. 5). Mean root yield loss by *Cylas* spp. was also significantly higher at the lowest altitude ranges (28.5%) than at mid and high altitude.

Table 1: Study area in Kabale district (1° 15′ 0″ S, 30° 0′ 0″ E), Uganda and altitude ranges of fields surveyed for *Acraea acerata* and *Cylas* spp.

Elevation level (Sub-county)	Altitude ranges (m a.s.l.) (mean)	
	Acraea acerata	*Cylas* spp.
Low (Kamwezi)	1422-1716 (1533)	1423-1814 (1597)
Mid (Bubaare, Hamurwa)	1775-1989 (1881)	1821-1995 (1914)
High (Muko and Bufundi)	1992-2438 (2165)	2012-2373 (2183)

Table 2: Abundance and damage by *Acraea acerata* in two sweet potato growing seasons

Season	Mean±SE	
	Number of *A. acerata*/plant	Defoliation per plant (%)
Season 1: March-May	1.41±0.66a	2.25±0.70a
Season 2: September -November	2.31±0.91a	0.83±0.32a
P value	0.7464	0.0922

Table 3: Abundance and damage by *Acraea acerata* across elevations in Kabale district, Uganda

Elevation (m a.s.l.)	Mean±SE	
	Number of *A. acerata*/plant	Defoliation per plant (%)
1533 (1422-1716)	4.26±1.35a	3.69±0.84a
1881 (1775-1989)	1.28±0.91b	0.88±0.71b
2165 (1992-2438)	0.05±0.05b	0.06±0.06b
Total mean	1.86±0.56	1.54± 0.39
P value	0.0002	<0.0001

Mean values with the same letter in the same column are not significantly different

Table 4: Vine damage and yield loss by *Cylas* species between seasons

Season	Mean±SE		
	Vine damage (score)		Root yield loss (%)
	External	Internal	
Season 1: March-May	1.08±0.04 a	1.08±0.04 a	12.46±2.38 a
Season 2: September -November	1.20±0.05 a	1.12±0.04 a	12.76±2.35 a
P value	0.0678	0.5467	0.9426

Table 5: Vine damage and yield loss by *Cylas* species across altitudes

Elevation (m a.s.l.)	Mean±SE		
	Vine damage (score)*		Root yield loss (%)
	External	Internal	
1603 (1423-1814)	1.41±0.08 a	1.26±0.07 a	28.46±3.19 a
1917 (1821-1995)	1.02±0.02 b	1.05±0.03 b	6.45±2.23 b
2183 (2012-2373)	1.00±0.00 b	1.00±0.00 b	3.90±1.31 b
Total mean	1.14±0.03	1.11±0.03	12.61±1.67
P value	<0.0001	<0.0001	<0.0001

*Basal segment vine damage scores: 1=0%; 2=1-25%; 3=26-50%; 4=51-75%; 5=76-100%; Mean values with the same letter in the same column are not significantly different

Correlation between altitude and pest characteristics

Altitude was observed to significantly and negatively influence both *A. acerata* and all the three damage characteristics of *Cylas* species (Tab. 6). All the pest characteristics were observed to decrease with increasing altitude.

Table 6: Correlation coefficients between elevation and pest characteristics

Pest characteristic	Spearman correlation coefficient	P value
Acraea acerata		
Number of larvae per plant	-0.4513	0.0000
Plant defoliation (%)	-0.4246	0.0000
Cylas spp.		
Vine external damage score	-0.4778	0.0000
Vine internal damage score	-0.3384	0.0002
Lost marketable root weight (%)	-0.5057	0.0000

*indicates that values are significantly different

DISCUSSION

The sweet potato butterfly *Acraea acerata* and the two sweet potato weevil species *Cylas puncticollis* and *C. brunneus* occurred at all altitudes of Kabale district where sweet potato was grown. With global warming these pests have potential to rapidly become important pests even at high altitudes. This study is the first to report *A. acerata* and *Cylas* spp. infestation densities and rates across an altitude gradient. Studies on pest damage in other low altitude districts of Nakasongola, Soroti, Kumi and Wakiso (1100 to 1200 m a.s.l.) in Uganda report root yield losses due to *Cylas* spp. damage of up to 100% (Ebregt *et al*., 2005; Muyinza *et al*., 2007; Smit, 1997). This notwithstanding, yield losses realized at the low altitude of Kabale in this survey of up to 28.5% are already substantial considering that poor sweet potato root yields in a season means hunger for family who subsist only on farm produce.

Season was observed not to have a significant effect on any of the pest characteristic probably because the two seasons had nearly similar rainfall amounts and temperatures (Fig. 1). The relatively low abundance levels of *A. acerata* in the two seasons could be because this insect pest is not always present in the fields every year (Ames *et al*., 1996). Outbreaks are seasonal and occur especially during dry seasons (Smit *et al*., 1997). It has been reported that farmers easily manage this pest mainly through application of chemical insecticides, a factor that could explain the relatively low abundance observed during this study (Bashaasha *et al*., 1995). Low abundance levels and defoliation rates for this pest were also reported in eastern Uganda and eastern Kenya (Ebregt *et al*., 2004; Nderitu *et al*., 2009). However, results from a recent household survey conducted in six districts of Uganda about farmers' perception of insect pests in sweet potato (Okonya and Kroschel, unpublished) revealed that *A. acerata* was ranked by farmers as most important insect pest of sweet potato in Masindi and Wakiso districts.

Damage by both *A. acerata* and *Cylas* spp. was found to increase with decreasing altitude in this survey. This negative correlation with altitude could be due to the fact that temperature is likely lower at the two mid and high altitude ranges than at the lower altitude. It is also probable that other factors like rainfall could be responsible for affecting the abundance of these pest species. For plant feeding insects, interactions with other herbivores may alter or override the determinants of abundance and the effect of climatic effects like temperature (Hodkinson, 2005). The results show that the three insect species react in a similar way to temperature changes. Rise in temperature could increase damage by both sweet potato pests. Further in depth temperature-dependent life table studies are proposed to better understand and model the direct effects of temperature on the development and reproduction of these pests.

Information on the environmental requirements that is reflected in pest incidence and infestation intensities along altitude gradients is a prerequisite in priority setting for *A. acerata* and *Cylas* spp. management. Results from this study are relevant to sweet potato production systems in tropical highlands of Africa.

CONCLUSION AND RECOMMENDATIONS

This study has established that incidence, abundance and damage by *A. acerata* and *Cylas* spp. decreased with increasing altitude. It's therefore most likely that global warming will induce a geographical shift in pest abundance and hence pest damage in mid and high altitude sweet potato growing regions.

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