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Relationships Between Stem Borer Resistance Traits and Grain Yield Reduction in Maize: Correlations, Path Analysis and Correlated Response to Selection

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Abstract: Information on the relationship between grain yield loss and stem borer damage is important in developing an efficient improvement programme for resistance to the borers. The relative contribution of damage parameters of *Sesamia calamistis* (Hampson) and *Eldana saccharina* (Walker) to grain yield loss in maize and interrelationships among them were studied in trials in the early and late seasons of 2002. Moderate to high correlations were observed among most pairs of resistance traits. Grain yield loss had moderate correlations with leaf feeding damage, number of broken stalks and stem tunnelling. Genetic correlations between resistance parameters and other agronomic traits were predominantly negative. In the path analysis, stem tunnelling and leaf feeding damage exerted the highest positive and direct effects on grain yield loss. Other resistance traits showed negative direct effects. Indirect effects of dead heart count and number of broken stalks were high through stem tunnelling whereas cob damage count showed high indirect effect through leaf feeding damage. Correlated responses to selection show that selection for improved grain yield would positively influence reduction in stem tunnelling.

Key words: Variablilty, additive variance, dominance, heritability, correlation, reciprocal recurrent selection

INTRODUCTION

Maize production in West and Central African sub-region is limited by many factors. One of the most important is the menace of insect pests. Their attacks result in reduction of the quality and quantity of crop yield. Lepidopterous insects are the most important pests of maize and stem borers, which attack the crop from seedling to storage, belong to this order. The pink stalk borer, *Sesamia calamistis* (Hampson) and the African sugarcane borer, *Eldana saccharina* (Walker) are members of this group. *Sesamia calamistis* and *Eldana saccharina* are found mostly in the lowlands of West and Central Africa. Among stem borers, these two species are most damaging and widespread in the sub-region (Bosque and Mareck, 1990).

Crop damage due to these stem borers varies. The larvae of *Sesamia calamistis* infest maize at the seedling stage and can thrive till maturity. The types of damage they cause the plant include feeding on the leaves of the young plants, causing dead hearts to the growing regions and boring holes into the stems, causing tunnels. *Eldana saccharina* attacks the crop at post-flowering stage (King and Bosque, 1995). Its larvae attack the cob causing damage. They also bore into upper part of the stem, causing the stalk to break.

Damage levels also vary, depending on the levels of susceptibility, tolerance or resistance of the genotype (Ajala, 1994) and the stage of plant growth at which infestation occurs. Estimated losses in farmers' fields have been reported to range from 10 to 100% (Usua, 1968). Breeding for resistance to damage has been suggested as the most promising approach to control the stem borers (Smith *et al.*, 1989). Information about relationships between the types of damage and their contribution to yield reduction are important in the development of an efficient breeding programme. The objectives of this study were to determine the degree of association between the parameters of resistance and yield: To determine the contribution of these parameters to yield reduction in maize and: estimate the correlated responses to selection for grain yield and the parameters of resistance in the maize populations.

MATERIALS AND METHODS

This study was conducted in the Ibadan station of the International Institute of Tropical Agriculture. Seven genotypes were used in the study. They included TZBR Comp1 F_2, TZBR Comp 2F_2, TZSR-W, TZBR ELD3C3, AMA-TZBR WC1, AK9443 DMRSR and TZBR Comp 1 S_1 x TZBR Comp 2 S_1, all obtained from the International Institute of Tropical Agriculture. Genotypes were evaluated in field trials in both early and late seasons of 2002 and the early season of 2003. The experiment was conducted in a randomized complete block design with

Table 1: Phenotypic (rp) and genotypic (rg) correlations of parameters of resistance and grain yield in seven populations of maize under artificially infested conditions

	rg						
	Leaf feeding damage (1-9)	Dead heart count	Number of broken stalks	Cob damage count	Stem tunnelling	Grain yield (Mg ha-1)	Grain yield loss (%)
Leaf feeding damage (1-9)		-0.89**	0.23	0.76**	-0.35**	0.16	0.26*
Dead heart count	0.03		-0.29*	0.94**	0.93**	-0.35**	0.07
rpNumber of broken stalks	0.06	0		0.1	0.56**	-0.05	0.38**
Cob damage count	0.09	-0.02	0.14		0.05	-0.01	-0.02
Stem tunnelling	-0.08	0.01	0.12	0.04		-0.24	0.24
Grain yield(Mg ha)		0.00	-0.07	0.08	0.06	-0.13	-0.02
Grain yield loss (%)	0.03	0.07	-0.02	-0.05	0.05	-0.50**	

three replications. Entries were planted in 2-row plots of 6.5 metres each. Each plot was divided into two halves of 3m each, with a space of 0.5m between them. Plants in one half were infested while those in the other half were protected with Pyrinex. For infestation, each plant was infested with egg masses of *Sesamia calamistis* at 3 Weeks After Planting (WAP) and *Eldana saccharina* at one week after silk emergence.

Two seeds were planted in each hole and thinned at 3WAP to one plant per stand. Fertilizer was applied in split doses. Basal application (immediately after thinning) was NPK 20-10-10, to provide the plants with 60kg ha^{1}N, 30kg ha^{1} each of P and K. For the second application, Urea was applied at 6 WAP, providing the plants with 60 kg N ha^{1}. Weeds were controlled with a pre-emergence application of Gramoxone (2 litres ha^{1}) and Primextra (4 litres ha^{1}). Manual weeding was carried out at 6 and 9 WAP, respectively. Finally, Gramoxone only was applied at 11WAP.

Data was collected on five damage parameters and five agronomic traits. The damage parameters were: Leaf feeding damage (on a rating scale of 1 to 9 (Davis and Williams, 1989)), number of dead hearts, stem tunnelling (length of stem tunnelled), number of broken stalks and number of damaged cobs (cob damage count). Agronomic traits included number of days to 50% silking, plant height, plant aspect, grain moisture (Moist) and Field Weight (FWT). Grain yield (Kg ha^{-1}) adjusted to 15% moisture and 80% shelling percentage calculated as

Grain Yield = FWT* (100-Moist%)/ 85*10,000/ Plot size.

Percentage grain yield loss in the infested plants was calculated as

Yield loss (%) = 100{(YC-Yi)/YC}, where: YC = Grain yield of uninfested plot and YI = Grain yield of infested plot.

Analyses of variance and of covariance were performed on the traits and pairs of traits using PROC GLM of SAS (SAS, 1998). Components of variance and covariance were estimated using the observed the mean squares and mean cross products. Genotypic and phenotypic correlations were computed according to the method of Mode and Robinson (Mode and Robinson, 1959). Covariance components can be obtained and used, together with individual trait variances, to calculate correlation coefficients as:

$$r = ./(:..:)^{1/2}$$

Where: *j* = genotypic (G) and phenotypic (P), ., = the covariance between traits X and Y, :. = the j variance for trait X, and :. = the j variance for trait Y. Path coefficient analysis (Wright, 1921; 1923) was calculated in order to study the interrelationship among the resistance parameters and their relationship to grain yield loss. Correlated responses to selection were calculated by using the formula: $CR_{yx} = k_x h_x h_y rg_{xy}$óp$_y$ (Falconer, 1988) Where CR_{yx} = expected correlated response in trait y when selection is for trait x; k_x = standardized selection differential applied in selection for trait x; hx and hy = square root of heritability of traits x and y; rg_{xy} = genetic correlation between traits x and y, and óp$_y$ = phenotypic standard deviation of trait y.

RESULTS

Correlations among resistance parameters and grain yield are presented in Table 1. There were no significant phenotypic correlations among resistance parameters. Leaf feeding damage had significant and positive genotypic correlations with cob damage count. However, its correlations with stem tunnelling and dead heart count respectively were negative. Dead heart count was negatively correlated with number of broken stalks but positively correlated with cob damage count and stem tunnelling respectively. Number of broken stalks had a significant and positive relationship with stem tunnelling. Grain yield had significant and negative and significant correlation with dead heart count.

Table 2: Phenotypic (rp) and genotypic (rg) correlations of some agronomic traits and parameters of resistance in seven populations of maize under artificially infested conditions

		rg				
		Days to 50% silking	Plant height (cm)	Plant aspect (1-9)	Ear aspect (1-9)	Grain moisture(%)
Number of broken stalks	rp	-0.08	0.01	-0.01	0.05	0.06
	rg	-0.21	-0.12	-0.18	0.66**	0.40**
Leaf feeding damage (1-9)	rp	-0.01	-0.05	0.03	-0.04	0.04
	rg	-0.11	-0.12	-0.05	0.02	0.04
Cob damage count	rp	-0.03	0.02	-0.01	0.1	-0.02
	rg	-0.22	-0.09	-0.45**	0.69**	0.05
Dead heart count	rp	0.04	-0.05	0.07	0.02	0.06
	rg	0.24	-0.1	0.75**	-0.38**	0.11
Stem tunnelling	rp	0.05	-0.05	0.05	0.1	-0.02
	rg	-0.14	-0.03	0.19	0.25*	0.03

Table 3: Phenotypic (rp) and genotypic (rg) correlations among grain yield and some agronomic traits in seven populations of maize under artificially infested conditions

	rg						
	Days to 50% silking	Plant height (cm)	Plant aspect (1-9)	Ear aspect (1-9)	Grain moisture (%)	Grain yield(Mg ha)	Grain yield loss (%)
Days to 50% silking		0.27*	0.12	-0.47**	0.33*	0.13	0.89**
Plant height (cm)	-0.23		0.28*	-0.71**	0.01	0.30*	0.52**
rpPlant aspect (1-9)	0.14	-0.03		0.39**	-0.75**	-0.21	0.96**
Ear aspect (1-9)	0.2	-0.35*	0.07		-0.38**	-0.83**	-0.18
Grain moisture (%)	0.11	-0.01	-0.07	-0.04		0.16	-0.01
Grain yield(Mg ha)	-0.37**	0.41**	-0.2	-0.46**	-0.1		-0.02
Grain yield loss (%)	0.14	-0.17	0.12	0.17	0.08	-0.50**	

Phenotypic correlations between agronomic traits and parameters of resistance were not significant (Table 2). However, there were some significant genotypic relationships. Number of broken stalks had significant and positive correlations with ear aspect and grain moisture respectively. The correlation between cob damage count and plant aspect was significant and negative but positive between cob damage count and ear aspect. Dead heart count had significant positive association with plant aspect, whereas that with ear aspect was negative. Stem tunnelling had a significant and positive correlation with ear aspect. Other correlations were not significant. In addition, days to 50% silking and plant height had no significant genotypic relationship with any damage parameter. Leaf feeding damage was not significantly correlated with any of the agronomic traits.

Most phenotypic relationships between agronomic traits were not significant (Table 3). However there was a negative relationship between plant height and ear aspect. Grain yield had negative correlations with days to 50% silking, ear aspect and grain yield loss. Grain yield also had a positive phenotypic relationship with plant height. For significant genotypic relationships, days to 50% silking was positively correlated with plant height, grain moisture and grain yield loss but negatively correlated with ear aspect. Plant height also had positive correlations with plant aspect, grain yield and grain yield loss but had a negative association with ear aspect. The relationship between plant aspect and grain moisture was negative but plant aspect had positive correlations with ear aspect and grain yield loss respectively. Ear aspect had negative correlations with grain moisture and grain yield respectively. There were no significant relationships between grain moisture, grain yield and grain yield loss.

To determine the relative contributions of the damage parameters to grain yield loss, genotypic correlation coefficients between the damage (resistance) parameters and grain yield loss were partitioned into direct and indirect relationships by path coefficient analysis (Table 4), with grain yield loss as the resultant variable. Stem tunnelling and leaf feeding damage showed positive direct effect on grain yield loss. Of the two, stem tunnelling showed a stronger effect (0.79). The other three traits, dead heart count, number of broken stalks and cob damage count exert negative direct effects on grain yield loss. Dead heart count had the strongest positive indirect effect through stem tunnelling (0.73), followed by number

Table 4: Direct (on diagonal bold) and indirect (off diagonal) effects of stem borer damage parameters on grain yield in a population cross of maize

	Leaf feeding damage (1-9)	Dead heart count	Number of broken stalks	Cob damage count	Stem tunnelling	Ia	Cb
Leaf feeding damage (1-9)	0.51	0.22	-0.06	-0.14	-0.28	-0.25	0.26
Dead heart count	-0.45	-0.25	0.07	-0.17	0.73	0.18	-0.07
Number of broken stalks	0.12	0.07	-0.24	-0.02	0.44	0.61	0.37
Cob damage count	0.39	-0.24	-0.02	-0.18	0.04	0.17	-0.01
Stem tunnelling	-0.18	-0.23	-0.13	-0.01	0.79	-0.55	0.24

Total direct effect: Effect coefficient (direct plus total indirect effects) which represent the genotypic correlation coefficient in Table. The little difference between both values is due to round-off error

Table 5: Predicted correlated response to selection for some agronomic traits and parameters of resistance in maize under infested conditions

	Days to 0% silking	Plant height (cm)	Plant aspect (1-9)	Ear aspect (1-9)	Grain moisture (%)	Grain yield (Mg ha^{-1})	Grain yield loss(%)	Leaf feeding damage(1-9)	Number of brokens stalks	Dead heart count	Cob damage count	Stem tunnel-ing
Days to 50% silking	1	1.9	0.01	-0.06	0.15	0.04	0.08	-0.02	-0.06	0	-0.12	-0.14
Plant heigh (cm)	0.04	1	0	-0.01	0	0.01	0.01	0	0	0	-0.01	0
Plant aspect (1-9)	1.13	17.71	1	0.41	-2.94	-0.64	0.74	-0.09	-0.47	0.08	-2.27	1.69
Ear aspect (1-9)	-4	-42.08	0.36	1	-1.4	-2.41	-0.13	0.04	1.63	-0.04	3.27	2.12
Grain moisture (%)	0.76	0.11	-0.19	-0.1	1	0.13	0	0.02	0.26	0	0.06	0.06
Grain yield (Mg ha^{-1})	0.38	6.02	-0.07	-0.28	0.2	1	-0.01	0.1	-0.04	-0.01	-0.01	-0.71
Grain yield loss (%)	10.42	42.31	1.24	-0.24	-0.05	-0.09	1	1.18	-1.26	0.74	-0.13	5.2
Leaf feeding damage (1-9)	-0.5	-3.9	-0.02	0.01	0.07	0.25	0.18	1	0.31	-0.05	1.93	-1.63
Number of broken stalks	-0.73	-2.81	-0.07	0.27	0.6	-0.06	-0.11	0.18	1	-0.05	0.2	1.96
Dead heart count	20.65	-61.98	7.11	-3.87	3.95	-10.14	39.3	-16.7	-31.98	1	44.82	80.03
Cob damage count	-0.39	-1.08	-0.09	0.14	0.04	0	0	0.3	0.05	0.02	1	0.1
Stem tunnelling	-0.14	-0.21	0.02	0.03	0.01	-0.08	0.04	-0.08	0.16	0.01	0.03	1

\# Responses are expressed as fractions of the expected genetic gain for the various traits

of broken stalks through stem tunnelling (0.44). Cob damage count also had a strong indirect effect on yield loss through leaf feeding damage (0.39). The strongest negative indirect effect was also shown by dead heart count through leaf feeding damage. Leaf feeding damage, which had a positive direct effect showed a strong and negative indirect effect on grain yield loss through stem tunnelling.

Correlated responses to selection (Table 5) were expressed as fractions of estimated gains from family selection for some traits. Selection for lesser days to silking would result in reduction in stem tunnelling that would be 14% of the gain attainable from selection for the latter trait. It was also observed that there would be reduction in leaf feeding damage, number of broken stalks and cob damage count. In the same manner, selection for improved grain yield would lead to reduction in number of broken stalks (4.47%), dead heart count (1%), cob damage count (0.82%) and in stem tunnelling (71%). In selecting for improved grain yield, favourable correlated responses were predicted for most other agronomic traits. Negative responses were obtained for plant aspect and ear aspect.

DISCUSSION

Knowledge of the magnitude of association between characters is useful to make simultaneous selection of more than one character. For the improvement of pest resistance and grain yield, it was necessary to determine the magnitude and direction of relationships between the parameters of resistance and grain yield and some other traits of importance. Phenotypic and genotypic correlation coefficients provided information on the degree of association between the parameters. Generally, moderate to high genetic correlations were observed between all pairs of resistance traits except for cob damage count on one hand, and stem tunnelling and number of broken stalks on the other. The significant relationship between the number bof broken stalks and stem tunnelling indicates a close relationship between the presence of the borer larvae and visible damage to the crop. This also implies that selecting for reduction in stem tunnelling would positively influence selection for reduced levels of stalk breakage.

Except for dead heart count and cob damage count, genotypic correlations between other resistance parameters and grain yield loss were positive. The direction of the relationship is suggestive of possible improvement of resistance traits along with reduction in grain yield loss within the populations. This is in agreement with some other studies (Bosque and Mareck, 1991; Ajala, 1994; Ajala and Saxena, 1994; Gounou *et al*., 1994). Correlations between most agronomic characters and the resistance parameters were significant. The number of broken stalks and stem tunnelling were negatively correlated with days to 50% silking, indicating better tolerance to stalk breaking and antibiosis type of resistance by later silking plants. Similar observations have been reported in the European corn borer resistance in other populations of maize (Hudon and Chiang, 1991; Schulz *et al*., 1997). In addition, a negative relationship between plant height and stem tunnelling suggests that taller and more vigorous plants are more resistant to both borers, particularly *Sesamia* sp. Among the agronomic traits, the positive genetic correlations between grain yield on one hand and plant height and days to 50% silking on the other indicated that taller and late maturing plants gave better grain yield. Such plants also have greater appeal, based on overall plant aspect. Similar results have been reported in some other populations (Holthous and Lamkey, 1995b; Betran and Hallouer, 1996).

When the contributions of the damage parameters to grain yield loss were examined, the path coefficient analysis results presented an interesting trend. Stem tunnelling, which was negatively correlated with grain yield, was the most important of the five resistance traits. Leaf feeding damage showed the same trend as stem tunnelling but in a lower magnitude. Stem tunnelling was also picked as the trait through which three other traits had their strongest indirect effects on grain yield loss.

The importance of stem tunnelling may be explained from the fact that this trait indicates the extent of damage to the vascular tissue. The vascular tissue is important in the translocation of nutrients from the soil to the photosynthetic sites and the translocation of the photosynthates from the source to the sink. This is more damaging of the two parameters, which showed positive effects. Leaf feeding damage reduces the photosynthetic tissue and consequently affects the photosynthetic rate. However, most leaf lesions observed were relatively small (rated between 2 and 4 on a 1-9 scale). These may not have seriously disrupted the photosynthetic activity of the maize plants. In addition, when grain yield was measured on plot basis there was the loss of one or two plants through dead heart or leaf feeding damage. However, there was the tendency to compensate by other plants, which utilized more of the available resources. Consequently, from the results obtained, stem tunnelling was the major trait, among the five traits under study, contributing to yield loss in maize. Ajala and Saxena (Ajala and Saxena, 1994) reported a similar observation on the effect of *C. partellus* on maize.

Correlated responses among plant characters are useful for predicting the effects of selection and for determining the feasibility of direct selection for a trait of interest. Indirect selection for any of the parameters of resistance through yield could be successful if there is a substantial negative genetic correlation between grain yield and the resistance parameter. The results from the experiment showed that this condition was met with respect to dead heart count and stem tunnelling. Number of broken stalks and cob damage count also had negative but non-significant correlations with grain yield. Leaf feeding damage did not meet the conditions. It had a positive genetic correlation with grain yield and also a positive correlated response. Consequently, selection for improved grain yield would lead to a reduction in stem tunnelling.

Host plant resistance and multiple borer resistance have been suggested as promising strategies in stem borer management (Mihm, 1985; 1995). Improvement for resistance traits along with yield by direct selection may be possible if the traits are highly heritable. A multitrait selection scheme using the resistance parameters may be used. Alternatively, indirect selection could be used.

REFERENCES

Ajala, S.O. and K.N. Saxena, 1994. Interrelationship among Chilo partellus (Swinehoe) damage parameters and their contribution to grain yield reduction in maize (Zea mays L.). Applied Entomol. Zool., 29: 469-476.

Ajala, S.O., 1994. Maize (Zea mays L.) stem borer (Chilo partellus Swinehoe) infestation/damage and plant resistance. Maydica, 39: 203-205.

Bosque-Perez, N.A. and J.H. Mareck, 1990. Distribution and species composition of Lepidopterous maize borers in southern Nigeria. Bull. Entomol. Res., 80: 363-368.

Bosque-Perez, N.A. and J.H.Mareck, 1991. Effect of stem borer Eldana saccharina (Lepidoptera: Pyralidae) on the yield of maize. Bull. Entomol. Res., 81: 243-247.

Betrán, F.J. and A.R. Hallauer, 1996. Characterization of interpopulation genetic variability in three hybrid maize populations. J. Heredity, 87: 319-328.

Davis, F.M. and W.P.Williams, 1989. Methods used to screen for and to determine mechanisms of resistance to the southwestern corn borer and fall armyworm. In CIMMYT. Towards Insect Resistant Maize for the Third World. Proc. Int Symp. Methodologies for Developing Host Plant Resistance to Maize Insects, El Batán Mexico. CIMMYT Mexico City, pp: 101-108.

Falconer, D.S., 1988. Introduction to quantitative genetics. (2nd Ed.), Longman Inc. N.Y., pp: 438.

Gounou, S., F. Schulthess, T. Shanower, W.N.O. Hammond, H. Braima, A.R. Cudjoe, R. Adjakloe, K.K. Antwi, and I. Olaleye, 1994. Stem and ear borer of maize in Ghana. Plant Health Management Division Research Monograph Int. Institute of Trop. Agric., Ibadan, Nigeria, pp: 31.

Hudon, M. and M.S. Chiang, 1991. Evaluation of resistance of maize germplasm to univoltine European corn borer Ostrinia nubilalis (Hübner) and relationship with maize maturity in Quebec. Maydica, 36: 69-74.

Holthaus, J.F. and K.R.Lamkey, 1995a. Population means and genetic variances in selected and unselected Iowa Stiff Stalk Synthetic maize populations. Crop. Sci., 35: 1581-1589.

Holthaus, J.F. and K.R. Lamkey, 1995b. Response to selection and changes in genetic parameters for 13 plant and ear traits in two maize populations. Maydica, 40: 357-370.

Kling J.G. and N.A. Bosque-Perez, 1995. Progress in breeding and screening for resistance to the maize stem borers Sesamia calamistis and Eldana saccharina. In: D.C. Jewell, S.R. Waddington, J.K. Ransom and K.V. Pixely (Eds.) Maize research for stress environments. Proceedings of the Fourth Eastern and Southern African Regional Maize Conferenceheld at Harare, Zimbabwe. Mexico D.F., pp: 182-186.

Mode, C.J. and H.F.Robinson, 1959. Pleiotropism and the genetic variance and covariance. Biometrics 15: 518-537.

Mihm, J.A., 1985. Breeding for host plant resistance in maize. Insect Science and Its Applications, 6: 405-408.

Mihm, J.A., 1995. Maize Pest Management-Multiple Insect and Disease Resistant Varieties Are the Key to Success. In: D.C. Jewell, S.R. Waddington, J.K. Ransom and K.V. Pixely (Eds.) Maize research for stress environments. Proceedings of the Fourth Eastern and Southern African Regional Maize Conference held at Harare, Zimbabwe. Mexico D.F., pp: 170-181.

Schulz, B.R., R. Kreps, D. Klein, R.K. Gumber and A.E. Melchinger, 1997. Genetic variation among European maize inbreds for resistance to the European corn borer and relation to agronomic traits. Plant Breeding, 116: 415-422.

Smith, M.E., J.H. Mihm and D.C. Jewell, 1989. Breeding for multiple resistance to temperate, sub-tropical and tropical maize pests at CIMMYT. In CIMMYT. 1989. Towards Insect Resistant Maize for the Third World. Proc. Int Symp. Methodologies for Developing Host Plant Resistance to Maize Insects, El Batán Mexico. CIMMYT Mexico City, pp: 222-234.

SAS Inst. Inc. 1998. SAS/STAT User's guide, Version 8. SAS Institute, Inc. Cary, N.C.

Usua, E.J.,1968. Effect of varying populations Busseola fusca larvae on the growth and yield of maize. J. Econ. Entomol., 61: 375-376.

Wright, S., 1921. Correlation and causation. J. Agric. Res., 20: 557-585.

Wright, S., 1923. The theory of path coefficients: A reply to Nile's criticism. Genetics, 8: 239-255.