AMARANTH PESTS ABUNDANCE AND DAMAGE LEVEL CORRELATES TO ENVIRONMENTAL TEMPERATURE REGIMES

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ABSTRACT
The grain amaranth, *Amaranthus hypochondriacus* (L.), is becoming an important crop worldwide due to its nutritional value. Various pests, among them the pigweed beetle, *Hypolixus haerens,* are the major biotic factors causing low yield of grain amaranth worldwide. It has been reported in the Latin America that the beetle causes high yield loss and plant stem breakage just before grain is harvested. The present study evaluated injury level of both foliar and stem damage pests on eight varieties of *A. hypochondriacus,* namely KAM 201, Kisii Brown, KSC, Kisii White, KAM 114, KAM 105, KAM 106 and KAM 115 during two seasons of production at Katumani and Kiboko in the low midland regions of Kenya. Both bollworm and leaf miner larvae were found to be the common foliar pests, although they caused no significant ($P>0.05$) yield loss in *A. hypochondriacus* varieties at the two sites. Stem tunnel length of beetle *H. haerens* correlated to environmental temperature where the hotter Kiboko site had highest stem damage. The same hotter Kiboko site of low midlands five (LM5) was drier (43.7 ± 15.9 mm, 28 ± 2°C) than the cooler Katumani zone of low midlands four (LM4), which was relatively wetter (57.1 ± 13.8 mm, 24 ± 2°C). Highly significant ($P<0.05$) yield resulted in chemical treated plots than in control ones for most varieties. Beetle stem tunnel length inversely correlated with yield of most varieties punctuated by climatic conditions. The stem damage levels at the cooler zone were lower by 35%, 42% and 47% in comparison to those from the hotter zone (LM5). The wetter and cooler zone (LM4) had lower stem damage and subsequently 5-9 times higher grain yield than the hotter zone LM5. In conclusion, considerations of the environmental factors in each agro-ecological zone would lead to right timing of insecticide spray for management of the pests of grain amaranth to prevent yield loss.
Key words: Bollworm larvae; Foliar damage; Leaf miner; Pigweed beetle; Stem damage; Tunnel length

INTRODUCTION

Amaranthus hypochondriacus L. belongs to the grain group of Amaranthaceae and is increasingly being grown in Kenya and the larger East African region after introduction from the Americas (Gupta and Thimba, 1992; Kaur *et al.* 2010). As a grain crop amaranth has been reported to provide low cholesterol diet as staple food stuff (Berger *et al.*, 2003; Kong *et al*., 2009; Escudero *et al*., 2011). Much research has been dedicated on the chemical composition and nutritive quality of the pseudo cereal amaranth, where several varieties of Amaranthus have been found superior to most other cereals (Gorinstein *et al.,* 1991; Gonzalez *et al.,* 2007). The importance of amaranth is increasingly being reported as an important food supplement for people living with HIV/AIDS in most Sub-Sahara Africa (Veeru *et al.*, 2009; Schoenlechner *et al.*, 2010; Kunyanga *et al.*, 2012). The plant has been found to be a heavy feeder of nitrogen and microelements (Zheleznov *et al.,* 1997; Skwaryło-Bednarz *et al.*, 2011; Skwaryło-Bednarz, 2012). On pest occurrence, some sucking plant bugs and the pigweed beetle *Hypolixus haerens* Boheman have been reported worldwide as the major agents constraining realization of variety genotype potential yield (FAO, 1988; Grubben *et al.*, 2004). It is at larval stage that *H. haerens H. haerens* causes plant stem damage after egg laying two weeks after plant emergence. Some disease pathogens like of *Pythium* species can be a problem under given environmental conditions. Disease fungus such as stem canker, caused by *Rhizoctonia* species which colonizes leaves and stems causing dieback has been cited in the Americas and Africa though causing <10% grain loss on most farms (Jansen *et al*., 2007). However, little information has been documented on the actual yield loss due to foliar and plant stem damage of specific pests like the pigweed beetle among others. Farmers in Kenya using various insecticides report no reduction of *H. haerens* on amaranth, as agro-chemical stockists experiment with them each season.

The objective of the present study was to evaluate both foliar pests and stem damage by pigweed beetle *H. haerens,* as well as variety tolerance of pests in two related agro-ecological zones in low midland regions of Kenya.

MATERIALS AND METHODS

Site Plot Establishment

Eight variety plots of amaranth were established on tractor ploughed and harrowed plots. The eight varieties were KAM 201, Kisii Brown, KSC, Kisii White, KAM 114, KAM 105, KAM 106 and KAM 115 planted at the onset of the short and long rain seasons in April-June, 2013 and October-December, 2014. The varieties had been collected from different KALRO-Centres' breeding programmes. Using Jaetzold *et al.* (2007) agro-ecological zonation, two sites were identified for pest tolerance evaluation at Kiboko, low midlands five (LM5) and Katumani, low midlands four (LM4) of the eastern region of Kenya. Plot layout was randomized complete block design (RCBD). Climate data (pooled) from the sites meteorological stations was analyzed for interpretation of plant and yield development in consideration to biotic and physical factors during production periods (Table 1). Kiboko site was hotter and drier with monthly rainfall of 43.7 ± 15.2 mm at an altitude of 940 m above sea level (asl). Katumani site was within the wetter zone with monthly rainfall of 57.1 ± 13.8 mm at an altitude of 1609 m asl. Site annual temperatures were 26-30ºC for Kiboko and 22-26ºC for Katumani.

Table 1: Mean (standard deviation) monthly climatic variables at the sites of amaranth production periods

Period	Site	Rainfall (mm)	Temp (°C)
April-June, 2013	Kiboko (LM5)	40.7 (15.3)	26.9 (2.1)
	Katumani LM4)	47.0 (13.8)	24.2 (2.0)
Oct.-Dec., 2014	Kiboko (LM5)	45.9 (15.1)	30.2 (4.8)
	Katumani (LM4)	67.2 (13.0)	24.3 (2.1)

Treatments

Composite manure was applied in the plots at planting at a rate of 2.7 t ha^{-1}. The eight varieties were planted in five rows of 90cm x 30cm spacing. The plots had 18 plants in five rows. The variety blocks were treated with the insecticide and replicated four times at the two different field plots. Spray of Bulldock Star® 262.5 EC (pyrethroid-organophosphate) of Beta-cyfluthrin 12.5 g/L-with-Chloropyrifos 250 g/L was carried out on the first three outer-most plant rows on all plant variety plots at two months' intervals until crop physiology maturity stage. The recommended manufacturer's rate of 10 ml/20-litre of water was used. The total sprays were two at each site with the first one done at one month after crop emergency.

Data Collection and Analysis

Insect foliar damage data was taken at the flowering stage (seven weeks after planting) of the crop and the pigweed stem tunnel length at harvest (nine weeks after planting) (WAP). For bollworm larvae, an estimate of percentage windowed leaf area per plant was taken. As for leaf miner damage, number of mined leaves per plant was scored on the same sample plants.

Other damage symptoms of beetle were taken as number of exit holes per stem, tunnel length (measured with a ruler) and number (counted) for each treatment plot. This was to enable comparison of variety pest tolerance as well as insecticide efficacy under the prevailing agro-climatic conditions at the two sites.

Level of pigweed beetle variety tolerance was observable on least value on control plots. Log transformation (x +5) was done on the number of pests per plant to remove effect of zero values on parameter means.

Analysis of variance (ANOVA) done to determine significant difference of parameter mean values of plant height (cm), stem tunnel length (cm), exit holes and number of pigweed beetles (larvae) per plant stem. The analyses were done using General Linear Method (GLM) of Student-Newman Keuls (SNK) Post Hoc Test, using SAS Version 8 (2001) at $P=0.05$. Correlation (R^2) of yield response to increase of stem tunnel length was graphed for interpretation of the relationship between the data parameters at the two experimental sites.

RESULTS

Foliar Damage

Mean bollworm *Helicoverpa armigera* Hubner infestation densities on varieties was not significantly ($P>0.05$) different on the unsprayed plots at Kiboko (Table 2). A similar trend was observable at Katumani. Three different species of leaf miners, *Liriomyza sativae* Blanchard, *L. trifolii* Burgess and *L. huidobrensis* Blanchard, were identified on amaranth leaves at the two sites. The most common leaf miners were *L. sativae* (40%,) and *L. trifolii* (35%) closely similar at the two sites. At Katumani, varieties KAM 201, Kisii White, KAM 105 and KAM 106 had significant ($P<0.05$) increase of plant height with insecticide application.

Table 2: Mean (± SE) amaranth variety height and foliar pests' occurrence at two different agro-ecological zones under unsprayed and sprayed treatments at flowering stage

Site		Plant height (cm)		No. bollworm larvae / plant		No. Leaf miner larvae / plant	
Kiboko (LM5)	*Variety*	*Unsprayed*	*Sprayed*	*Unsprayed*	*Sprayed*	*Unsprayed*	*Sprayed*
	KAM 201	86 ± 3.9aA	86 ± 5.4aA	0.6 ± 0.2aA	0.2 ± 0.1bB	1.2 ± 0.4aA	0.2 ± 0.1bB
	Kisii Brown	64 ± 5.4bB	84 ± 4.6aA	0.5 ± 0.3aA	0.1 ± 0.0cA	0.2 ± 0.1bA	0.1 ± 0.0cA
	KSC	78 ± 4.2abB	93 ± 3.6aA	0.4 ± 0.2 aA	0.2 ± 0.1bA	0.5 ± 0.2bA	0.3 ± 0.1aA
	Kisii White	86 ± 3.4aB	104 ±2.5aA	0.7 ± 0.4aA	0.1 ± 0.0cA	0.6 ± 0.5bA	0.2 ± 0.1bA
	KAM 114	88 ± 4.6aA	94 ± 4.7aA	0.5 ± 0.1aA	0.3 ± 0.1aB	0.2 ± 0.0bA	0.2 ± 0.1bA
	KAM 105	81 ± 2.9abA	77 ± 2.75aA	0.4 ± 0.1aA	0.1 ± 0.0cB	0.1 ± 0.0bA	0.1 ± 0.0cA
	KAM 106	89 ± 2.3aA	90 ± 3.6aA	0.6 ± 0.5aA	0.2 ± 0.1bA	0.2 ± 0.1bA	0.1 ± 0.0cA
	KAM 115	81 ± 2.5abA	85 ± 1.6aA	0.4 ± 0.1aA	0.1 ± 0.0cB	0.3 ± 0.1bA	0.1 ± 0.0cA
	P-value	*0.028*	*0.727*	*0.375*	*0.003*	*<0.001*	*0.002*
Katumani (LM4)	KAM 201	125 ± 2.3ab A	130 ± 1.3abA	1.9 ± 1.3abA	1.8 ± 1.0aA	1.2 ± 0.8aA	0.8 ± 0.1aA
	Kisii Brown	127 ± 2.0abA	122 ± 2.3cB	1.3 ± 1.2abA	1.2 ± 1.0aA	1.0 ± 0.2abA	0.2 ± 0.1cA
	KSC	127 ± 3.6abA	129 ± 2.5cA	2.1 ± 1.8abA	1.4 ± 1.3aA	0.8 ± 0.2abA	0.4 ± 0.1bA
	Kisii White	127 ± 4.8abA	142 ± 2.9aA	1.1 ± 0.7abA	2.0 ± 1.3aA	0.7 ± 0.6abA	0.3 ± 0.1bA
	KAM 114	114 ± 3.4bA	124 ± 3.0cA	1.4 ± 1.3bA	1.7 ± 0.8aA	0.5 ± 0.2bA	0.1 ± 0.1dA
	KAM 105	113 ± 5.4bA	137 ± 3.6abA	0.8 ± 0.7abA	1.1 ± 1.0aA	0.8 ± 0.4abA	0.0 ± 0.0eA
	KAM 106	138 ± 5.2aA	142 ± 4.5aA	2.2 ± 2.0abA	3.1 ± 2.6aA	1.1 ± 0.5aA	0.2 ± 0.1cA
	KAM 115	120 ± 3.0abB	135 ± 2.9bA	2.3 ± 1.3aA	1.2 ± 1.0aA	0.9 ± 0.6abA	0.1 ± 1.0dA
	P-value	*0.011*	*0.003*	*0.015*	*0.367*	*0.028*	*<0.001*

Similar lower case letters denote insignificant (*P*>0.05) mean value parameter difference among different amaranth varieties (SNK at 5% level). Different upper letters denote significant (*P*<0.05) difference between sprayed and unsprayed treatment within rows.

Bollworm larvae density level on the varieties was insignificant (*P*>0.05) among unsprayed plots at both Kiboko and Katumani. Notably, significant (*P*<0.05) higher number of bollworms and leaf miners was observed at Katumani than at Kiboko. Insecticide application significantly (*P*<0.05) lowered bollworm densities on the varieties at Kiboko but it did not effect significant (*P*>0.05) pest reduction at Katumani. Leaf miner pest density was significantly (*P*<0.001) different amongst the different varieties for the unsprayed plots at Kiboko and Katumani.

Beetle stem damage

The *H. haerens* beetle caused highest stem damage on amaranth in the hotter Kiboko site (28 ± 2°C) than in the cooler Katumani (24 ± 2°C) (Figure 1). The 4°C difference in temperatures at Kiboko and Katumani resulted in twice higher tunnel length increase across most varieties.

Yield at the sites

On unsprayed plots, variety yield was significantly (*P*<0.001) different among the varieties in the two sites (Table 3). Highest yield was recorded at Katumani on variety Kisii White (1,524.8 kg/ha) followed by Kisii Brown (1,323.3 kg/ha). The least yield was for variety KAM 114 (808.7 kg/ha) in the same site. At the hotter Kiboko, the highest yield was for variety KAM 201 (238.4 kg /ha), which was closely similar to Kisii Brown yield (237.1 kg/ha). All varieties in Katumani had over 100% yield increase in comparison to Kiboko site. Some varieties had 400% (Kisii White, Kisii Brown, KAM 201 and KSC) grain yield increase. Figure 2 shows that beetle tunnel length was inversely correlated to yield, the higher tunneling the lower the yield.

On the insecticide treated plots at Katumani, Kisii Brown variety had highest yield of 2,113 kg /ha and KSC had 1,735 kg /ha as the second highest. At Kiboko insecticide treated plots, variety KAM 201 led with 628.1 kg/ha followed by Kisii White (618.9 kg /ha). Significant (*P*<0.001) yield difference was realized among the different varieties in both sites on control and insecticide treated plots. The cooler zone had 5-9 times higher yield than the hotter zone irrespective of treatment. The insecticide application effected significant (*P*<0.05) yield increase in Kiboko of between 23% (Kisii Brown) to 163% (KAM 201) but it did not bring similar increase in Katumani plots (Table 4). In Katumani, low stem damage led to higher yield than in Kiboko plots. Grain yield was influenced by other environmental factors (independent variables) besides stem damage level as Figure 2 shows of the two sites.

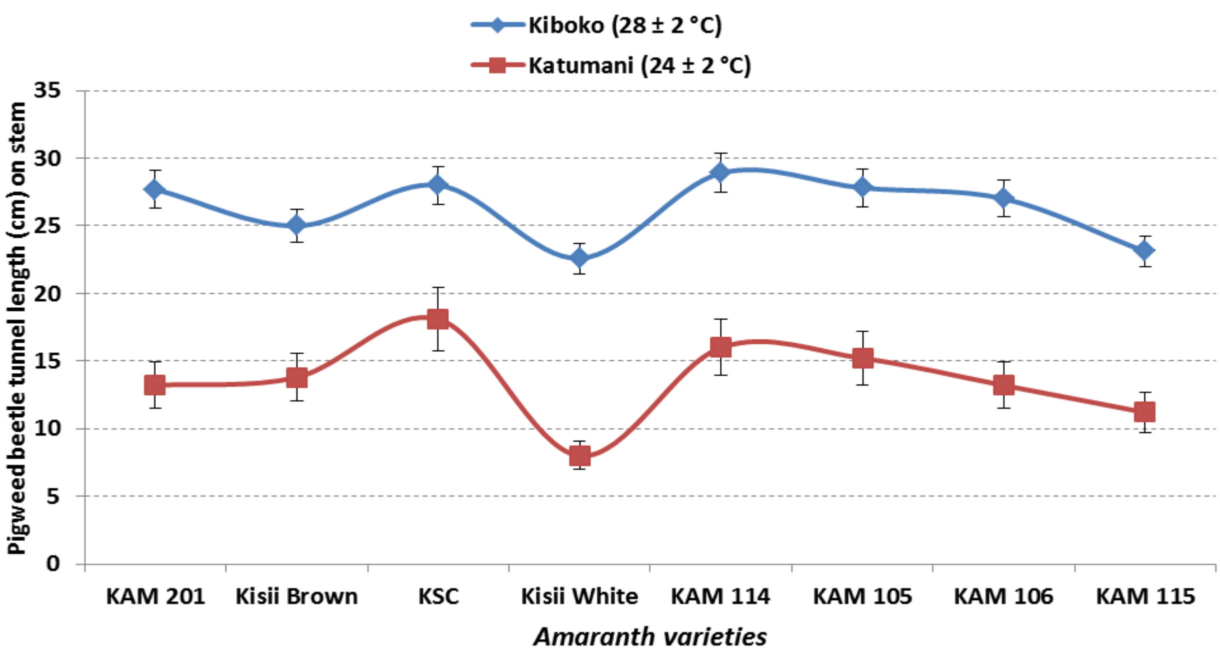

Figure 1: Pigweed beetle tunnel length on different amaranth varieties at two temperatures regimes

Table 3: Mean (±SE) amaranth variety grain yield (kg/ha) under treatments plots

Site	Variety	Unsprayed kg ha^{-1}	Sprayed kg ha^{-1}	*F (df), P*
Kiboko (LM5)	KAM 201	238.4 ± 24.9abB	628.1 ± 33.5aA	*6231.2 (1,3), 0.001*
	Kisii Brown	237.1 ± 22.4abB	292.9 ± 18.3cA	*553.9 (1,3), 0.008*
	KSC	155.3 ± 24.5dB	291.7 ± 11.2cA	*1577.8 (1,3), 0.006*
	Kisii White	210.5 ± 21.9bcB	618.9 ± 91.5aA	*103.3 (1,3), 0.009*
	KAM 114	208.2 ± 25.9bcB	457.7 ± 38.8bA	*1147.8 (1,3), 0.001*
	KAM 105	189.3 ± 30.6bcdB	471.6 ± 150.8bA	*19.9 (1,3), 0.046*
	KAM 106	165.4 ± 13.3cB	441.2 ± 45.2bA	*244.3 (1,3), 0.044*
	KAM 115	264.3 ± 34.5aB	349.1 ± 47.1bcA	*215.9 (1,3), 0.041*
	F (df), P	*10.2 (7,14), 0.001*	*17.2 (7,14), <0.001*	
Katumani (LM4)	KAM 201	1,230.8 ± 30.7cdA	1,572.9 ± 117.6cA	*7.1 (1,3), 0.116*
	Kisii Brown	1,323.3 ± 107.7bA	2,113 ± 112.5aA	*3.9 (1,3), 0.184*
	KSC	1,279.8 ± 74.4bcA	1,735.0 ± 108.1bA	*0.1(1,3), 0.835*
	Kisii White	1,524.8 ± 73.7aA	1,538.9 ± 76.7cA	*0.1 (1,3), 0.882*
	KAM 114	808.7 ± 80.6gB	1,461.2 ± 49.6dA	*20.6 (1,3), 0.045*
	KAM 105	1,168.5 ± 36.5edA	1,183.4 ± 104.3fA	*0.2 (1,3),0.754*
	KAM 106	914.5 ± 56.6fA	887.3 ± 41.2gA	*9.5 (1,3), 0.090*
	KAM 115	1,101.6 ± 25.9eA	1,265.2 ± 104.5eA	*13.2 (1,3), 0.068*
	F (df), P	*86.6 (7,14), <0.001*	*397.3 (7,14), <0.001*	

Different lower case letters denote significant (*P*<0.05) mean value parameter difference among different amaranth varieties (SNK at 5% level). Similarly, different upper letters denote significant (*P*<0.05) difference between sprayed and unsprayed treatment within rows.

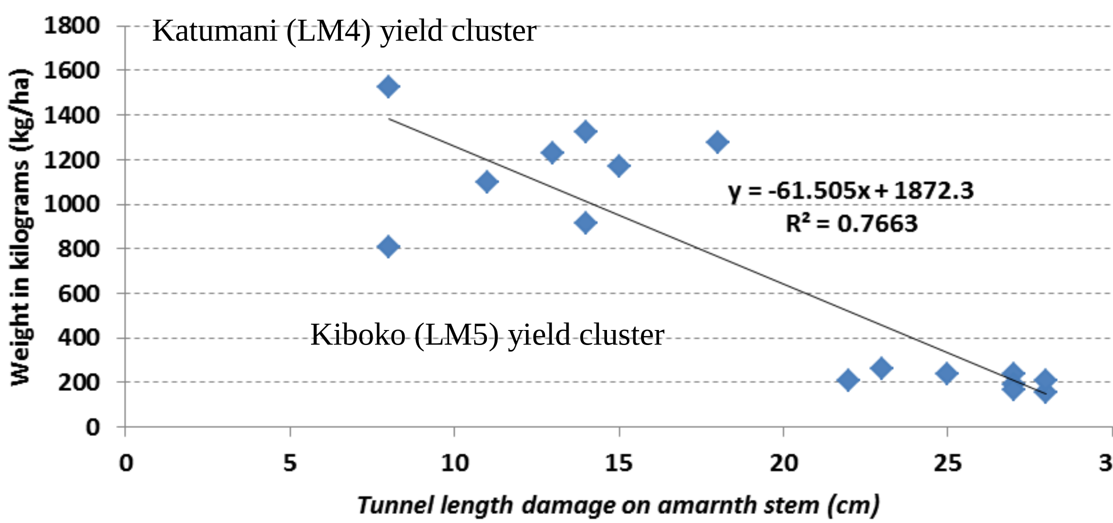

Figure 2: Regression of Katumani (LM4) and Kiboko (LM5) yields against stem tunnel length

DISCUSSION

Pest foliar damage of the grain amaranth had no significant effect on the yield, as was the case of maize stem borers (Kfir *et al.*, 2002; Beyene *et al.*, 2011). The hotter Kiboko zone (LM5) had lesser foliar damage of bollworms and leaf miners than the cooler Katumani zone (LM4). The foliar damage of bollworm and leaf miner pests on grain amaranth did not reduce yields in the cooler Katumani site. The spray of pyrethroid-organophosphate insecticide reduced plant pest stress and led to significant (*P*<0.05) height gain by the different varieties in Kiboko, but less same effect in Katumani where yield increase was as a result of other favourable factors.

There was no significant reduction of *H. haerens* beetle development at the two sites among varieties even where insecticide spray was used, indicating possible late spray when eggs had already been laid into the plant stems. Nevertheless, higher beetle density resulted in the hotter Kiboko site than in the cooler Katumani site. The pest control of foliar damage in the low midland zones led to increased plant height and this showed improved plant health, which is good for higher grain yield as found in other related studies (Gimplinger, *et al.*, 2007). As a fact, yield level was as result of variety potential, prevailing weather conditions and level of pest stress. As observed from the results, cooler and wetter conditions in Katumani led to higher yields with reduced pigweed damage in the site even on the control plots. On the other hand, higher temperatures and subsequent higher beetle stem damage led to lower grain yield among the different varieties. Farmers can realise higher crop yield in Katumani than in Kiboko due to the more favourable environmental conditions even with minimal insecticide spray regimes.

Bautista *et al.* (1997) has described a dipteran borer pest on grain amaranth in South America with similar symptoms as for *H. haerens*. This could indicate that *A. hypochondriacus* may be attacked by various pest insects from Diptera, Coleoptera and Lepidoptera order species, depending on the locality. De Oliveira *et al.* (2012) presented similar tunnel length and exit holes of a moth, *Herpetogramma bipunctalis* Fabricius. The present study has analyzed the effect of *H. haerens* on grain amaranth in the two sites and found variety yield is as result of other environmental factors. Further comparison of environmental factors of rainfall amount and temperature influence to grain yield showed that higher tonnage of between 5-9 times was realized in the cooler/wetter zone (LM4-Katumani) than in the hotter/drier LM5 (Kiboko) on almost all the varieties.

Kunyanga *et al.* (2012) reported that amaranth ecological requirement for optimum production include medium soil fertility and rainfall amount >100 mm per production season and medium pH level of 4.5-6.5. The present work has shown yield increase of over 400% with increase of monthly rainfall amount changing from 43.7 mm to 57.1 mm in a higher altitude zone. The environmental effect on both plant development and yield was a strong determinant of final effect of pests. Beetle stem tunnel length was found to be inversely correlated to yield as in maize (Beyene *et al.,* 2011). The tunnel length on the maize plant stem is the criterion used to indicate resistance of a crop variety (Bautista *et al.*, 1997; Butron *et al.*, 2014). All the eight evaluated amaranth varieties did not indicate resistance to *H. haerens* as they displayed closely similar high stem damage indicated by long tunnel lengths and high beetle survival. Higher stem tunnel length led to lower yield tonnage in all varieties, as found in other studies (De Oliveira, *et al.*, 2012).

There was significant difference in tunnel length for the varieties where the hotter/drier zone site had higher lengths than the cooler/wetter zone on both insecticide sprayed and non-sprayed plots. Both tunnel lengths and number of beetles per stem parameters showed no significance difference between sprayed and unsprayed plots, leading to the conclusion that the insecticide pyrethroid-organophosphate was not applied at the right time to prevent oviposition or larval survival on the stem. Being a contact insecticide no significant control could be achieved on stem tunneling of *H. haerens* as the beetle could lay its eggs within one month when potency of the insecticide was absent. One of the factors found to lead to high stem damage by *H. haerens* larvae was hot-warm environment, while the wetter-cool conditions led to faster plant growth and better plant health, leading to higher grain yield as reported on cereal stem borers (Abro *et al.*, 2013; Bamaiyi and Ifejeola-Joan, 2011).

In conclusion, a further evaluation is needed to correct the timing of spray to be 7-14 interval days but not at one month interval as farmers' were directed by agro-chemical dealers. A systemic insecticide would likely protect amaranth crop from such foliar and stem pests.

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