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ENVIRONMENTAL FACTOR INFLUENCE ON FOLIAR AND STEM PESTS OF GRAIN AMARANTH IN LOW MIDLANDS AGRO-ECOLOGICAL ZONES OF KENYA: CORRECT TIMING FOR EFFECTIVE PEST MANAGEMENT

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ABSTRACT

The pigweed beetle *Hypolixus haerens* Boheman has been cited as a major insect pest of grain amaranth worldwide. A study to evaluate injury level of both foliar and stem damage pests in Kenya revealed that the stem beetle *H. haerens* caused higher stem damage in the hotter zone (26-30 ºC) than the cooler zone (22-26 ºC) in the low midlands zones of Kenya. Eight varieties of *Amaranthus hypochondriacus* (L.) were evaluated during the two seasons study. The hotter zone of low midlands five (LM5) was drier (43.7 ± 15.9mm) than the cooler zone of low midlands four (LM4) which was relatively wetter (57.1 ± 13.8mm). Beetle stem tunnel length was inversely correlated to yield. The stem damage levels at the cooler zone were lower by 35, 42 and 47% in comparison to those from the hotter zone (LM5). Foliar damage level did not reflect direct grain loss. No variety was found resistant to *H. haerens* stem injury from the eight accessions evaluated. The wetter and cooler zone (LM4) was found to influence lower stem damage and subsequently 5-9 times higher grain yield than the hotter zone. In conclusion, considerations of the environmental factors in each agro-ecological zone would lead to right time of insecticide spray for management of the pests of grain amaranth to prevent yield loss.

INTRODUCTION

The amaranth species *Amaranthus hypochondriacus* L. belongs to the grain group of Amaranthaceae and is increasingly being grown in Kenya 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; Milan *et al*., 2012). 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).

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On pest occurrence, some sucking plant bugs and the pigweed beetle have been reported worldwide as the major agents constraining realization of variety genotype potential yield (FAO, 1988; Grubben *et al*., 2004). Some disease pathogens like Pythium can be a problem under some environmental conditions.

Another disease fungus of Rhizoctoniagenus, as well as stem canker, caused by Phormaor Rhizoctoniagenus which colonizes leaves and stems and causes dieback was highlighted in the Americas and Africa (vanRensburg *et al*., 2007). However, little information has been documented on the actual yield loss due to foliar and plant stem damage of specific pests. Farmers in Kenya have used various insecticides reporting no reduction of *H. haerens* on amaranth as agro-chemical stockists experiment with farmers each season. The objective of the present study was to evaluate both foliar pests and the stem damage by the pigweed beetle *Hypolixus haerens* Boheman, as well as variety tolerance of other pests in two related agro-ecological zones in the low midlands region of Kenya. The right time to spray against common pests was tested using Beta-cyfluthrin-Chlorpyrifos insecticide.

MATERIALS AND METHODS

Site plot establishment

Eight variety plots of amaranth *Amaranthus hypochondriacus* L. were established on tractor ploughed and harrowed plot to make a fine seedbed. The eight varieties were planted on the onset of the short and long rain seasons in April-June (2013) and January-March (2014). Using Jaezold *et al* (2007) agro-ecological zonation, the two plots were located at two low midlands ecological zone sites; at Kiboko, low midlands five (LM5) and Katumani, low midlands four (LM4) of the eastern region of Kenya (Fig.1). Plot design was randomized complete block design (RCBD). The eight varieties were planted in five rows of 90cm x 30cm spacing. The plot sizes were 18 plants in the five rows. Climate data from the sites meteorological stations was analyzed for interpretation of plant development and final yield in consideration to biotic and physical factors during production periods. Kiboko site plot was drier, monthly rainfall of 43.7 ± 15.9mm at an altitude of 940m above sea level (asl). Katumani plot was within the wetter zone of monthly rain fall of 57.1 ± 13.8mm at an altitude of 1609m asl. Site annual temperatures were 26-30 ºC for Kiboko and 22-26 ºC range for Katumani.

Treatments and data collection

One month after plant emergence, foliar damaging insects like bollworms and leaf miners showed windowed leaves and lamina mining. The stem pest pigweed beetle *H.haerens* damage symptoms was observed on most plant stems as pin hole-punches three weeks after plant germination. Bioassay studies on the efficacy level of Bulldock Star® 262.5 EC (pyrethroid-organophosphate) of Beta-cyfluthrin (12.5g/litre)-with-Chlorpyrifos (250g /litre) was carried out at the rate of5ml/20-litre, 10ml /20-litreand 15ml/20-litre to determine dose effectiveness on the two pests. The result of bollworm and leaf miner larvae mortality in different insecticide concentrate levels at recommended (1), below and (z) above manufacturer's rate is shown on Figure 2.

Three different species of leaf miners, *L. iriomyzasativae* Blanchard, *L. trifolii* Burgess and *L.huidobrensis* Blanchard were identified on amaranth leaves at the two sites. Composite manure was applied at the plots at planting at the rate of 2.7 t ha^{-1}. The variety blocks were treated with the insecticide together with the control plot treatments replicated four times at the two different field plots. Spray of Bull dock Star® 262.5 EC was carried out on the first three outer- most plant rows on all plant variety plots in two months' intervals to crop physiology maturity. The manufacturer's rate of recommendation of 10ml / 20-litre of water was followed. The total sprays were two at each site with the first one carried out after one month of crop emergency. Insect foliar damage data was taken at the flowering stage (seven weeks after planting) of the crop and the pigweed stem tunnel leng at harvest; nine weeks after planting (WAP). Other damage symptoms of beetle exit holes, tunnel length and number of beetles were scored 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. Log transformation (x +5) was carried out on the number of pests per plant to remove effect of zero values on parameter means.

Analysis of variance (ANOVA) was carried out 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 carried out using General Linear Method (GLM) of Student-Newman Keuls (SNK) Post Hoc Test using SAS Version 8 (2001) at 5% significance level. Correlation (R^2) trend of yield response to increase of stem tunnel length was graphed for interpretation of the relationship between the two parameters at the two sites.

RESULTS

Foliar damage

At Katumani site, bollworm foliar damage was at least twice higher than leaf miner on most varieties on control plots (Fig. 3). Combined overall bollworm foliar damage was over 50% on four varieties; KAM 201, Kisii Brown, KSC and KAM 106. Total foliar damage for varieties Kisii White, KAM 114, KAM 105 and KAM 115 was less than 40% at Katumani site. Leaf miner pest damage at the site was highest on variety KAM 114 at 21% in comparison to Kiboko site where it was less than 5% on the other varieties. Unlike Katumani, bollworm damage at Kiboko was less than 30% on most varieties. Similarly, overall bollworm foliar damage at Kiboko was less than 30% on all varieties besides Kisii White (36%) as shown on Figure 3.

Variety heightresponse

Amaranth varieties displayed significance height difference to insecticide application against the foliar pests at flowering stage as shown on Table 1. On unsprayed plots, highest plant height was recorded on variety KAM 106 at 89cm at Kiboko which also led at 138cm at Katumani. Kisii White had significantly ($P<0.05$) height increase when spayed with the insecticide from 86cm to 104cm (21%) at Kiboko while KAM 115 led with close similar range of height increase from 120cm to 135cm (25%) at Katumani. Overall variety plant height was higher at Katumani at 34% than Kiboko on unsprayed plots while on sprayed ones it was 33%. Mean bollworm infestation densities on varieties was not significantly ($P>0.05$) different on the unsprayed plots at Kiboko. At Katumani, varieties KAM 201, Kisii White, KAM 105 and KAM 106 indicated significant ($P<0.05$) increase of plant height with insecticide application. Bollworm larvae density difference on the varieties was insignificant ($P>0.05$) among unsprayed plots at Kiboko while at Katumani where KAM 115 led with 2.3 larvae / plant. Insecticide application lowered significantly ($P<0.05$) 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 at the unsprayed plots at Kiboko. Likewise, leaf miner density was significantly ($P<0.05$) different among varieties at Katumani on the same unsprayed plots. Insecticide application did not significantly ($P>0.05$) decrease leaf miner densities on the varieties at both sites.

Pigweed stem damage

There was significant ($P<0.001$) difference of plant height among the eight varieties at both Kiboko and Katumani on

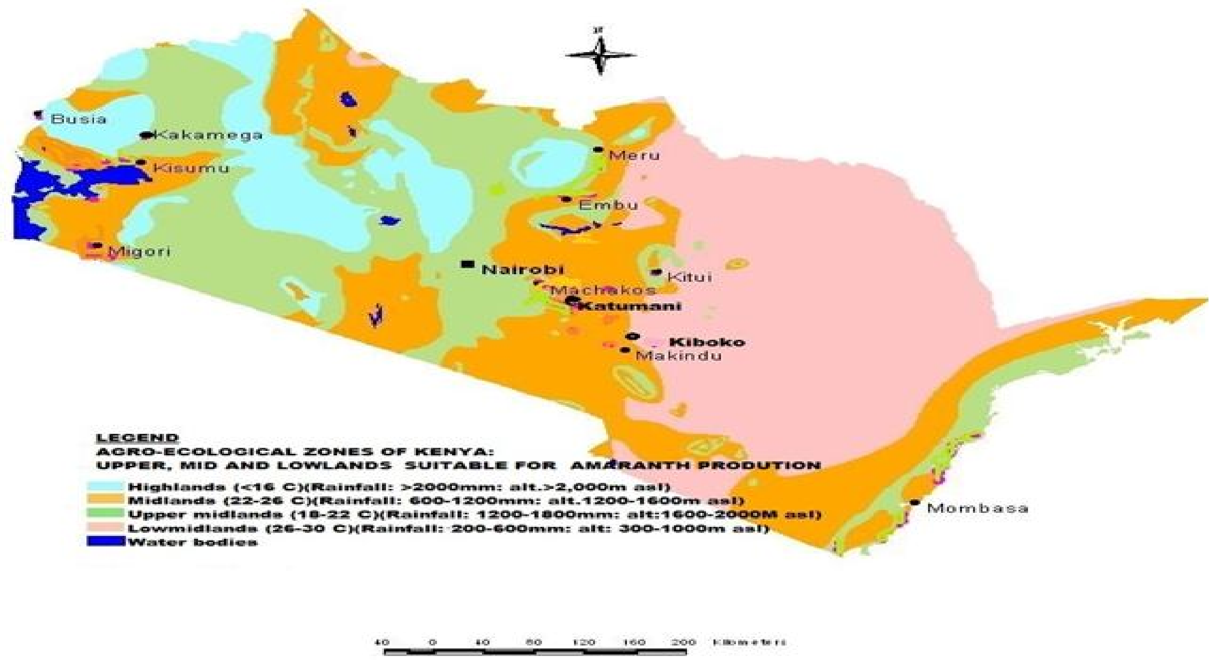


Fig. 1. Transect map of Kenya indicating the experimental sites at Katumani (LM4) and Kiboko (LM5) of the low midlands of eastern region

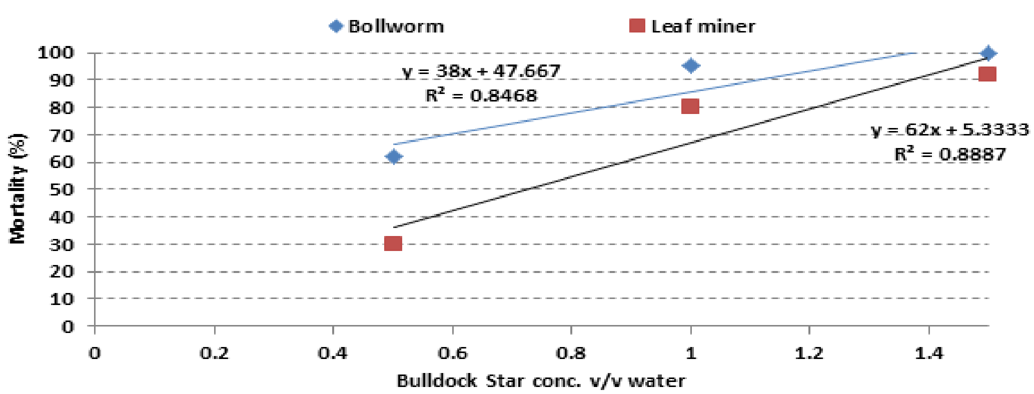


Fig. 2. Bollworm *Olicover perarmigera* and leaf miner *Linomyza*ss plarvae lethal dose response to Bulldock Star® 262.5 ECon amaranth, *Amaranthus hypochondriacus* L. under normal laboratory conditions

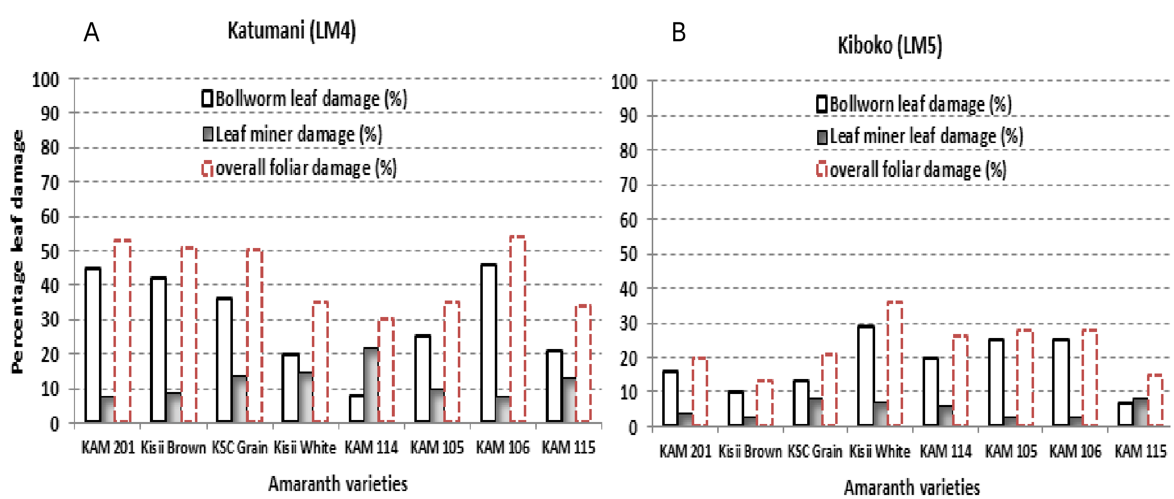


Fig. 3. Meanpercentage (%) amaranth variety foliardamage in two different agro-climatic sites; (A) Katumani (LM4) and (B) Kiboko (LM5) during plant development at flowering stage

Table 1. 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.

Table 2. Mean (SE) amaranth variety height (cm), tunneling length (cm), exit holes and number of adult pigweed beetle *Hypolixush aerens* per stem at two different agro-climatic conditions under two different spray treatments

Site		Plant height (cm)		Tunnel length (cm) / stem		Exit holes / stem		No. beetles/ stem	
Kiboko (LM5)	*Variety*	*Unsprayed*	*Sprayed*	*Unsprayed*	*Sprayed*	*Unsprayed*	*Sprayed*	*unsprayed*	*sprayed*
	KAM 201	107 ± 3.9cB	122 ± 3.8bA	27.7 ± 15.4abB	29.7 ± 14.5aA	0.5 ± 0.4aA	0.6 ± 0.2abA	2.6 ± 1.2aA	2.6 ± 1.4aA
	Kisii Brown	129 ± 3.8aA	127 ± 5.2bA	25.0 ± 12.6abcA	25.9 ± 13.5aA	0.4 ± 0.3aA	0.9 ± 0.5aA	2.5 ± 1.5aA	2.1 ± 1.2aA
	KSC	120 ± 4.1bA	125 ± 3.4bA	28.0 ± 14.7abA	28.8 ± 15.2aA	0.3 ± 0.1aA	0.4 ± 0.2abA	9.9 ± 8.5aA	2.3 ± 1.5aA
	Kisii White	119 ± 5.4bB	130 ± 3.0aA	22.6 ± 10.6cA	19.6 ± 13.8aA	0.6 ± 0.5aA	0.6 ± 0.3abA	2.2 ± 1.4aA	1.7 ± 1.3aB
	KAM 114	127 ± 3.4aA	124 ± 5.0bA	28.9 ± 14.3aA	29.8 ± 15.2aA	0.3 ± 0.1aA	0.6 ± 0.2abA	2.7 ± 1.6aA	2.1 ± 0.9aA
	KAM 105	118 ± 4.5bA	115 ± 3.0cA	27.8 ± 16.7abA	24.8 ± 15.9aA	0.5 ± 0.3aA	0.3 ± 0.1bA	2.5 ± 1.4aA	3.1 ± 1.4aA
	KAM 106	94 ± 10.4dB	126 ± 4.3bA	27.0 ± 13.9abcA	24.5 ± 12.7aA	0.3 ± 0.1aA	0.6 ± 0.3abA	2.3 ± 1.2aA	1.9 ± 1.3aB
	KAM 115	121 ±5.2bB	131 ± 4.2aA	23.1 ± 12.4bcA	30.9 ± 14.4aA	0.2 ± 0.1aA	0.2 ± 0.1bA	2.6 ± 1.5aA	2.5 ± 1.6aA
	P-value	*<0.001*	*<0.001*	*0.007*	*0.877*	*0.803*	*0.029*	*0.192*	*0.949*
Katumani (LM4)	KAM 201	158 ± 19abcA	138 ±5.2dA	13.2 ± 9.9aA	12.4 ± 7.6aA	0.3 ± 0.2aB	0.4 ± 0.2aA	1.9 ± 0.8aA	1.2 ± 0.8aA
	Kisii Brown	167 ± 23aA	152 ±2.9bA	13.8 ± 11.7aA	17.9 ± 16.5aA	0.1 ± 0.0aB	0.3 ± 0.2aA	0.8 ± 0.6aA	0.6 ± 0.4aA
	KSC	145 ±12acA	156 ±3.4aA	18.1 ± 15.0aA	7.9 ± 7.6aA	0.3 ± 0.2aA	0.2 ± 0.1aA	1.3 ± 1.0aA	0.6 ± 0.2aA
	Kisii White	165 ± 19abA	157 ±4.3aA	8.0 ± 2.3aA	9.5 ± 5.7aA	0.2 ± 0.1aA	0.1 ± 0.0aA	0.8 ± 0.6aA	0.5 ± 0.3aA
	KAM 114	151 ± 18bcA	149 ±3.4cA	16.0 ± 11.9aA	20.2 ± 18.3aA	0.2 ± 0.1aA	0.5 ± 0.3aA	1.3 ± 1.2aA	1.4 ± 1.3aA
	KAM 105	132 ± 29dA	135 ±4.3eA	15.2 ± 12.3aA	15.5 ± 12.7aA	0.4 ± 0.3aA	0.6 ± 0.5aA	1.0 ± 0.9aA	1.0 ± 0.8aA
	KAM 106	151 ±12bcA	133 ±3.6fA	13.5 ± 12.9aA	14.9 ± 11.1aA	0.4 ± 0.3aA	0.4 ± 0.3aA	1.1 ± 0.8aA	1.2 ± 1.0aA
	KAM 115	153 ± 14bcA	148 ±2.3cA	11.2 ± 8.9aA	15.4 ± 13aA	0.3 ± 0.1aA	0.3 ± 0.1aA	0.9 ± 0.7aA	0.9 ± 0.8aA
	P-value	*<0.001*	*<0.001*	*0.977*	*0.940*	*0.615*	*0.189*	*0.705*	*0.799*

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

Table 3. Mean (±SE) amaranth variety grain yield (kg/ha) under chemical spray and control (unsprayed) plots

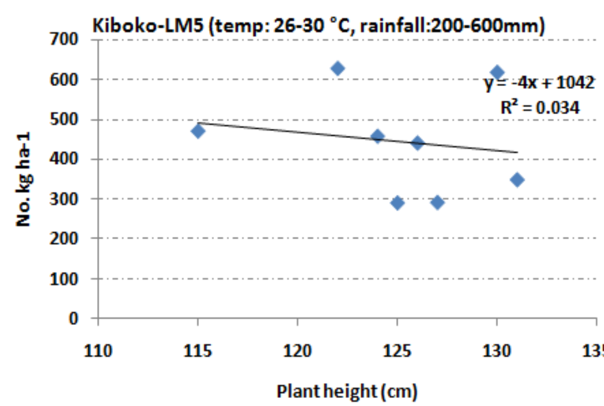
Site	Variety	Unsprayed: t ha^{-1}	Sprayed: t ha^{-1}	*F (df), p*
Kiboko (LM5)	KAM 201	238.4 ± 24.9abB	628.1 ± 33.5aA	*6231.2 (1,3), 0.001*
	Kisii Brown	237.1 ± 22.4abB	292.9 ± 18.3cA	*553.9 (1,3), 0.008*
	KSC	155.3 ± 24.5dB	291.7 ± 11.2cA	*1577.8 (1,3), 0.006*
	Kisii White	210.5 ± 21.9bcB	618.9 ± 91.5aA	*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 ± 13.3c	441.2 ± 45.2b	*244.3 (1,3), 0.044*
	KAM 115	264.3 ± 34.5a	349.1 ± 47.1bc	*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.

unsprayed plots at harvest (Table 2). Kisii Brown led with 129cm plant height at Kiboko while at Katumani it had 167cm, 30% increase on the unsprayed plots as shown in Table 2. Positive spray effect was only realized on three varieties as their plant height increased with 14, 9 and 34% for KAM 201, Kisii White and KAM 106 respectively. Tunnel length was not significantly (P>0.05) different among most varieties at the two different agro-ecological zone sites and between unsprayed and sprayed plots. The highest beetle tunnel lengths were recorded at Kiboko on varieties KAM 201, KSC and KAM 114 at 27.7, 28.0 and 28.9cm respectively on unsprayed plots. Close similar tunnel length damage levels were realized on the sprayed plots at Kiboko. At Katumani highest tunnel lengths were on variety KSC, KAM 114 and KAM 105 at 18.1, 16.0 and 15.2cm lengths, respectively (Table 2). The stem damage values at Kiboko were higher at 28.0, 28.9 and 27.8cm per plant stem for the same KSC, KAM 114 and KAM 105 respectively. These lengths represented 53, 80 and 82% higher stem damage at Kiboko than Katumani on the three varieties of KSC, KAM 114 and KAM 105. While stem exit holes appeared similar at both sites for both insecticide sprayed and unsprayed plots, variety KSC had the highest adult pigweed beetle survival at 9.9/ stem while all other varieties scored less than 3 beetles per plant stem.

Yield response

On unsprayed plots, variety yield tonnage / ha was significantly (P<0.001) different among the varieties at the two sites. Highest yield was recorded at Katumani on variety Kisii White (1,524.8 kg /ha) followed by Kisii Brown (1,323.3 kg/ha) as shown on Table 3. The least yield was on variety KAM 114 of 808.7 kg /ha at the same site. At the drier Kiboko, the highest yield was on variety KAM 201 with 238.4 kg /ha closely similar to Kisii Brown yield (237.1 kg/ha). All varieties at Katumani site had>100% yield increase in comparison to Kiboko site. Some varieties recorded over 400% (Kisii White, Kisii Brown, KAM 201 and KSC) grain yield increase. On the insecticide treated plots at Katumani, Kisii Brown variety had highest yield at 2,113 kg /ha with KSC recording 1,735 kg /ha as the second highest (Table 3). 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 at both sites on on control and insecticide treated plots. The cooler zone had 5-9 times higher yield than the hot and drier zone irrespective of treatment. The insecticide application effected significant (P<0.05) yield increase at Kiboko of between 23% (Kisii Brown) to 163% (KAM 201) but did not bring similar increase at Katumani plots as shown in Table 3. Plant height at Katumani was positively corrected to yield and less so at Kiboko (Fig. 4). Stem damage (tunnel length) was inversely correlated to yield increase as shown on Figure 5.



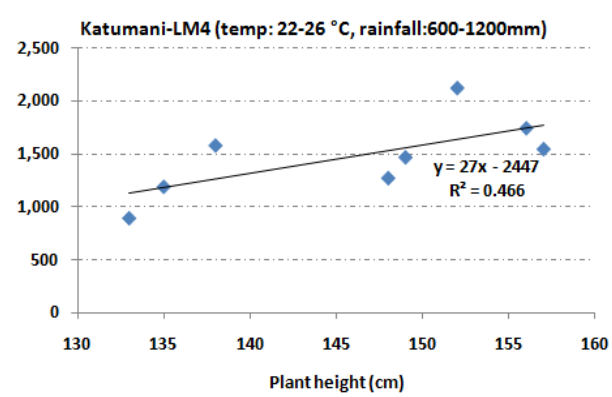


Fig. 4. Relationship between plant height and yield in kg ha^{-1} at sites of (A) Kiboko and (B) Katumani of low midlands zones

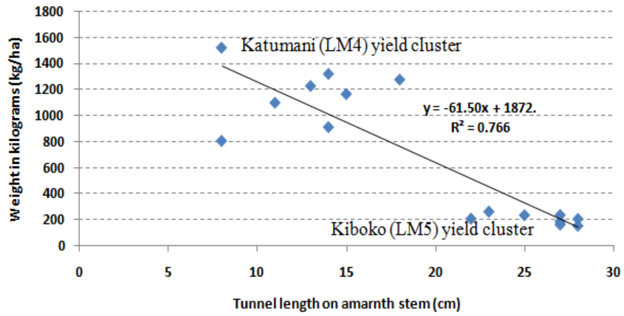


Fig. 5. Relationship between amaranth stem tunnel length (cm) and yield at Katumani (LM4) and Kiboko (LM5)

At Katumani low stem damage led to higher yield than at Kiboko plots. Grain yield (dependent variable) was influenced by other environmental factors (independent variables) besides stem damage level as Figure 4 shows at the two sites.

DISCUSSION

Pest foliar damage of the grain amaranth was found to have no significant effect to the yield as in maize stem borers (Kfir *et al*., 2002; Beyene *et al*., 2011). The drier and hotter zone at Kiboko (LM5) had lesser foliar damage of bollworms and leaf miners than the cooler zone at Katumani (LM4). The indication was that foliar damage of bollworm and leaf miner pests on grain amaranth did not appear to reduce yield loss at Katumani. The spray of pyrethroid-organophosphate insecticide reduced plant stress and led to significant ($p<0.05$) height gain on the different varieties at Kiboko but less same effect at Katumani. There was no significant reduction of *H. haerens* beetle development at the two sites among varieties even where insecticide spray was used. Higher beetle density was recorded at the drier Kiboko than 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, good for higher grain yield as found in other related studies (Gimplinger, *et al*., 2007). Bautista *et al* (1997) has described a dipteran borer pest on grain amaranth in South America with close symptoms as *H. haerens*. Oliveira *et al* (2012) recently 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 at the two sites.

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 at the cooler/wetter zone (LM4-Katumani) than the hotter/drier LM5 (Kiboko) on almost all the varieties. Kunyanga *et al* (2012) detailed amaranth ecological requirement for optimum production as medium soil fertility and rainfall amount of >100 mm per production season and medium pH level of 4.5-6.5. The present work has shown yield increase to over 400% with increase of monthly rainfall amount change from 43.7mm to 57.1mm in a higher altitude. The environmental effect to both plant development and yield was found a strong determinant to final effect of pests. Beetle stem tunnel length was found inversely correlated to yield as in maize (Beyene *et al*., 2011). Further, a parallel comparable similarity damage traits of two different orders of insects; Lepidopteran and Coleoteran, respectively comes to the fore. As determined on maize recently, the tunnel length on the plant stem is the criteria for resistance on a crop variety (Bautista *et al*., 1997; ButrÓn *et al*., 2014). All the evaluated eight amaranth varieties did not indicate resistance to *H. haerens* as they displayed high similar stem damage indicted by long tunnel lengths. Higher stem tunnel length led to lower yield tonnage on all varieties, as found in other studies (De Oliveira, *et al*., 2012). There was significant difference on tunnel length on 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 effective in controlling *H. haerens* on grain amaranth. Being a contact insecticide no significant control was achieved on stem tunneling *H. haerens* as the beetle could lay its eggs between the one month or so period of spray application. One of the factors found to lead to high stem damage by *H. haerens* 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). Nevertheless, the timing of spray could have been done every 7-14 days but not at one month interval as farmers' were directed by agro-chemical dealers, with a systemic insecticide to protect amaranth crop from pests.

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