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Full Length Research Paper

Assessment of the response of tropical maize inbred lines in resistance to *B. fusca* and *C. partellusin* Eastern Africa.

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Stem borers, *Busseola fusca* (Fuller) Noctuidae*, Lepidoptera* and *Chilo partellus* (Swinhoe) Pyralidae*, Lepidoptera*, are serious insect pests of maize. However, genotypes showing exclusive resistance to each of these borers and with resistance to both species have not been identified in Kenya. The objective of this study was to evaluate tropical maize inbred lines for resistance to the two species. 112 maize inbred lines were artificially infested with the stem borers at three sites in Kenya. Each row of each line received three different treatments in different parts, namely infestation with *B. fusca* larvae, infestation with *C. partellus* larvae, and protection with beta 25 g/L cyfluthrin pesticide*.* Data was collected on leaf feeding damage rating, cumulative stem tunnel length, number of exit holes, number of dead-hearts, stalk strength and selected agronomic traits. There were significant differences among the test genotypes, (p<0.01) for resistance to *B. fusca* and *C. partellus,* for all the traits measured. The results also showed that most of the test genotypes were susceptible to *B. fusca* and less so to *C. partellus*. Twenty one (21) lines showed resistance to both *B. fusca and C. partellus* in at least two sites, and only four lines showed resistance to both species across the locations. Among all the test genotypes, 26 lines showed resistance to *C. partellus* only, while five entries had resistance to *B. fusca* only*.* Furthermore, 84 and 28 entries showed susceptibility to *B. fusca* and *C. partellus,* respectively. The others were categorized as either moderately resistant or moderately susceptible to either species. The identified inbred lines variously resistant to *B. fusca* and *C. partellus* may be used as parents in hybrid breeding programmes that emphasize stem borer resistance or as sources of resistance in breeding programs.

Key words: *Busseola fusca*, *Chilo partellus*, combined resistance, tropical maize inbred lines.

INTRODUCTION

New maize varieties with tolerance to biotic and abiotic stresses and with better agronomic traits have been developed in Africa maize breeding programs. The spotted stem borer (*Chilo partellus* Swinhoe) Pyralidae and African stem borer (*Busseola fusca* Fuller)Noctuidae*,* Lepidoptera are among the most damaging insect pests that greatly reduce maize grain yield in east African environments (Citation). Tropical environments are favourable for insect development and lead to the formation of several generations of the pests in the same

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*Corresponding Author. Email: odin.richard@hotmail.com season leading to severe crop yield losses (Mailafiya et al., 2011). For example, in Kenya, grain yield loss due to stem borers in maize is estimated annually at about 400,000 metric tons or about $72 million (De Groote et al., 2003; De Groote et al., 2005). This amount represents an average of 13.5% of the farmers' total annual harvest of maize.

There is, however, limited germplasm with resistance to these pests in most maize breeding programs. There are seldom those identified with combined resistance to both insect pests if they occur. Several options for managing maize stem borers have potential to mitigate their damaging effects, but each option has its own limitations. Host plant resistance forms an important part of integrated pest management as it provides inherent control without environmental issues and is compatible with other pest management approaches (Singh et al., 2012). Effective breeding methods for resistance to borer damage could, therefore, be designed by plant breeders using both improved and new sources of stem borer resistance.

Development of effective methods requires a better understanding of the genetic basis of the resistances among the germplasm used. Suitable maize germplasm should have resistance to both *B. fusca* and *C. partellus*. Recent reports indicate that climate change has led to *C. partellus* increasingly displacing *B. fusca* from the high altitude areas in Kenya (Mailafiya et al., 2011; Tefera et al., 2011; Mwimali et al., 2015). Furthermore, farmers exchange maize germplasm across agro-ecologies, therefore, the need to investigate the reaction of these tropical maize inbred lines for resistance to these borers becomes paramount. The aim of this study was to evaluate the responses of tropical maize inbred lines for resistance to *B. fusca* and *C. partellus* the two major stem borer species in Eastern Africa.

MATERIALS AND METHODS

Germplasm

One hundred and twelve (112) maize inbred lines used in the study were sourced from the International Maize and Wheat Improvement Center (CIMMYT), Mexico and the Kenya Agricultural and Livestock Research Organization (KALRO) breeding programmes (Table 1). Two elite, but stem borer resistant and susceptible maize lines from CIMMYT and KALRO were included as checks. The lines were developed from the CIMMYT multiple borer resistance (MBR) population. The MBR population was developed through a recurrent selection method under artificial infestation with southern corn borer (SWCB), sugarcane borer (SCB) *Diatrae sacharalis*, European corn borer (ECB) *Ostrinia nubilalis*, and fall armyworm (FAW) *Spodoptera* species in various locations globally (Smith et al., 1989).

Testing locations

Experiments were established at KALRO Kakamega, KALRO Kiboko, and KALRO Embu sites in Kenya. KALRO Kakamega (37°75'E 2° 15'S, 1585 m asl) centre is located in the moist transitional mid altitude agro-ecological zone of Western Kenya and experiences mean annual temperatures of 25°C. Kakamega lies within a high potential agro-ecological zone and receives a bimodal mean annual rainfall of approximately 1850 to 1916 mm. The soils in Kakamega are well drained, moderately deep to very deep, red to dark in colour and in some places shallow over petroplinthite (Jaetzold and Schmidt, 1982).

KALRO-Kiboko (2°15'S 37°75' E, 975 m asl) is located in the dry mid altitude agro-ecological zone of Eastern Kenya and experiences mean annual temperature ranges of 28 to 37°C, with February and October being the hottest months. Kiboko receives a mean annual rainfall of approximately 530 mm. The soils are well drained, Fluvisols, Ferralsols, and Luvisols with soil pH of about 7.9 (Jaetzold and Schmidt, 1982; KARI Land Resources and Analytical Services, 2007).

KALRO-Embu centre (03°56' 44'S and 39°46' 00'E, 1510 m asl) is located in the moist transitional mid altitude agro-ecological zone of eastern slopes of Mt. Kenya and experiences mean annual temperature ranges of 14 to 25°C. Embu lies within a high potential agro-ecological zone. Rainfall received is bi-modal ranging between 800 and 1400 mm annually. The soils are deep (about 2 m); well weathered Humic Nitisols with moderate to high inherent fertility (Jaetzold and Schmidt,1982).

Experimental design and treatments

The maize inbred lines were evaluated in a 28 × 4 α-lattice design with three replications in each location. Each inbred line was sown to one row plot of 6.75 m each per replication. Two seeds were sown per hill and later thinned to one. Each plot consisted of one row with inter-row spacing of 0.75 m and inter-hills spacing of 0.25 m within the rows.

Fertilizers were applied to give 60 kg N and 60 kg P_2O_5 ha^{-1} as recommended for each location. Nitrogen was applied in two splits, while supplementary irrigation was applied when needed. The fields were kept free of weeds by hand weeding throughout the growth cycle.

Artificial infestation with insects

Each 6.75 m plot was divided into three parts, namely, *B. fusca* and *C. partellus* infested on either side of the plot at Embu and Kakamega, while the middle part was protected using insecticide Bulldock® (active ingredient, beta cyfluthrin 25 g/L). At Kiboko, 5 m row plots were used, and were infested with *C. partellus* on one half of the plot while the remaining part was protected using the insecticide. Insect larvae were obtained from the International Centre for Insect Physiology and Ecology (ICIPE) and the KALRO Katumani centres' stem borer insect pests mass rearing facilities (Tefera et al., 2010, 2011). Plants were artificially infested in a controlled and uniform manner with the respective stem borer species by placing 10 first instar larvae in the maize whorl using a camel brush 21 days after planting.

Table 1. Scale for scoring stem borer leaf damage from seedling to whorl-stage in maize (CIMMYT, 1989).

Numerical scores	Visual ratings of plant damage	Reaction to resistance
0	No damage	Probable escape
1	Few pin holes	Highly resistant
2	Few shot holes on a few leaves	Resistant
3	Several shot holes on leaves (<50%)	Resistant
4	Several shot holes on leaves (>50%) or small lesions (<2 cm long)	Moderately resistant
5	Elongated lesions (>2 cm long) on a few leaves	Moderately resistant
6	Elongated lesions on several leaves	Susceptible
7	Several leaves with long lesions with leaf tattering	Susceptible
8	Several leaves with long lesions with severe leaf tattering	Highly susceptible
9	Plant dying due to death of growing points (dead-hearts)	Extensively sensitive to damage

Data collection and analysis

Plants were evaluated for leaf damage scores using a scale of 1 (resistant) to 9 (susceptible) (Table 1) (CIMMYT, 1989) at the V3 stage of maize growth.

Other plant damage parameters were measured at harvest, namely, cumulative tunnel length (measured as the total length of tunneling along the maize stalk), tunnel length to plant height ratio, number of exit holes, number of dead-hearts, stalk strength, and number of larvae recovered per plant. Agronomic traits were measured following standard protocols used at CIMMYT (CIMMYT, 1989). The traits measured were number of days to anthesis and to silking, plant height (cm), ear height (cm), ear position (ratio of plant height to ear placement), number of ears harvested, stem and root lodging, grain weight (kg) and moisture content (%) at harvest, plant stand (number of plants per row at harvest), number of rotten ears, plant and ear aspect (where 1=good and uniform plants/ears with the stature, colour and strength preferred in the area, 5=ugly plants/ears with the undesirable features in the area), stem diameter (measurement across the stalk) (cm), internode length (four below the upper-most ear), and leaf damage.

A rank summation index (RSI) was constructed to determine the ranking of each line within the population for suitable response. The index was obtained by the sum of the means of each of the leaf feeding damage score, number of dead-hearts, number of exit holes, and cumulative stem tunnel length for each line, to get its mean performance when compared with other lines within the same population. An entry with the least value was ranked higher for the resistance traits. The rank selection index (Mulamba and Mock et al., 1978; Mutinda et al., 2013) was determined as follows:

$$RSI = \sum Ri\text{'s}$$

where Ri is the rank of mean of each of the desired traits. Rank summation index is the mean performance of each of the desired traits of each genotype using the ranking of leaf feeding damage score, number of dead-hearts, number of exit holes, and cumulative stem tunnel length.

Least square means for insect damage parameters and agronomic traits were calculated using plot data for each location separately. All analysis of variance using PROC GLM of SAS was performed for individual as well as for combined environments, considering environments as random effects and genotypes as fixed effects (SAS Institute Inc., 2012). Genotypic and phenotypic correlation coefficients were determined using variance-covariance matrix and estimates of genotypic and phenotypic variances (Falconer and Mackay, 1996).

Genotypic correlation was calculated as follows:

$$r_{G} = \sigma_{G\ (X,\ Y)} / \surd\ \sigma^{2}_{G(X)},\ \sigma^{2}_{G(Y)}$$

where r_G is the genetic correlation between traits X and Y, $\sigma_{G\ (X,\ Y)}$ is the genotypic covariance between trait X and Y, and $\sigma^2_{G(X)}$ is the genotypic variance of trait X and the $\sigma^2_{G(Y)}$ is the genotypic variance of trait Y.

Phenotypic correlation was calculated as follows:

$$r_{P} = \sigma_{P\ (X,\ Y)} / \surd\ \sigma^{2}_{P(X)},\ \sigma^{2}_{P(Y)}$$

where r_P is the phenotypic correlation between traits X and Y, $\sigma_{P\ (X,\ Y)}$ is the phenotypic covariance between trait X and Y, and $\sigma_{P\ (X)}$ is the genotypic variance of trait X and the $\sigma^2_{P(Y)}$ is the phenotypic variance of trait Y.

Correlation coefficients based on plant damage and some agronomic traits for *B. fusca* and *C. partellus* were also computed. In broad-sense heritability, H^2 was estimated using the following formulae:

$$H^2 = Vg/Vp,$$

where Vg is the genotypic variance, while the Vp is the phenotypic variance.

RESULTS

Mean performance of maize inbred lines

There were highly significant differences for resistance to both *B. fusca* and *C. partellus* ($p \leq 0.01$) (Tables 2 and 3). At Embu and Kakamega, significant differences were observed for leaf feeding damage ($p \leq 0.01$), number of exit holes ($p \leq 0.03$ to 0.04), and number of dead hearts ($p \leq 0.01$) for *B. fusca* and *C. partellus*, except for cumulative stem tunnel length for both sites.

At Embu and Kakamega, the genotypic variances ranged from 0.01 to 0.36 for all sites under *B. fusca* and *C. partellus* infestation (Table 3). Mean performance of entries at Embu under *B. fusca* infestation showed a wide range for dead hearts (0 to 3.05), leaf feeding damage (1 to 6.76), number of exit holes (0 to 11.40), and cumulative tunnel length (0.08 to 5.48 cm). There was a

Table 2. Mean performance of top 19 maize inbred lines for selected stem borer resistance traits under *B. fusca* infestation at Embu (averaged over two seasons).

Entry	Genotype	No. of dead hearts	No. of exit holes	Stem borer leaf Damage scores (1-9)	Cumulative tunnel length (cm)	Rank selection index	Rank
91	CKSBL10040	0.01	1.20	1.69	0.11	0.75	1
90	CKSBL10045	0.01	0.80	2.20	0.08	0.77	2
85	CKSBL10039	0.03	3.50	1.67	0.98	1.55	3
82	CKSBL10042	0.02	2.40	2.32	0.44	1.30	4
81	CKSBL10038	0.02	6.90	1.44	0.87	2.31	5
16	CKSBL10206	0.02	4.70	2.52	0.16	1.85	6
10	CKSBL10026	0.28	8.80	2.25	0.12	2.86	7
61	CKSPL10090	0.03	8.10	1.63	1.00	2.69	8
73	CKSBL10016	0.19	6.50	2.11	0.92	2.43	9
75	CKSBL10028	0.08	3.10	2.46	0.82	1.62	10
41	CKSBL10157	0.00	5.10	2.02	1.12	2.06	11
13	CKSBL10203	0.00	0.00	2.31	0.79	0.78	12
70	CKSBL10013	0.02	7.90	1.80	1.23	2.74	13
24	CKSBL10165	0.03	3.50	1.96	1.32	1.70	14
95	CML312	0.02	11.40	2.33	0.60	3.59	15
21	CKSBL10213	0.00	10.40	2.13	0.86	3.35	16
65	CKSPL10229	0.07	5.10	2.12	1.22	2.13	17
49	CKSPL10028	0.02	8.30	2.50	0.76	2.90	18
63	CKSPL10146	0.75	6.90	1.97	0.66	2.57	19
96	CML395 (sus. check)	3.05	8.71	6.76	5.48	6.00	92
	Genotype variance	0.01	0.05	0.18	0.22	-	-
	Residual variance	0.06	0.31	0.39	3.06	-	-
	Grand mean	0.21	4.90	2.55	2.08	-	-
	LSD	0.42	0.99	1.13	3.12	-	-
	CV	23.65	28.69	22.43	25.75	-	-
	Heritability	0.21	0.32	0.58	0.18	-	-
	P-value	0.01	0.03	<0.0001	0.16	-	-

sus. check: Susceptible check.

varied range for heritability estimates (0.18 to 0.58) for all traits among the top 19 entries under *B. fusca* infestation (Table 2).

In Kakamega, the mean performance of entries under *B. fusca* infestation showed a wide range for dead hearts (0 to 3.31), leaf feeding damage (0.96 to 4.03), number of exit holes (2.15 to 9.08), and cumulative tunnel length (0.02 to 2.27 cm). There was a diverse range for heritability estimates (0.28 to 0.58) for all traits among the top 19 entries under *B. fusca* infestation (Table 3).

Mean performance of entries at Embu under *C. partellus* infestation showed a wide range for dead hearts (0.00 to 1.33), leaf feeding damage (1.72 to 6.65), number of exit holes (0.30 to 6.93), and cumulative tunnel length (0.02 to 0.52). There was a varied range for heritability estimates (0.31 to 0.74) for all traits among the top 19 entries under *B. fusca* infestation (Table 4).

In Kakamega, the mean performance of entries under *C. partellus* infestation revealed a widespread range for dead hearts (0.00 to 1.32), leaf feeding damage (1.80 to 3.47), number of exit holes (0.17 to 1.79), and cumulative tunnel length (0.00 to 2.18). There was a varied range for heritability estimates (0.11 to 0.78) for all traits among the top entries under *C. partellus* infestation (Table 5). Similarly, in Kiboko, the mean performance of entries under *C. partellus* infestation revealed a wide range for dead hearts (0.00 to 1.02), leaf feeding damage (1.40 to 6.65), number of exit holes (0.10 to 6.21), and cumulative tunnel length (0.08 to 2.29). There was a diverse range for heritability estimates (0.11 to 0.78) for all traits among the top entries under *C. partellus* infestation (Table 6).

There were *C. partellus* only resistant entries at Embu (8), Kiboko (9), and Kakamega (4) and 6 each for *B. fusca* only resistant entries at Embu and Kakamega. Twenty one entries showed combined resistance to both *B. fusca* and *C. partellus* in at least two sites: entries

Table 3. Mean performance of top 18 maize inbred lines for selected stem borer resistance traits under *B. fusca* infestation at Kakamega (averaged over two seasons).

Entry	Genotype	No. of dead hearts	No. of exit holes	Stem borer leaf Damage scores (1-9)	Cumulative tunnel length (cm)	Rank selection index	Rank
22	CKSBL10250	0.07	2.22	1.53	0.57	1.10	1
79	CKSBL10043	0.87	2.15	2.38	0.5	1.48	2
90	CKSBL10045	0.24	2.55	2.24	0.42	1.36	3
80	CKSBL10035	0.01	3.39	1.91	0.06	1.34	4
25	CKSBL10169	0.02	2.91	3.12	0.55	1.65	5
75	CKSBL10028	0.08	3.51	1.83	0.15	1.39	6
91	CKSBL10040	0.01	4.18	1.26	0.05	1.38	7
85	CKSBL10039	0.05	5.13	1.13	0.04	1.59	8
49	CKSPL10028	0.01	5.33	1.53	0.03	1.73	9
56	CKSPL10081	0.02	5.53	1.82	0.04	1.85	10
100	CKSBL10026	0.28	5.68	0.96	0.2	1.78	11
29	CKSBL10286	0.03	5.61	2.02	0.02	1.92	12
7	CKSBL10194	0.03	5.61	2.08	0.45	2.04	13
38	CKSBL10321	0.00	5.15	2.35	2.27	2.44	14
92	CML264	0.01	5.8	1.93	0.78	2.13	15
111	CML489	0.07	7.05	1.16	0.23	2.13	16
95	CML312	0.02	7.03	1.52	0.4	2.24	17
60	CKSPL10089	0.25	6.96	2.14	0.64	2.50	18
102	CML334	0.33	9.08	1.38	0.13	2.73	89
96	CML395 (susceptible check)	3.31	8.3	4.03	0.21	3.96	102
	Genotypic variance	0.01	0.27	0.06	0.36	-	-
	Residual variance	0.06	33.14	0.26	1.52	-	-
	Grand mean	0.07	6.73	2.55	2.08	-	-
	LSD	0.42	0.99	1.13	3.12	-	-
	CV	25.65	23.69	22.43	25.73	-	-
	Heritability	0.41	0.35	0.58	0.28	-	-
	P-value	0.009	0.04	<0.0001	0.36	-	-

sus. check: Susceptible check.

CKSBL10026 and CKSBL10028.

DISCUSSION

The analysis of variance revealed significant variation among the genotypes for all characters examined. The partitioning of the phenotypic variance and genotypic variance provided a better understanding of the variation patterns among *B. fusca* and *C. partellus* and their response to the test genotypes across different environments. For example, the number of dead hearts exhibited the least genotypic variance (0.01), while the number of exit holes had the highest (0.27) in Kakamega for *B. fusca*, compared to Embu which had 0.01 and 0.05, respectively. Kiboko had the least genotypic variance for all traits measured for *C. partellus*.

Observations on the number of dead hearts and Number of exit holes may imply that trait variations for borer resistance are not completely under genetic control. The higher genotypic variances than the environmental variances suggest that selection for particular stem borer resistance trait can be carried out and that progress can be made.

The suggestions may apply to observations on the moderate to high broad sense heritability values for borer resistance traits. In both maize and sorghum, the role of leaf resistance and other traits in conferring resistance to stem borers *C. partellus* (Swinhoe), *O. nubilalis* (Hubner), *Sesamia nonagrioides*, and *Diatreae* species is well documented (Butrón et al., 2009; Singh et al., 2012). Even though heritability estimates indicate the relative values of selection based on the phenotypic expression, it is not definitive unless genetic gain under selection is considered together with heritability (Akinwale et al., 2011). The low to moderate broad sense heritability

Table 4. Mean performance of top maize inbred lines for selected stem borer resistance traits under *C. partellus* infestation at Embu (averaged over two seasons).

Entry	Genotype	No. of dead hearts	No. of exit holes	Stem borer leaf Damage scores (1-9)	Cumulative tunnel length (cm)	Rank selection index	Rank
100	CKSBL10026	1.33	1.98	1.72	0.20	0.45	1
91	CKSBL10040	0.00	0.30	1.72	0.05	0.47	2
49	CKSPL10028	1.32	1.65	1.80	0.04	0.48	3
73	CKSBL10016	0.02	0.93	2.16	0.25	0.48	4
90	CKSBL10045	0.33	0.57	2.17	0.39	0.68	5
97	CKSBL10001	0.01	1.02	2.19	0.27	0.68	6
79	CKSBL10043	1.28	3.66	2.20	0.50	0.7	7
41	CKSBL10157	0.21	2.04	2.21	0.02	0.74	8
82	CKSBL10042	0.01	1.20	2.39	0.27	0.75	9
25	CKSBL10169	0.03	2.52	2.46	0.09	0.76	10
80	CKSBL10035	0.07	2.25	2.54	0.1	0.78	11
109	LPSC7-F86-3-1-1-1-BB-#-B-B	0.34	2.28	2.58	0.02	0.81	12
70	CKSBL10013	0.03	4.86	2.59	0.23	0.83	13
9	CKSBL10197	0.03	6.12	2.60	0.07	0.84	14
13	CKSBL10203	0.01	2.61	2.60	0.52	0.85	15
81	CKSBL10038	0.38	6.84	2.78	0.10	0.86	16
101	CML444	0.01	6.93	2.97	0.02	0.88	17
53	CKSPL10070	0.01	5.22	3.23	0.03	0.89	18
93	CML202	0.36	4.50	6.51	0.09	0.89	19
96	CML395 (susceptible check)	1.02	6.21	6.65	0.23	3.75	90
	Genotype variance	0.05	0.08	0.29	0.36	-	-
	Residual variance	0.25	0.50	0.31	1.52	-	-
	Grand mean	0.26	1.09	3.23	0.79	-	-
	LSD	0.85	1.27	1.1	2.07	-	-
	CV	24.14	28.58	17.17	23.14	-	-
	Heritability	0.38	0.31	0.74	0.41	-	-
	P-value	0.49	0.001	<0.0001	0.01	-	-

sus. check: Susceptible check.

estimates ($H^2<0.50$) for characters, such as number of dead hearts, number of exit holes, leaf feeding damage and cumulative stem tunneling may be due to environmental influence on the traits.

Since selection indices for stem borer resistance traits provide efficiency in the improvement of quantitatively inherited traits, such as stem borer resistance in maize (Mulamba and Mock, 1978; Mutinda et al., 2013), a rank selection index was used to identify genotypes with resistance for both *B. fusca* and *C. partellus*. In response to tropical maize inbred lines for resistance to two *B. fusca* and *C. partellus*, stem borers showed that resistance may be exclusive for *B. fusca* only or *C. partellus* only or for both borers where they exist. It was observed that five entries had resistance to *B. fusca* only, 26 entries showed resistance to *C. partellus* only, and 21 entries showed combined resistance to both *B. fusca* and *C. partellus* in at least two sites. Four entries CKSBL100 25, CKSBL10039, CKSBL10040, and CKSBL10028 showed resistance to both species across the sites. Eighty four and 28 entries, respectively showed susceptibility to *B. fusca* and *C. partellus* in all test genotypes (Table 7). Most of the genotypes were found to be susceptible to *B. fusca* and less so for *C. partellus.* These may be attributed to its (*B. fusca*) fitness and adaptation in Africa, because it is indigenous unlike *C. partellus*. These findings suggest that genotypes with the specific borer resistance can be deployed directly as parent lines in the formation of hybrids with resistance to *B. fusca* and *C. partellus* to areas where these borers occur in league or exclusively.

The knowledge on genetic correlations between borer resistance traits is important in creating selection criteria (Sujiprihati et al., 2003). Since grain yield is a result of interrelationships of yield components (Schnable and Springer, 2013; Udaykumar et al., 2013), to maintain grain

Table 5. Mean performance of top maize inbred lines for selected stem borer resistance traits under *C. partellus* infestation at Kakamega (averaged over two seasons).

Entry	Genotype	No. of dead hearts	No. of exit holes	Stem borer leaf Damage scores (1-9)	Cumulative tunnel length (cm)	Rank selection index	Rank
100	CKSBL10026	0.07	0.17	2.75	0.59	3.58	1
91	CKSBL10040	0.03	0.31	3.26	0.14	3.74	2
80	CKSBL10035	0.01	1.09	2.46	0.24	3.80	3
79	CKSBL10043	0.31	1.34	2.16	0.14	3.95	4
4	CKSBL10073	0.31	1.38	2.16	0.14	3.99	5
12	CKSBL10200	0.23	1.29	2.03	0.67	4.22	6
47	CKSPL10280	0.04	1.25	3.03	0.06	4.38	7
49	CKSPL10028	0.01	0.74	3.00	0.85	4.60	8
45	CKSPL10256	0.70	1.52	2.57	0.00	4.79	9
38	CKSBL10321	1.32	1.79	1.80	0.04	4.95	10
37	CKSBL10155	0.03	1.16	3.31	0.47	4.97	11
56	CKSPL10081	0.30	1.32	2.98	0.43	5.03	12
5	CKSBL10107	0.74	1.61	2.61	0.14	5.10	13
83	CKSBL10008	1.04	1.65	2.41	0.03	5.13	14
60	CKSPL10089	0.34	1.40	2.37	1.07	5.18	15
15	CKSBL10205	0.68	1.50	3.02	0.00	5.20	16
6	CKSBL10195	0.66	1.42	2.00	1.23	5.31	17
92	CML264	1.28	1.71	2.85	0.19	6.03	18
48	CKSPL10309	0.68	1.43	2.66	2.18	6.95	19
96	CML395 (susceptible check)	0.99	1.62	3.47	1.04	7.12	86
	Genotype variance	0.05	0.09	0.05	0.05	-	-
	Residual variance	0.25	17.72	0.38	1.19	-	-
	Grand mean	0.26	4.54	2.3	0.77	-	-
	LSD	0.85	8.72	1.12	1.85	-	-
	CV	19.14	19.53	24.58	20.67	-	-
	Heritability	0.58	0.78	0.65	0.11	-	-
	P-value	0.50	<0.0001	<0.0001	0.27	-	-

sus. check: Susceptible check.

yield, breeding for stem borer resistance should be based on multi-trait selection. To do this, several correlations for stem borer resistance traits for *B. fusca* and *C. partellus* were examined to understand their relationships. There were highly significant differences for correlations among the lines for resistance to both *B. fusca* and *C. partellus* and agronomic traits in all sites. The correlation coefficients were positive and significant for the number of exit holes and stem diameter for *B. fusca* r=0.83, (p≤0.01) while that for *C. partellus* was r=0.39, (p≤0.01).

The findings from the current study, corroborate with previous studies that have shown that most cultivated grass species have large stem diameters that support a higher larval survival and more larvae have been recovered per plant unlike wild grass species (Akinwale et al., 2011; Hosseini et al., 2011). However, there were no significant correlations between leaf feeding damage and the number of exit holes for *B. fusca,* but a negative significant correlations r=-0.45, (p≤0.01) for *C. partellus*. For both borers, besides the length of the life cycles for the two borers, morphological characteristics such as trichome density, leaf pubescence, leaf glossiness, thorns, spines, cuticles, and waxes may hinder insect development (Munyiri et al., 2013; Santamaria et al., 2013). These may in turn affect the observed differences in resistance traits due to leaf feeding and larval survival on hosts.

Similarly, both *B. fusca* and *C. partellus* had negative significant correlations for number of exit holes r=0.68 (p≤0.01) and plant aspect r=-0.62 (p≤0.01), plant height r=-0.22 (p≤0.01) and leaf feeding damage r=-0.49 (p≤0.01) respectively. In addition, both *B. fusca* and *C. partellus* showed negative significant correlation for plant height r=-0.53 (p≤0.01) and plant aspect r=-0.53 (p≤0.01), respectively. Leaf feeding damage relative to the cumulative tunneling for both stem borers indicated no

Table 6. Mean performance of top maize inbred lines for selected stem borer resistance traits under *C. partellus* infestation at Kiboko (averaged over two seasons).

Entry	Genotype	No. of dead hearts	No. of exit holes	Stem borer leaf Damage scores (1-9)	Cumulative tunnel length (cm)	Rank selection index	Rank
91	CKSBL10040	0.00	0.10	2.00	0.11	0.55	1
82	CKSBL10042	0.01	0.29	2.08	0.79	0.79	2
90	CKSBL10045	0.01	0.40	1.40	0.44	0.56	3
49	CKSPL10028	0.01	0.58	1.52	1.88	1.00	4
79	CKSBL10043	0.01	0.77	1.79	1.48	1.01	5
4	CKSBL10073	0.02	0.31	1.76	0.92	0.75	6
13	CKSBL10203	0.02	0.90	2.12	0.89	0.98	7
81	CKSBL10038	0.03	0.54	2.01	1.23	0.95	8
85	CKSBL10039	0.03	0.65	2.31	1.00	1.00	9
80	CKSBL10035	0.03	0.84	1.49	1.27	0.91	10
99	CKSBL10004	0.04	0.49	1.97	1.32	0.96	11
70	CKSBL10013	0.05	0.84	1.49	1.22	0.90	12
24	CKSBL10165	0.06	0.55	1.68	0.66	0.74	13
32	CKSBL10178	0.06	0.86	1.54	1.56	1.01	14
53	CKSPL10070	0.21	0.33	1.99	0.16	0.67	15
7	CKSBL10194	0.31	0.53	1.73	0.98	0.89	16
111	CML489	0.33	0.19	1.87	0.08	0.62	17
103	CML254	0.38	0.76	1.49	0.87	0.88	18
61	CKSPL10090	0.89	1.46	2.69	2.29	1.83	19
96	CML395 (susceptible check)	1.02	6.21	6.65	0.23	3.53	95
	Genotype variance	0.05	0.08	0.24	0.22	-	-
	Residual variance	0.25	0.5	0.33	3.06	-	-
	Grand mean	0.26	1.09	2.29	2.08	-	-
	LSD	0.85	1.27	1.01	3.12	-	-
	CV	27.14	28.35	20.16	35.73	-	-
	Heritability	0.38	0.34	0.69	0.18	-	-
	P-value	0.16	0.05	0.01	0.02	-	-

significant correlations (Table 8). Based on stem borer resistance trait rank selection indices leaf feeding damage, cumulative stem tunneling and number of exit holes were found to be reliable parameters that may be used in discriminating genotypes for resistance to the two borers. The findings may imply that both *B. fusca* and *C. partellus* affect plants negatively in a similar manner. For example, stem tunneling disrupts nutrients and water uptake, leaf feeding damage reduces the photosynthetic area, exit holes may cause weakened stems which may result in susceptible to stem lodging and other plant deformities, thus result in increased losses to grain yield.

Previous studies showed that stem tunneling damage had a significant influence on maize plant growth, and that the direct effect of stem tunneling on loss in maize grain yield was greater than the effect of leaf feeding (Kumar, 1997; Singh et al., 2012).

The results from the current study agree with the findings of Ajala et al., (2010), Akinwale et al. (2011), and Mailafiya et al., (2011) reported that leaf damage and cumulative tunneling were positively correlated. These may show differences among *B. fusca* and *C. partellus* nature of feeding, stem tunneling, oviposition, and exit from host plants. Other studies found that *B. fusca* and *C. partellus* stem borer damage reduced the number of ears harvested per plant and plant height (Sujiprihati et al., 2003; Sharma et al., 2007; Akinwale et al., 2011).

Further trait correlations between *B. fusca* and *C. partellus* revealed positive and significant correlations for for both borers for number of exit holes (r=0.75, p≤0.01), leaf feeding damage score (r=0.55, p≤0.05), cumulative stem tunneling (r=0.26, p≤0.01), number of rotten ears (r=0.47, p≤0.05), number of ears harvested (r=0.72, p≤0.05), number of plants per plot (r=0.73, p≤0.05), plant aspect (r=0.99, p≤0.05), plant height (r=0.81, p≤0.01), root lodging (r=0.50, p≤0.05), and stem lodging (r=0.56, p≤0.05). However, no significant differences were observed for trait correlations between *B. fusca* and *C. partellus* for number of dead hearts, stem diameter and internode length across the sites (Table 9).

Table 7. Distribution of maize inbred lines for resistance to under *B. fusca* and *C. partellus* infestation at Embu, Kiboko and Kakamega.

Entry	Genotype	Species and location				
		Chilo partellus			***Busseola fusca***	
		Embu	**Kakamega**	**Kiboko**	**Embu**	**Kakamega**
13	CKSBL10203	+	-	+	-	-
49	CKSPL10028	+	+	+	+	+
53	CKSPL10070	+	-	+	-	-
75	CKSBL10028	-	+	-	+	+
79	CKSBL10043	+	+	+	-	-
80	CKSBL10035	-	-	+	-	-
81	CKSBL10038	+	-	+	-	-
85	CKSBL10039	-	-	-	+	+
91	CKSBL10040	+	+	+	+	+
95	CML312	+	-	-	+	+
100	CKSBL10026	+	-	-	+	+
101	CML444	-	-	+	-	-
96	CML395 (susceptible check)	+	+	+	+	+
Total		9	9	9	7	7

+ = Present; - = Absent.

Table 8. Correlation coefficients for selected stem borer resistance traits under *B. fusca* and *C. partellus* infestation at Kakamega, Kiboko, and Embu.

Correlation		*Chilo partellus*					
		EXHL	**LD**	**NE**	**PA**	**PH**	**TL**
Busseola fusca	DIAM	0.39**	0.22	0.17	0.24	0.40*	0.03
	EXHL	1	-0.46**	0.61**	-0.62**	0.89**	0.14
	LD	0.83**	1	-0.45**	0.29*	-0.49**	-0.06
	NE	0.14	-0.17	1	-0.61**	0.65**	0.11
	PA	0.38**	0.54**	-0.20*	1	-0.53**	-0.23
	PH	0.69**	-0.68**	0.06	-0.50**	1	0.11
	TL	0.68**	0.89**	-0.22*	0.51**	-0.53**	1
-	**-**	0.34**	0.46**	0.26	0.12	-0.30**	0.47**

DIAM: Plant diameter; EXHL: number of exit holes; LD: leaf damage scores; NE: number of ears harvested; PA: plant aspect; PH: plant height; TL: cumulative stem tunneling; and *,**Significant (p≤0.05), highly significant (p≤0.01), ns: non-significant.

For successful selection of useful genotypes, an understanding of the genotypic and phenotypic inter-trait correlations is essential. The magnitude of genotypic and phenotypic correlations and their use in selection has been reported in literature (Ali et al., 2008; Al Tabbal and Al-Fraihat, 2012). For example, in this study, genotypic correlations were greater for most of the traits than the phenotypic correlation coefficient values (Table 9).

Grain yield showed significant and high positive genotypic (1.13) and phenotypic (0.83) correlation coefficients and high heritability values for both *B. fusca* (0.68) and *C. partellus* (0.80). Similarly, high genotypic correlations were observed for number of exit holes (1.01), leaf feeding damage (1.06), and cumulative stem tunneling (1.56) for both *B. fusca* and *C. partellus*. These may indicate a heritable correlation of these traits (Sahoo et al., 2011; Al Tabbal and Al-Fraihat, 2012). However, stem borer resistance traits had low heritability for number of dead hearts (0.21), leaf feeding damage (0.47), and cumulative stem tunneling (0.25), except for the number of exit holes (0.71); and correspondingly low phenotypic correlation values of less than 0.60.

Most agronomic traits had high phenotypic and genotypic correlations (0.58 to 1.68) and a wide range for heritability estimates for both *B. fusca* (0.18 to 0.86) and *C. partellus* (0.19 to 0.87). Despite the high genotypic variability revealed by the genetic coefficients of variation for the various stem borer resistance and agronomic

Table 9. Correlation coefficients for selected stem borer resistance traits between *B. fusca* and *C. partellus* infestation at Embu, Kakamega and Kiboko.

Parameter	Correlation coefficient (r)
Number of dead hearts	0.09**
Number of exit holes	0.75**
Leaf feeding damage score	0.55*
Cumulative stem tunneling	0.26*
Number of rotten ears	0.47*
Number of ears harvested	0.72*
Plant aspect	1.00*
Root lodging	0.50*
Stem lodging	0.56*
Plant height	0.81**
Stem diameter	0.40
Internode length§	0.70

§Four internodes below the uppermost ear.

traits, it may not provide information on the heritable variation that is useful for genetic improvement (Akinwale et al., 2011; Singh et al., 2012).

Expected genetic advance may be achieved through phenotypic selection when the genotypic coefficients of variation are coupled with heritable estimates (Sahoo et al., 2011; Al Tabbal and Al-Fraihat, 2012). Correlation coefficients may be useful as indicators of trait association among the borers, for example, the high number of exit holes and cumulative tunnel length shows the probability that either may be a useful selection criterion for resistance to *B. fusca* and *C. partellus* in maize.

Similar results have been reported indicating that selection based on these traits may lead to improvement in stem borer resistance (Munyiri et al., 2013). Low to moderate heritability values were observed for stem*. B.* fusca and *C. partellus* stem borers' resistance traits in the test germplasm suggest that those traits are under genetic control.

Previous studies have shown low heritability for various stem borer resistance traits due to compromised experimental procedures, low frequency for resistance genes in the reference populations (Singh et al., 2012; Chaudhary, 2013), or due to environmental influence or due to few sites used for evaluations (Falconer and Mackay, 1996).

Conclusions

The overall results suggest that a high variability of germplasm for resistance to *B. fusca* and *C. partellus* stem borers exists. Since both *B. fusca* and *C. partellus* stem borers are serious insect pests of maize, the identification of germplasm with resistance to these pests is key. The high heritability, genotypic and phenotypic correlations values showed the presence of inherent association between some stem borer resistance traits for both borers. Further genetic improvement may be explored for number of exit holes, cumulative stem tunneling alongside the agronomic traits in selection for the resistance to either or both *B. fusca* and *C. partellus* in maize. Leaf feeding damage scores, cumulative stem tunnel length and number of exit holes were the most effective parameters in discriminating the test genotypes for resistance to the two borers.

Genotypes identified for resistance to *C. partellus* only may be deployed in breeding programmes in zones where *C. partellus* exclusively occurs and likewise for regions with *B. fusca* only. Genotypes that showed combined resistance to both borers may be deployed to areas where these borers exist in league. However, breeding for resistance to these borers should continue besides deployment of these stem borer resistant hybrids.

The observed responses to either or both *B. fusca* and *C. partellus*, stem borers where they occur exclusively or in league helped to identify resistant maize inbred lines, and showed their possible use in hybrid breeding programmes in tropical maize that emphasize stem-borer resistance especially in Eastern and Southern Africa.

Conflict of Interests

The authors have not declared any conflict of interests.

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