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Full Length Research Paper

Responses of tropical maize landraces to damage by *Chilo partellus* stem borer

Munyiri S. W.[1,2], Mugo S. N.[3]*, Otim M.[4], Tefera T.[2], Beyene Y.[2], Mwololo J. K.[1,5] and Okori P.[1]

[1]Makerere University, P. O. Box 7062, Kampala, Uganda.
[2]Chuka University College, P. O. Box 109-60400, Chuka, Kenya.
[3]International Maize and Wheat Improvement Center (CIMMYT), P. O. Box 1041-00621, Nairobi, Kenya.
[4]National Crops Resources Research Institute (NaCRRI), P. O. Box 7084, Kampala, Uganda.
[5]Pwani University College, P. O. Box 195-80108, Kilifi, Kenya.

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The potential to manage insect pests using host-plant resistance exists, but has not been exploited adequately. The objective of this study was to determine the resistance of 75 tropical maize landraces through artificial infestation with *Chilo partellus* Swinhoe. The trial was laid in alpha-lattice design and each seedling was infested with five neonates three weeks after planting, over two seasons in 2009 and 2010. The number of exit holes, tunnel length, ear diameter, ear length, plant height, stem diameter, stem lodging and grain yield were measured and a selection index computed. GUAT 1050 was the most resistant with an index of 0.56, while BRAZ 2179 was the most susceptible with an index of 1.66. Ear characteristics were negatively correlated with damage parameters. The principal component biplot suggested that exit holes, cumulative tunnel length, leaf damage, cob diameter, stem lodging, selection index, ear and plant height contributed 71.2% of the variation in resistance. The mean number of exit holes and tunnel length for resistant landraces and resistant hybrid checks were similar; at 5.5 and 2.48 cm, respectively. The identified resistant landraces (GUAT 1050, GUAT 280, GUAT 1093, GUAT 1082, GUAT 1014, CHIS 114, and GUAN 34) could be used to develop *C. partellus* stem borer-resistant maize genotypes.

Key words: C*hilo partellus*, ear length, exit holes, stem borer resistance, tunnel length.

INTRODUCTION

In sub-Saharan Africa, maize is a staple food crop for about 50% of the population and serves as a source of carbohydrate, protein and minerals (Ogunniyi, 2011). It is the most important cereal crop in eastern and southern Africa and the staple food in Kenya, where per capita annual consumption is in excess of 100 kg (Pingali and Pandey, 2001). The lepidopteran stem borers in Kenya cause losses of maize of 13.5%, thus contributing to increased malnutrition and poverty (De Groote, 2002). Stem borers destroy maize leaves, stem, ear and cob, leading to a reduction in grain quantity and quality.

*Corresponding author. E-mail: s.mugo@cgiar.org. Tel: +254 733720297.

Amongst stem borer insect-pest species, *Chilo partellus* Swinhoe (Lepidoptera: Crambidae) is the most widely distributed and most damaging maize-field pest in Kenya. Though the African stem borer *Busseola fusca* Fuller (Lepidoptera: Noctuidae) is the indigenous species in Africa, *C. partellus* has continued to expand its distribution from the warm, low, to the mid-altitude and the moist, transitional agro-ecological zones of Kenya since its appearance in Africa in 1932 (Mbapila et al., 2002). Host plant resistance (HPR) is a practical way to overcome the stem borer constraint in maize production among smallholder resource-poor farmers (Afzal et al., 2009). Host plant resistance in most plants is manifested as non-preference or antixenosis, which negatively affects the feeding or oviposition behavior of the pest. Antibiosis denotes adverse effects on the pest due to plant chemical composition, while tolerance is where the plant grows and reproduces in spite of infestation and/or damage (Painter, 1951). These factors contribute to impaired feeding or oviposition, or contribute to the action of other mortality factors that hinder increase in insect population (Kumar, 1997). Morphological traits are important in conferring HPR and are responsible for the suitability of a cultivar for feeding by the insect, oviposition and development. In many crop species, the degree of a genotype's resistance to insect pests is associated with the plant's morphological characteristics (Afzal et al., 2009). Antixenosis and/or antibiosis for leaf feeding, tunneling, and number of exit holes results in resistance to *C. partellus* damage (Singh et al., 2011). Grain yield in maize is a product of several plant traits. The stem borer may directly or indirectly attack and affect the development of the maize plant and thus affect grain yield. Borer damage has been reported to affect plant growth and specifically ear development, and this impact negatively on grain yield (Afzal et al., 2009). The number of exit holes is an indicator of the number of borers that have successfully completed the life cycle within a stem, while the stem tunnels indicate the extent of plant damage. Landraces are important for crop genetic-resource conservation and for sustainable agricultural development. They are a reservoir of genes with potential for maize improvement that needs to be exploited (Pressoir and Berthaud, 2004). An understanding of the effects of *C. partellus* damage on the ear morphological characteristics, plant height, stem lodging, stem diameter and grain yield could add information on the selection process in maize landraces. This study aimed at identifying new sources of resistance to *C. partellus* from among CIMMYT gene bank maize-landrace accessions.

MATERIALS AND METHODS

Site description

The experiments were conducted at the Kenya Agricultural Research Institute (KARI) Kiboko Farm in mid-altitude, dry agro-ecological zone of Kenya. Kiboko lies at 950 m above sea level, 37.75E, and 2.15S and receives about 530 mm of rainfall per annum that falls in two short rainy seasons. Kiboko's maximum daily temperature is 35.1°C with a minimum of 14.3°C. The soils are sandy clays.

Germplasm and field experimental set up

Sixty-nine (69) white endosperm CIMMYT gene-bank accessions previously evaluated for drought tolerance, and six insect-resistant CIMMYT hybrid checks were grown in a 15 x 5 α-lattice experimental design, on two-row plots replicated three times, for two seasons in 2009 and 2010. These landraces represent some Caribbean gene bank accessions collected from *P. truncatus* endemic areas of Latin America stored in CIMMYT maize germplasm bank (Kumar, 2002). Each entry was planted in two rows of 5 m spaced at 75 cm and 25 cm between and within rows, respectively. Planting, weeding, harvesting and shelling operations were performed manually. Each plot was divided into two parts; one section for 10 stem borer-infested plants, while the remaining portion consisted of 28 plants protected from borer damage by applying insecticide (Bulldock® 25 EC = 25 g/l Beta-Cyfluthrin – AI). Ten plants per plot (five plants per row) were infested with five *C. partellus* first-instar neonates three weeks after planting. The crop was grown under rain-fed conditions but supplemental irrigation was applied as needed. Fertilizers were applied at the rate of 60 kg/ha N and 102 kg/ha P_2O_5 at planting. The crop was top-dressed at the rate of 48 kg N/ha 30 days after planting.

Data collection

Data was taken on leaf-damage visual-rating score two weeks after infestation on a scale of 1 to 9 on an individual plant basis, where 1 = no visible leaf damage and 9 = plants dying as a result of leaf damage (Tefera et al., 2011). At harvest, the numbers of stem exit holes were counted and the cumulative tunnel length (cm) was measured after splitting the stems. Ear diameter (ear with grains), cob diameter (cob without grains) and ear length (cm) taken from the fully-developed grain at the base to the last tip grain were measured. Plant height (cm) was taken during mid grain-filling stage as the distance from the soil level to the base of the flag leaf. Stem diameter (cm) was measured on the internode below the top or primary ear, and root and stem lodging counts were done at harvesting. Grain yield (t/ha) was computed from shelled grain weight and standardized to 12.5% moisture content.

Data analysis stat

Data was analyzed using PROC GLM of SAS 2003 package. Analysis of variance was done and the means were separated using LSD at P < 0.05. Genotypes were considered as fixed effects. Pearson's correlation coefficients were computed from among the stem borer-damage parameters and other parameters measured. A selection index based on leaf damage score, number of borer exit holes and cumulative tunnel length was computed by summing up the ratios between values and overall mean and dividing by the number of parameters evaluated. Germplasm with selection-index values less than 0.8 were regarded as resistant, and those with a selection index greater than 0.8 as susceptible (Tefera et al., 2011). Variable association was further explored through multivariate analysis using Genstat software. Principal component analysis (PCA) biplot which reduces multiple testing in the association analyses by summarizing the variables over the various entries and by combining correlated traits into single PCA indices was generated using the genotype means (Dudley and Lambert, 2004). Variable association was further explored through multivariate analysis using Genstat software. Principal component analysis (PCA) biplot reduces multiple testing in the association analyses by summarizing the variables over the various entries and by combining correlated traits that was generated into single PCA indexes.

RESULTS

Grain yield and ear characteristics

There were significant differences (P<0.0001) in grain yield among the (Table 1). Grain yields under infestation ranged from 2.72 t/ha in GUAN 28 which was susceptible to 8.40 t/ha in GUAT 1100 which was moderately resistant (data not shown). Lesser grain-yield variations

Table 1. Means for maize resistant checks to *Chilo partellus*, and resistant and susceptible landraces evaluated in the two seasons in 2009 and 2010.

Category	Genotype	Index	EH	TL	LD	ED	CD	EL	GY	PH
Resistant	GUAT 1050	0.6	3.9	16.5	2.4	3.8	2.5	9.7	4.7	174.1
Landraces	GUAT 280	0.8	5.2	23.2	2.5	3.8	2.2	10.4	5.4	192.7
	GUAT 1093	0.7	5.3	22.1	2.5	3.6	2.1	13.8	6.7	223.3
	CHIS 114	0.6	5.5	24.1	2.5	4.2	2.6	12.4	5.1	227.5
	GUAT 1082	0.7	6.0	31.2	1.4	3.8	2.4	11.5	6.6	209.4
	GUAT 1014	0.7	6.5	23.1	2.6	4.3	2.4	14.1	7.4	241.4
	GUAN 34	0.6	6.7	22.3	2.0	3.6	2.3	10.4	3.6	214.0
	CAQU 321	0.6	4.0	24.3	2.3	3.9	2.2	12.1	4.4	207.8
	GUAT 1034	0.8	6.2	31.2	1.8	4.0	2.5	10.9	3.0	185.3
	GUAT 1038	0.8	6.1	30.0	2.0	4.1	2.4	12.3	6.1	208.8
Mean		0.7	5.5	24.8	2.2	3.9	2.4	11.8	5.3	208.4
Resistant	CKIR07013	0.7	4.7	19.6	2.0	4.9	3.0	15.6	9.3	229.7
Hybrid check	CKIR06009	0.7	4.4	20.4	1.6	4.7	2.7	13.6	7.9	194.1
	CKIR07001	0.7	5.8	24.5	1.9	4.6	2.8	14.7	8.8	223.8
	CKPH09001	0.8	6.7	35.3	2.1	4.4	2.7	16.6	7.1	222.8
	CKPH08032	0.6	5.9	24.3	2.2	4.6	2.8	15.8	8.5	225.0
Mean		0.7	5.5	24.8	2.0	4.6	2.8	15.3	8.3	219.1
Susceptible	BRAZ 2179	1.7	11.5	52.7	2.3	4.2	2.6	11.0	3.7	271.7
Landraces	VENE 897	1.5	10.4	45.3	2.9	4.3	2.5	14.3	6.5	257.6
	BRAZ 1384	1.4	13.1	63.8	2.5	4.6	2.6	9.2	4.7	247.4
	NAYA 129	1.4	11.9	68.5	2.3	4.1	2.5	14.5	4.6	232.1
	VENE 414	1.4	50.2	11.2	2.6	4.3	3.4	11.0	5.4	329.3
	BRAZ 1346	1.3	10.9	48.4	2.1	3.9	2.2	14.0	4.6	235.8
	BRAZ 1371	1.3	48.5	9.7	2.2	4.7	2.8	12.1	5.9	247.7
	PARA GP3	1.3	40.1	8.1	2.2	4.0	2.2	13.2	5.0	189.1
	BRAZ 4	1.3	68.5	10.9	2.3	3.6	2.1	12.2	3.9	271.7
	BRAZ 222	1.3	58.6	11.8	2.1	4.8	2.6	14.5	7.2	250.3
Mean		1.4	32.4	33.1	2.4	4.3	2.6	12.6	5.2	253.3
Overall Trial Mean			9.0	43.1	2.5	4.2	2.5	13.2	5.6	237.7
CV			24.4	27.4	23.8	5.6	9.5	11.3	45.2	9.8
Pr > Value			<.0001	<.0001	0.3	<.0001	<.0001	<.0001	<.0001	<.0001
LSD (0.05)			3.6	19.1	0.7	0.4	0.4	2.4	3	37.7

EH, Number of exit holes; TL, cumulative tunnel length in cm; ED, ear diameter in cm; CD, cob diameter in cm; EL, ear length in cm; GY, grain yield in t/ha; PH, plant height in cm.

were observed in the hybrid checks (not all were resistant to stem borers) ranging from 7.08 t/ha in CKPH09001 to 9.33 t/ha in CKIR07013 which was the highest yielding check in both seasons. The landraces' mean yield was 5.29 t/ha compared to the hybrid checks' mean yield of 8.32 t/ha (Table 3). The higher and stable yield potential recorded in the hybrid checks was expected, as these were elite cultivars carrying the benefits of hybrid vigor and better adaptations due to advances in breeding. These tropical landraces could however be superior sources of resistance to *C. partellus.* Ear morphological characteristics were negatively correlated with damage parameters (leaf damage, stem exit holes and cumulative tunnel length), and positively and significantly correlated with grain yield even though the correlation coefficients were low (Table 2).

The PCA-1 which explained 71.21% of the variation in the biplot further indicated that grain yield was most closely related to ear length, stem diameter and ear diameter in that order. The most stable of these parameters in explaining yield were ear diameter and stem diameter, though there were variations in their contributions to yield (Figure 1). Grain yield was positively and significantly correlated with ear diameter (r=0.401***), cob diameter (r=0.249**) and ear length (r=0.446***) (Table 2). Among the ear traits measured, ear length contributed most to grain yield, probably through improved kernel number and kernel weight under

Table 2. Pearson's correlation coefficient (r) for damage parameters and ear characteristics among tropical maize landraces.

	LD	EH	TL	PH	EH	SL	GY	ED	CD
EH	0.256***								
TL	0.177**	0.759***							
PH	-0.009ns	0.272***	0.393***						
EH	0.013ns	0.302***	0.374***	0.773***					
SL	0.189**	0.157**	0.125ns	-0.038ns	0.051ns				
GY	-0.169**	-0.156**	-0.139**	0.072ns	0.024ns	0.217**			
ED	-0.149**	0.033ns	-0.012ns	0.206**	0.147**	0.053ns	0.401***		
CD	-0.069ns	-0.022ns	-0.031ns	0.330***	0.127ns	0.029ns	0.249**	0.551***	
EL	-0.258***	-0.005**	0.018ns	0.220**	0.242**	0.153**	0.446***	0.312***	0.062ns

*Significant at 10%; ** significant at 5%; *** significant at 1%, ns; not significant. LD, Leaf damage; EH, number of exit holes; TL, tunnel length in cm; PH, plant height in cm; EH, ear height in cm; SL, number of stems lodged; GY, grain yield in t/ha; ED, ear diameter in cm; CD, cob diameter in cm; EL, ear length in cm.

Table 3. Analysis of variance for stem borer damage evaluation traits.

Parameter		**Leaf damage**		**Exit holes**		**Tunnel length**		**Grain yield**		**Root-Stem lodging**	
Source	DF	F-value	Pr.>F	F-value	Pr.>F	F-value	Pr.>F	F-value	Pr.>F	F-value	Pr.>F
Genotype	74	1.1	0.29	2.99	0.0001	3.39	0.0001	1.94	0.0001	1.17	0.22
Season	1	191.97	0.0001	35.16	0.0001	342.94	0.0001	2.91	0.89	94.55	0.0001
Entry*Season	74	1.06	0.35	1.66	0.0021	2.11	0.0001	1.1	0.29	1.16	0.19

borer infestation.

Stem borer exit holes and cumulative tunneling length

The landraces showed significant differences ($P < 0.0001$) for borer-damage traits that is stem borer exit holes and cumulative tunneling length (Table 1). The overall trial means for damage parameters were 9.0 for exit holes and 43.1 cm for tunnel length. The 10 most resistant landraces based on the selection index had exit holes mean of 5.5 and tunnel length mean of 24.8 cm, the same as the hybrid checks. Ten landraces were resistant, with a selection index of between 0.56 and 0.81.Thirty eight (38) of the landraces were, however, susceptible with a damage-selection index between 1.00 and 1.67, and 22 landraces were moderately susceptible with a selection index of 0.81 to 0.99. The most resistant landrace was GUAT 1050 with 3.87 exit holes and 16.54 cm tunnel length, while the most susceptible landrace was BRAZ 2179 with 11.51 exit holes and 52.68 cm tunnel length. The most resistant check was the stem borer-resistant hybrid CKIR06009 with 1.6 holes and 4.37 cm tunnel length, while the most susceptible check was the post-harvest pest-resistant hybrid CKPH09001 with 6.9 exit holes and 35.6 cm tunnel length.

Tunnel length, however, increased with increasing exit holes and so did the susceptibility index, an indication that the two parameters are related. Stem lodging increased with increasing plant height and tunnel length. Reduced tunneling resulted in lower damage to *C. partellus* in the

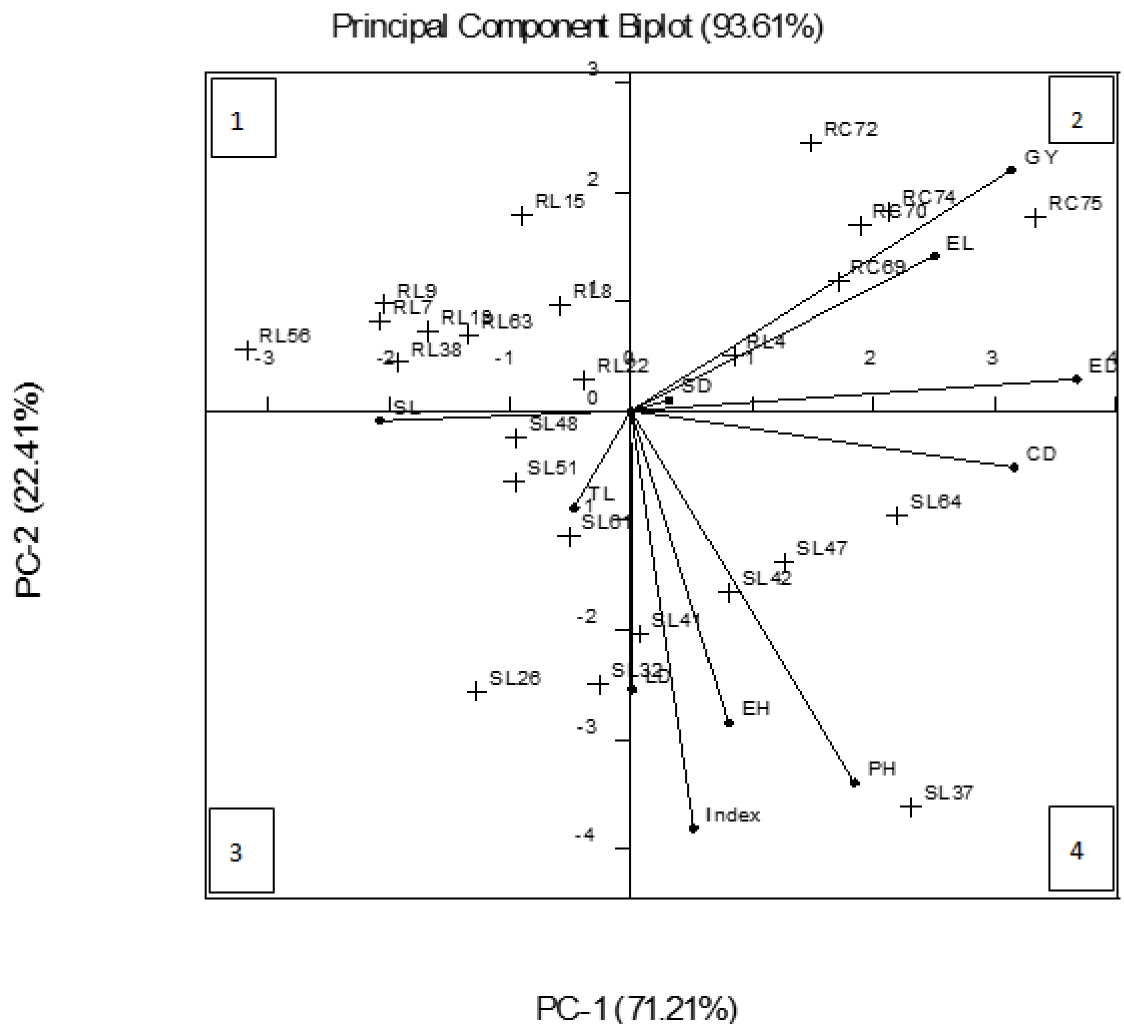

Figure 1. Principal component analysis biplot for variables measured and resistance categories. GL, Grain yield; EL, ear length; ED, ear diameter; CD, cob diameter; PH, plant height; EH, exit holes; TL, tunnel length; SL, stem lodging; RL, resistant landraces; RC, resistant checks; SL, susceptible landraces.

resistant landraces. The mean selection index for the resistant landraces was 0.70, which was almost as low as that of the resistant hybrid checks (0.69). Most of the GUAT accessions exhibited resistance, while most BRAZ accessions were susceptible. GUAT accessions were mostly early maturing and shorter in height, while BRAZ accessions were taller and late maturing, probably allowing stem borers more time for stem feeding and thus increasing tunneling.

Principal component biplot

The principal component analysis biplot explained 93.61% of the variation in resistance and grouped the damage parameters, the resistant germplasm and the yield components into different categories (quadrants). All resistant landraces were grouped in quadrant one (1) while the hybrid checks were grouped in quadrant two (2) next to grain yield, ear length, stem diameter, and ear diameter, which could be an indication of the contribution of these traits to the yield of these hybrid checks (marked RC in Figure 1). Tunnel length, stem lodging, leaf damage, exit holes, plant height and selection index were grouped as indicators of susceptibility in the landraces in quadrants three (3) and four (4), though there were variations among these parameter's contribution to damage.

The leaf damage trait was right between the two susceptible germplasm quadrants, a strong suggestion as to its contribution to susceptibility, but the long distance from the origin of the two axes indicated its instability as a resistance measure. This interpretation is based on observations made by Naveed et al. (2007) who reported that displacement of cotton genotypes along the coordinates showed differences in interaction effects.

Correlation between traits

Leaf damage, number of exit holes and tunnel length were all positively correlated with each other though some of the correlations were low (r=0.256***, r=0.177**, r=0.759***, respectively) (Table 2). The highest correlation coefficient was between the number of exit holes and tunnel length (r = 0.759***). Leaf damage, number of exit holes and tunnel length were all negatively and significantly correlated with grain yield (r=-0.169**, r=-0.156**, r=0.-139**, respectively). The high correlation between stem exit holes and tunnel length could be an indication of the interrelatedness between the two parameters, and the possibility of the use of either of the two to measure resistance in maize to *C. partellus*. Tunnel length was also significantly and positively correlated with plant height and ear height (r=0.393***, r=0.374***, respectively), suggesting that the taller the genotype, the greater the stem damage, probably because there was a prolonged feeding period before the maize reached maturity. There were some highly significant correlations among ear traits. Ear length was correlated with ear diameter (r=0.312***) and cob diameter with ear diameter (r=0.551***), while cob diameter was not significantly correlated with ear length.

DISCUSSION

Leaf damage scores were not significantly different. This was unexpected and could have been an indication of the unreliability of using leaf damage to measure resistance to stem borers in maize. In contrast, Singh et al. (2011) had reported that reduced leaf feeding resulted in lower damage by *C. partellus*. Exit holes and tunnel lengths were highly significant and more reliable in expressing resistance.

In the PCA biplot, tunnel length and stem lodging were nearest to the axes and origin, and thus were more stable in expressing resistance than the other parameters, however, tunnel length was the most stable of the two (Figure 1). This suggested that the two parameters could be used as stem borer damage-measurement parameters. Tunnel feeding reduces stem strength and predisposes the plant to stem lodging, breakage and ear drop, further compounding the yield losses. Stem lodging contributes to reduced maize grain yield through reduced photosynthetic area in the canopy and destruction of vascular bundles. According to Afzal (2009), the most damage in maize from stem borers was from stem tunneling which lowered plant growth and reduced potential yield through interruption of the flow of second generation moths, thus increasing their susceptibility in comparison with early maturing genotypes.

Among the ear characteristics measured, ear length contributed most to grain yield. Khayatnezhad et al. (2010) observed that ear length was the most important ear aspect in the determination of grain yield in maize. Nemati et al. (2009) reported that increased ear length highly influenced grain yield through increased number of kernels and kernel weight. The recorded highly positive and significant correlation between ear length and grain yield could be attributed to the effect of the ear on grain yield through increased grain number, size and weight. However, yield is affected by many other factors within and outside the plant environment including the genotype, the environment, genotype x environment interactions, and management.

Grain yield was negatively correlated with stem tunneling; the longer the tunnels were, the lower the yield. Stem tunneling disrupts nutrients- and water uptake resulting in grain-yield penalties in susceptible germplasm. Kumar (1988) found that stem-tunneling damage had a significant influence on maize plant growth. Odiyi (2007) and Singh et al. (2011) observed that the direct effect of stem tunneling on loss in maize grain yield was greater than the effect of leaf feeding. Leaf damage score was low throughout the trial and may not have appreciably affected photosynthesis and hence lowered grain yield. Better yields in resistant genotypes may be attributed to lower stem-tunneling damage and less disruption to water- and nutrient uptake, leading to bigger ears.

Conclusions

Resistant landraces were identified among the CIMMYT tropical gene-bank accessions evaluated. The resistance of these landraces was comparable to that of the resistant hybrid checks. Among the resistant landraces, GUAT accessions were the most resistant (GUAT 1050, GUAT 280, GUAT 1093, GUAT 1082, GUAT 1014, CHIS 114, GUAN 34). Ear length, ear diameter and stem diameter were the traits that had most influence on grain yield. Stem tunneling and the numbers of borer exit holes were better indicators of resistance to *C. partellus* damage than was leaf damage. The resistant landraces identified could be used to develop *C. partellus*-resistant maize genotypes for tropical regions, or improved for yield and stability of other favorable traits.

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