This paper was published *in the International Journal of Tropical Insect Science* http://dx.doi.org/10.1017/S1742758411000105

Comparison of selection indices to identify sorghum genotypes resistant to the spotted stemborer, *Chilo partellus* (Swinhoe) (Lepidoptera: Noctuidae)

B.U. Singh[1, 2], K.V. Rao[2] and H.C. Sharma[1*]

[1]International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh 502 324, India.[2]Centre for Plant Molecular Biology, Department of Genetics, Osmania University, Hyderabad 500 007, Andhra Pradesh, India

Abstract. The resistance or susceptibility of sorghum genotypes to damage by the spotted stemborer, *Chilo partellus* (Swinhoe) (Noctuidae: Lepidoptera) in sorghum is commonly measured in terms of leaf damage, deadheart formation and stem tunneling. Effect of the host plant on the insect survival and development (antibiosis), and the plant's response to insect damage (tolerance or recovery resistance) are also important parameters for measuring host plant resistance to stemborers. We compared 10 selection indices commonly used to select genotypes for tolerance/ resistance to various stresses, namely functional plant loss index (FPLI), antibiosis index (ABI), mean productivity index (MPI), mean relative performance (MRP), relative efficiency index (REI), tolerance index (TOL), Fischer and Maurer's stress susceptibility index (FMSSI), Fernandez stress tolerance index (FSTI), Geometric mean productivity (GMP), and Schneider's stress severity index (SSSI). The indices based on grain yield reduction can be combined with those associated with grain yield response and potential under borer-infested and -uninfested conditions, since each index assesses different biological mechanisms (such as tolerance, adaptation, and/or productivity). Amongst these, FPLI can be used to differentiate the sorghum genotypes for different components of resistance by taking into account both the foliar damage and deadheart formation. GMP, REI, and FSTI provided a better discrimination of the stemborer tolerant genotypes under borer-infested condition, and were good predictors of grain yield performance than TOL, MPI, MRP, ABI, SSSI, FMSSI, and FPLI. A strong association between

* Email: h.sharma@cgiar.org

GMP and REI indicated that both these indices could be used to select for low grain yield loss and high productivity. However, the selection of genotypes with high grain yield potential and adaptation to borer infestation may be achieved by combining selection indices related to the mean grain yield performance under borer-infested and uninfested conditions (GMP and REI), and low levels of grain yield loss under borer infestation.

Key words: sorghum, *Sorghum bicolor*, selection indices, host plant resistance, spotted stemborer, *Chilo partellus*

Introduction

Sorghum, *Sorghum bicolor* (L.) Moench, is a major cereal crop in the semi-arid tropics (SAT), but grain yields on the smallholder farms are generally low (500 to 800 kg ha^{-1} compared to potential yields of >10 tones ha^{-1}), with insect pests constituting a major constraint to increased production (Sharma, 1993). Of the more than 150 insect species that damage sorghum, the spotted stemborer, *Chilo partellus* (Swinhoe) (Lepidoptera: Noctuidae) is a major pest in Asia and eastern and southern Africa (Jotwani *et al*., 1980). It attacks all the above-ground parts of the sorghum plant, from the second week after seedling emergence until crop harvest. Feeding by the young larvae results in pinholes and elongated lesions on the whorl leaves. Early infestation may also destroy the growing point, resulting in the drying of two to three central leaves, commonly known as deadheart. In addition, leaf feeding also reduces plant vigor, affects photosynthetic efficiency, delays flowering, and leads to a reduction in grain-filling and yield. Older larvae (3^{rd} instar) leave the whorl leaves and bore into the stem at the plant base, causing extensive stem tunneling that affects not only nutrient supply to the developing grain, but also results in partially or completely chaffy panicles. Stemborer damage also results in losses in fodder yield and quality (Bardner and Fletcher, 1974; Sharma, 2002). Global sorghum crop losses due to stem borer damage have been estimated at over US$ 300 million annually (ICRISAT, 1992; Sharma et al., 1997). In general, the yield losses range between 5 and 10%, especially when the infestation occurs early.

Stemborer damage in sorghum is a complex interaction between the insect and the host plant. In addition to its effects on the plant, the survival, development, and fecundity of the borer are also affected by the plant's resistance mechanisms (Singh et al., 1983; Dabrowski and Kidiavai, 1983; Singh and Rana, 1984, 1989; Rana et al., 1984, 1985; Sharma and Nwanze, 1997). The use of insecticides for stemborer control is often uneconomical and beyond the reach of resource-poor farmers. As such, host plant resistance (HPR) offers the best option for minimizing losses due to stemborers (Davies, 1981). Host plant resistance also assumes greater significance in sweet sorghums, which are now being exploited as a source of ethanol for energy. Genotypic resistance to stemborer damage in sorghum is based on leaf feeding, number of deadhearts, exit holes, tunnel length, effect of the host plant on survival and development of the insect, and recovery resistance (production of auxiliary tillers following borer damage to the main shoot) (Ajala and Saxena 1994; Sharma and Nwanze, 1997).

However, the effect of stemborer damage on grain yield is a complex interaction between the insect and the host plant, and expression of resistance varies depending on time of infestation (Alghali, 1985, 1987; Jarvis et al., 1986; Klenke et al., 1986; Taneja and Nwanze, 1989; MacFarlane, 1990; Thome et al., 1994); interplant variation (Harris, 1962); recovery resistance; ability to withstand stemborer damage (Flattery, 1982); compensation in grain yield (Heinrich *et al*., 1983; van den Berg *et al*., 1990), or a combination of two or more of these parameters.

Selection for resistance to *C. partellus* based on a single parameter is therefore difficult, as a sorghum genotype resistant to one form of damage may be susceptible to another (Ajala *et al*., 1993; Alghali, 1987). However, there is considerable interaction among the parmeters associated with reduction in grain yield due to stem borer damage (Ajala and Saxena, 1994). The accumulation of resistance traits through phenotypic recurrent selection accounted for the high grain yields observed in some borer-resistant selections. To achieve an overall improvement in the level of genotypic resistance that protects all stages of plant growth, resistance to more than one damage variable is required (Ampofo, 1986; Saxena, 1990).Thus, it is important to develop approaches that eventually improve the efficiency of selecting borer-resistant genotypes in a high-yielding background. The selection criteria should consider measuring the combined effect of different components of host plant resistance, an approach that requires the use of appropriate indices that result in simultaneous selection for resistance *per se,* as well as grain yield performance.

A fundamental limitation to selection is the difficulty in weighting the various damage traits used to calculate selection indices. Antibiosis against larvae and tolerance for grain yield loss are considered important for genotypic resistance to stemborer damage (Anglade, 1992; Anglade *et al*., 1996). Several selection indices have been used for crop improvement under stress, based on grain yield performance under stress and non-stress environments, to select resistant genotypes (Ortega et al., 1980; Ampofo, 1986; Fischer and Maurer, 1978; Rosielle and Hamblin, 1981; Samper, 1984; Graham, 1984; Fernandez, 1993; Schneider et al., 1997). The susceptibility of a genotype is often measured as a function of the reduction in grain yield under infested conditions, while taking into account the variable yield potential of the genotypes. The studies reported in this article compared the utility of 10 selection indices based on tolerance, antibiosis and grain yield potential and response for identifying sorghum genotypes that perform well under borer-infested conditions.

Materials and methods

Plant material

Twenty-five sorghum genotypes comprising of 15 germplasm accessions, three landraces, one commercial hybrid, four improved varieties, and a resistant and a susceptible check (Table 1) were evaluated for resistance to *C. partellus* under artificial infestation during the rainy and post-rainy seasons at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh, India. All the genotypes were planted in 4-row plots, each 2-m long with ridges 75 cm apart, in a randomized complete block design (RCBD) with three replications. The plots were fertilized with a basal application of 40 kg N and 40 kg P_20_5 per hectare. The seedlings were thinned to a spacing of 10 cm by maintaining a population of 20 seedlings per 2-m row. At the flowering stage, the panicles were covered with pollination paper bags, which were subsequently replaced with nylon bags (30 mesh) at the milk stage to prevent bird damage. In each plot, two rows were infested with stemborer neonates, as described below. The remaining two rows served as an uninfested control.

Stemborer rearing and infestation

Artificial diet developed at ICRISAT was used for mass rearing the *C. partellus* (Taneja and Leuschner, 1985). Eighteen days after seedling emergence (Sharma *et al*., 1992), the plants were artificially infested with 5 to 7 freshly emerged neonate larvae using a 'bazooka' applicator, between 0800 to 1100 h. Leaf feeding data were recorded on a rating scale of 1-9 (where 1 = ≤ 10% leaf area damaged, and 9 = ≥ 80% leaf area damaged), and the percentage of plants with deadhearts at 15 and 40 days after infestation.

Grain yield

At physiological maturity, all the panicles were harvested and threshed from the borer-infested and uninfested plots separately, and represented as grain yield response and potential (in kg/ha), respectively. Grain yield loss was calculated as the difference between grain yields from the infested and uninfested plots of each genotypes following Walker (1981, 1983):

$$\text{Grain yield loss (\%)} = \frac{\text{Grain yield potential (uninfested)} - \text{Grain yield response (infested)}}{\text{Grain yield potential (uninfested).}} \times 100$$

Selection indices

The following selection indices were used to characterize the test genotypes into different categories of resistance or susceptibility, based on grain yield performance under stemborer-infested and uninfested conditions, with an exception of functional plant loss index (FPLI), which is based solely on leaf feeding damage and deadheart formation during the vegetative stage of the sorghum crop. The following abbreviations were used in the formulae given below:

$GY_{I\,(IN)}$ = Grain yield of I^{th} genotype under borer infestation;
$GY_{I\,(UN)}$ = Grain yield of I^{th} genotype under uninfested conditions
$GY_{I\,(SC)}$ = Grain yield of susceptible check under borer infestation
LFS = leaf feeding score
DH (%) = deadheart percentage

1. Functional plant loss index (FPLI) was calculated by modifying the methods of Morgan *et al*. (1980), Ortega *et al*. (1980), and Panda and Heinrichs (1983) as:

$$FPLI = [1 - (\text{LFS of } I^{th} \text{ genotype / Mean LFS across the test genotypes}) + 1 - (\text{DH \% of } I^{th} \text{ genotype / Mean DH\% across the test genotypes})]$$

Mean grain yield under borer-infested conditions and the FPLI of each genotype under borer infestation have been used to categorize the genotypes for expression of resistance to *C. partellus* (Ortega *et al*., 1980; Ampofo, 1986; Kumar, 1994).

2. Antibiosis index (ABI) was calculated as:

$$ABI = [GY_{I\,(IN)} / GY_{I\,(SC)}]$$

High ABI values indicated high levels of resistance to the stemborer.

3. Mean productivity index (*MPI*) was calculated as:

$$MPI = [GY_{I\,(IN)} + GY_{I\,(UN)}] / 2$$

MPI is based on arithmetic mean, and therefore, has an upward bias wherein there are large differences between grain yield under borer-infested and uninfested conditions (Rosielle and Hamblin, 1981). MPI favours genotypes with high grain yield performance and low stress tolerance.

4. Mean relative performance (MRP) was calculated as:

$$MRP = [GY_{I\,(IN)} / GY_{(IN)}] + [GY_{I\,(UN)} / GY_{(UN)}]$$

The MRP indicates selection for tolerance based on differences in grain yield performance under borer-infested and uninfested conditions. Selections for tolerance based on MRP suggest selection of genotypes with low loss in grain yield, and low grain yield performance under borer-infested and uninfested conditions.

5. Geometric mean productivity (GMP) (Samper, 1984; Samper and Adams, 1985; Ramirez and Kelly, 1998) was calculated as:

$$GMP = \sqrt{(GY_{I\,(IN)} \times GY_{I\,(UN)})}$$

GMP accounts for large differences in performance between borer-infested and uninfested conditions than does the simple arithmetic mean, and identifies genotypes with high grain yield potential and adaptation to borer infestation.

6. Relative efficiency index (REI) was calculated by modifying the formula of Graham (1984) and Rosales-Serna *et al*. (2000) to:

$$REI = [(GY_{I\,(IN)}/GY_{(IN)}) \times (GY_{I\,(UN)}/GY_{(UN)})]$$

The REI can be used to classify genotypes based on grain yield under borer-infested and uninfested condition. The index is suitable for genotypes with high grain yield potential and tolerance to borer damage.

7. Tolerance index (TOL) (Rosielle and Hamblin, 1981) was calculated as:

$$TOL = [GY_{I\,(IN)} - GY_{I\,(UN)}]$$

Selection based on TOL favors genotypes with low grain yield potential under infestation, and higher grain yield response under borer infestation. A larger value of TOL represents greater sensitivity to borer infestation and greater yield reduction.

8. Fischer and Maurer's stress susceptibility index (FMSSI). The FMSSI has been used to select for drought tolerance (Fischer and Maurer, 1978), and was modified to estimate relative susceptibility to stemborer damage.

Stemborer susceptibility index (SBI) was calculated as:

$$SBI_I = [1 - (GY_{IN} / GY_{UN})]$$

Using the SBI, the FMSSI for each genotype was calculated:

$$FMSSI = \{[1-(GY_{I\,(IN)}/GY_{I\,(UN)})] / SBI_I\}$$

The FMSSI separates the effects of grain yield potential and borer susceptibility in terms of grain yield response under borer infestation. However, selection based on FMSSI favors genotypes with low grain yield potential and high yield response. Thus, FMSSI values that are <1.00 or >1.00 indicate high or low tolerance to stemborer infestation respectively.

9. Fernandez stress tolerance index (FSTI). Based on grain yield reduction adjusted to stemborer intensity in a particular environment, the FSTI (Fernandez, 1993) was estimated as:

$$FSTI = [GY_{I\,(IN)}/GY_{(IN)}] \times [GY_{I\,(UN)}/GY_{(UN)}] \times [GY_{(IN)}/GY_{(UN)}]$$

High FSTI value for a genotype indicated high tolerance to stemborer damage and high grain yield potential.

10. *Schneider's stress severity index (SSSI)*. The SSSI was derived by modifying the formula of Schneider *et al*. (1997) as:

$$SSSI = \{[1-(GY_{I\,(IN)} / GY_{I\,(UN)})]-[1-(GY_{(IN)} / GY_{(UN)})]\}$$

The SSSI estimates the relative tolerance for yield reduction of a genotype relative to the population mean reduction in grain yield response due to stemborer damage. It is useful for the identification of both stable and responsive sorghum genotypes with better grain yield response under borer infestation.

Statistical analyses

Data were subjected to analysis of variance for each parameter, and the significance of differences between the genotypes was tested using the F-test, while the significance of differences between the genotypic means was judged by using LSD (least significant difference) at $P \leq 0.05$. Data were also subjected to correlation and regression analyses to elucidate the relationship among the selection indices, and their association with grain yield performance and loss.

Results

Grain yield performance under borer-infested and uninfested conditions

Differences in grain yield responses and potentials among the test genotypes were significant (Table 1). Yield potentials varied from 1134 to 8750 kg ha^{-1}during the rainy season and 647 to 2116 kg ha^{-1}in the post-rainy season. Yield responses varied between 1122 and 6074 kg ha^{-1}, and 480 and 1934 kg ha^{-1} in the rainy and the post-rainy seasons, respectively. Grain yield response and potential were positively correlated under stemborer-infested and uninfested conditions during the rainy (r = 0.65*) and postrainy (r = 0.54*) seasons. The genotypes ICSV 743, CSH 9, ICSV 112, IS 2309, IS 1054, ICSV 714, and IS 5469 showed high yield potential and yield response under borer un-infested and infested conditions during the rainy season (Fig. 1a). Both, the potential yield and the response were very low for IS 12308 and IS 13100; while IS 2269, IS 2146, IS 2123, and IS 2205 exhibited moderate levels of yield under borer infested and un-infested conditions. During the postrainy season, CSH 9, AF 28, IS 5469, ICSV 112, IS 21444, and ICSV 714 showed high yield potential and response; while IS 18573, IS 5604, IS 12308, IS 13100, IS 1044, is 2263, and IS 5566 exhibited low yield potential and low yield response (Fig. 1b). The genotypes IS 2269, IS 2123, IS 2146, Seredo, ICSV 1, and IS 2205 exhibited moderate levels of yield under stemborer infested and un-infested conditions.

There was a very poor relationship between grain yield potential and loss in grain yield (r = 0.05 to 0.15). However, the genotypes IS 2123, IS 2146, IS 18333, and IS 21444 in the rainy season; and IS 5469, IS 5604, IS 2205, IS 5469, and IS 18573 in the postrainy season showed an increase of 1.7 to 24.0% in grain yield response, indicating that recovery (tolerance) is an important component of resistance in these genotypes to damage by *C. partellus* (Table 1). Accession IS 21444 had low grain yield potential, but exhibited high compensation in grain yield under borer infestation; while the genotypes IS 12308, IS 18573, IS 5604, ICSV 1, Naga white, and Seredo exhibited low yield potential, and also suffered high grain yield loss during the rainy season (Fig. 2a). IS 1054, IS 5469, IS 2309, ICSV 714, and IS 2269 exhibited moderate grain yield potential, and suffered low loss (10 to 20%) in grain yield; while IS 2123, IS 18333, IS 2146, and IS 2205 suffered no loss in grain yield, and also showed moderate levels of yield potential under stem borer infested and uninfested conditions. During the post-rainy season, the genotypes IS 5469, CSH 9, AF 28, and ICSV 714 showed high yield potential, and also displayed good compensation in grain yield under borer-infestation (Fig. 2b). On the other hand, the genotypes ICSV 743, IS 21444, and ICSV 112 exhibited high grain yield potential, but suffered high grain yield losses under borer-infestation.

Selection indices

The selection indices based on grain yield potential and response are given in Table 2. There were significant differences among the genotypes based on different selection indices.

Functional plant loss index. There were significant differences among the test genotypes for FPLI, which provides a reasonable estimate of resistance at the vegetative stage for each genotype in relation to grain yield response, under borer infestation. CSH 9, IS 1054, AF 28, and ICSV 743 displayed antibiosis, while IS 1044, IS 5604 and IS 18573 showed tolerance to *C. partellus* damage during the rainy season. Both antibiosis and tolerance were observed in IS 13100 and IS 12308; while IS 5604 and ICSV 705 displayed both tolerance and antibiosis in the post-rainy season.

Antibiosis index. The ABI values were significantly low for IS 2123, IS 2146, IS 18333, IS 21444, and IS 2205 in the rainy season, and IS 5469, IS 5604, IS 18573, and IS 2205 in the postrainy season (Table 2), suggesting that these genotypes had a high degree of antibiosis combined with tolerance mechanism of resistance to stemborer damage.

Mean productivity index. The mean productivity was high in IS 1054, IS 2309, AF 28, CSH 9, ICSV 714, and ICSV 743 during the rainy season, and IS 5469, AF 28, and CSH 9 during the postrainy season (Table 2). Based on productivity and grain yield loss, the genotypes ICSV 743, CSH 9, IS 1054, and IS 5469 exhibited high productivity, but also suffered high grain yield losses in the rainy season, while ICSV 705, IS 1054, IS 5566, and IS 2263, with exhibited low productivity, suffered high grain yield loss in the postrainy season.

Mean relative performance. The MRP values were significantly high in IS 2309, CSH 9, ICSV 112, and ICSV 743 in the rainy season, and IS 5469, AF 28, and CSH 9 in the postrainy season (Table 2). However, the MRP values were low (<1.45) for IS 1044, IS 12308, and IS 21444, and high (>2.63) for ICSV 714, IS 2309, ICSV 743, ICSV 112, and CSH 9 during the rainy season. Based on MRP values and grain yield loss, CSH 9, IS 1054, and IS 5469 showed high productivity, but suffered high grain yield loss. IS 21444, IS 2146, IS 2123, IS 18333, and IS 2205 showed high tolerance in the rainy season, while ICSV 112, ICSV 743, and IS 21444 exhibited high productivity and high grain yield loss. The genotypes IS 18573, IS 2205, and IS 5604 displayed moderate grain yield potential, and also exhibited tolerance to stemborer damage during the post-rainy season (Tables 1 and 2).

Geometric mean productivity. There were significant differences in GMP among the test genotypes. ICSV 743, CSH 9, IS 1054, and IS 5469 exhibited high productivity, and also suffered high loss in grain yield; while ICSV 112, ICSV 714, IS 2309, IS 2269, IS 18333, IS 2123, IS 2146 and IS 2205 showed moderate to high productivity, and suffered low loss in grain yield during the rainy season. During the postrainy season, ICSV 112, ICSV 743 and IS 21444 showed high productivity, but also suffered high grain yield loss; while IS 5469, ICSV 714, CSH 9 and AF 28 showed high productivity and suffered low loss in grain yield.

Relative efficiency index. The REI values for IS 2309, CSH 9, ICSV 112, ICSV 714, and ICSV 743 were high during the rainy season, and IS 5469, AF 28, and CSH 9 in the postrainy season. These genotypes had a high grain yield potential and also showed adaptation to borer damage (Tables 1 and 2).

Tolerance index. Selection based on TOL indicated that ICSV 743 had low tolerance and suffered high losses in grain yield; while high tolerance to stemborer damage was observed in IS 21444 during the rainy season. In addition, ICSV 705, IS 5566, IS 2309, and IS 2263 exhibited high tolerance, and suffered modest losses in grain yield due to stemborer damage during the post-rainy season (Tables 1 and 2).

Fischer and Maurer's stress susceptibility index. There were significant differences in FMSSI among the genotypes tested. Based on FMSSI values and grain yield loss, the genotypes IS 5604, ICSV 743, and ICSV 1 had low levels of tolerance associated with high grain yield losses. IS 2123, IS 2146, IS 2205, and IS 21444 exhibited high tolerance and suffered low loss in grain yield during the rainy season. During the postrainy season, the genotypes ICSV 743, IS 2309, ICSV 705, IS 21444, IS 2263, IS 1054, and IS 5566 not only showed low tolerance, but also suffered high grain yield loss; while IS 5604, IS 2205, IS 5469, ICSV 714, and IS 18573 exhibited high tolerance during the postrainy season.

Fernandez stress tolerance index. There were significant differences among the test genotypes for FSTI. Grouping of genotypes based on grain yield loss and FSTI indicated that CSH 9, ICSV 112, and ICSV 743 had low tolerance, associated with high grain yield loss in both the rainy and postrainy seasons. Genotypes IS 2146, IS 2205, IS 2123, and IS 18333 exhibited high levels of tolerance to stemborer damage in the rainy season. IS 2205, IS 5604, and IS 18573 showed high tolerance to borer damage in the post-rainy season.

Schneider's stress severity index. IS 12308 and ICSV 743 showed highly positive SSSI values during the rainy season, suggesting that they suffered high stress and high grain yield loss. IS 21444, IS 2146, IS 2205, IS 2123, IS 18333, and IS 13100 had negative SSSI values, indicating that they experienced low stress and low grain yield loss. Similarly, positive SSSI values in IS 1054, ICSV 743, ICSV 705, and ICSV 112 during the postrainy season indicated that they are prone to stress caused by stemborer damage, and also suffered greater grain yield loss (Table 2).

Association of selection indices with grain yield performance under borer-infested and uninfested conditions

There were highly significant and positive correlations between GMP and MPI with MRP, REI and FSTI. Higher GMP and FSTI values indicated greater tolerance to borer infestation, as observed for drought tolerance (Fernandez, 1993).

FMSSI was positively correlated with ABI, SSSI, and TOL (Table 3). Similarly, positive correlations were observed between ABI and SSSI and TOL; REI and FSTI, and SSSI and TOL. FLPI did not show any association with other selection indices or with grain yield performance under borer-infested and uninfested conditions, including grain yield loss; and hence, it may not be a reliable criterion for use in the selection for host plant resistance to *C. Partellus*, as it is based on damage at the vegetative stage.

FMSSI, ABI, SSSI, and TOL exhibited strong correlation with grain yield loss due to borer infestation, in both rainy and postrainy seasons, but correlation coefficients with grain yield were non-significant (except for TOL, which was significantly correlated with grain yield during the rainy season under uninfested conditions) (Table 4). GMP, MPI, MRP, REI, and FSTI exhibited highly significant association with grain yield, but had no association with grain yield loss.

Discussion

Selection based on a combination of indices may provide a more useful criterion for improving stemborer resistance in sorghum, but an indication of the association between different indices and/or loss in grain yield is useful in finding the degree of overall linear association between any two attributes, which could be used for identification of the superior genotypes for borer-infested and uninfested conditions. The FSTI and GMP were quite reliable for identifying genotypes with high yield potential and good response to stem borer damage. The FSTI, REI, GMP, MRP, and MPI were useful in identifying genotypes with high yield potential under both borer-infested and uninfested conditions. However, when the severity of stemborer damage is high, TOL, SSSI, ABI, and FMSSI were more useful for discriminating tolerant/resistant cultivars, although none of the indicators could clearly identify genotypes with high yield potential under both infested and uninfested conditions.

An optimal selection criterion should be able to distinguish genotypes exhibiting high yield potential and suffering low loss in grain yield. But the selection indices based on tolerance and antibiosis mechanisms such as FPLI, TOL, MPI, MRP, SSSI, STR, ABI, and FMSSI did not provide a good separation of the genotypes exhibiting high yield potential and suffering low loss in grain yield. GMP was found to be better than MPI in separating genotypes exhibiting high yield potential and suffering low loss in grain yield. The studies indicated that breeding for improved grain yield response in sorghum can be realized under stemborer infestation, while maintaining high grain yield potential.

TOL did not distinguish between the genotypes exhibiting high yield potential and suffering low loss in grain yield. Similar observations for TOL have earlier been made by Clarke et al. (1992) for drought tolerance in wheat. Under borer infestation, selections for high grain yield response using TOL would be ineffective to breed for resistance to *C. Partellus,* since the stemborer infestation under natural conditions is often uneven and sporadic.

FMSSI has been widely used by researchers to identify genotypes that are sensitive or tolerant to drought (Fischer and Maurer, 1978). Genotypes with low FMSSI values are considered stress-tolerant; and such genotypes exhibit lower reduction in grain yield under stress compared to non-stress conditions. MPI can be related to grain yield response only when infestation is not too severe. Genotypes with a high MPI have similar performance in both stress and non-stress conditions. However, genotypes with relatively low yields under borer infestation exhibited high MPI values. MPI was highly correlated with grain yield performance, REI, and FSTI, but not with TOL. Genotypes with high MPI may not be in the lowest TOL, and selecting superior genotypes may be difficult. These observations are in agreement with the results obtained for drought tolerance (Clarke et al., 1992; Rosielle and Hamblin, 1981). There was a large variation in index based on geometric mean productivity of the genotypes tested, and it was strongly correlated with both yield potential and grain yield response under stemborer infestation. A highly significant correlation between MPI and GMP suggested that GMP is a good indicator of genotypic performance under stemborer infestation. FMSSI tends to favor low-yielding genotypes, but to a much smaller extent than selection for TOL. The FSTI was highly correlated with GMP, MPI, MRP, and REI. FSTI is also correlated with both grain yield potential and response, and these indices account for large differences in grain yield performance of the genotypes between borer-infested and uninfested conditions, and is similar to drought tolerance reported by Rosielle and Hamblin (1981).

Selections based solely on grain yield response provided an estimate of tolerance to stemborer damage, but may be associated with low grain yield potential under uninfested conditions. Similar observations have earlier been reported for drought tolerance in dry bean (*Phaseolus vulgaris*) under stress and unstressed conditions (Samper, 1984; Samper and Adams, 1985). Therefore, FSTI and GMP seem to be more useful for resistance to stem borer damage in sorghum, as FSTI discriminates the genotypes with high yield and stress-tolerance potential. A general linear model regression of grain yield response on FMSSI revealed a positive correlation during the rainy and post-rainy seasons (R^2= 0. 89** and 0.98**respectively). However, the FMSSI did not differentiate between potentially borer-tolerant genotypes and those that possess low overall yield potential.

Although a potential selection criterion to differentiate the role of antibiosis and tolerance (components of resistance) to *C. partellus* damage, FPLI showed no relationship with grain yield performance under borer-infested and uninfested conditions. However, FPLI has a great bearing since the leaf feeding injury reflects antixenosis and/or early stage antibiosis to stemborer larvae, which restricts the establishment of the borer larvae on the plant, and thus, its population buildup.

Breeding for high grain yield response under borer-infestation is quite difficult, since selections based on resistance to stemborer damage often are associated with low grain yield potential. Negative association between grain yield and FMSSI has been observed under drought conditions in wheat (Fischer and Maurer, 1978), maize (Fischer *et al*., 1983, 1989), lentil (Hamdi and Erskine, 1986), and sunflower (Fereres *et al*., 1986). FMSSI has been considered to be of limited value as a selection criterion for measuring tolerance to drought in wheat (Clarke *et al*., 1992) and common bean (White and Singh, 1991; Schneider *et al*., 1997), as it does not differentiate between potential drought-resistant genotypes and those possessing overall high yield potential. The use of FMSSI is inherently problematic, as it measures tolerance to stemborer rather than grain yield response. Intrinsically low-yielding genotypes exhibit low FMSSI values, since only a small differential in grain yield exists between borer-infested and uninfested conditions. On the other hand, genotypes with a large reduction in grain yield may have superior yielding capacity under both conditions (White and Singh, 1991; Clarke et al., 1992). Selection indices based solely on grain yield response under borer infestation are poor estimators of resistance (Samper, 1984; Samper and Adams, 1985).

Genotypes with small differences in grain yield performance under borer-infested and uninfested conditions had relatively low FMSSI and high GMP and REI values, suggesting that selection should not be based on a single index as this will result in the selection of genotypes with similar grain yields and low grain yield losses. Strong correlations between GMP and REI indicated that both these indices could be used to select for low grain yield loss and high productivity. However, the selection of genotypes with high grain yield potential and adaptation to borer infestation may be achieved by combining selection indices related to the mean grain yield performance under borer-infested and uninfested conditions (GMP and REI), and low levels of grain yield loss under borer infestation.

Selection based solely on grain yield response under borer infestation is a poor estimator of resistance; the resistance may be associated with reduced grain yield potential under un-infested conditions, as seen inbreeding for drought resistance (Samper, 1984; Samper and Adams, 1985). These observations are consistent with those reported for drought tolerance in mungbean (Fernandez, 1993), maize (Farshadfar and Sutka, 2003), and durum wheat (Golabadi et al., 2006). A significant and positive correlation between grain yield and MPI and FSTI indicated that the first dimension separated the high yielding genotypes from the low yielding ones, and the second one separated the borer-tolerant and susceptible genotypes. Thus, most of the genotypes exhibiting high yield potential and suffering low loss in grain yield had high FSTI values, while others had moderate FSTI values, and therefore, FSTI could be used to distinguish the high-yielding genotypes under borer infested and un-infested conditions. Grain yield reduction due to stemborer damage showed a strong association with FMSSI, ABI, SSSI, and TOL. However, GMP, MPI, MRP, REI and FSTI were better predictors for grain yield. These indices can be combined with those associated with grain yield performance under borer-infested and uninfested conditions, since each type of index assesses different biological mechanisms (e.g. tolerance, adaptation, and/or productivity).

The effectiveness of selection indices depends on the borer-induced stress severity, and potential yield greatly influences yield response under stemborer infested conditions. Similar observations have been reported for drought tolerance (Blum, 1996; Panthuwan et al., 2002). It is also important to consider phenological characteristics of sorghum genotypes, such as time to flower and maturity, and grain yield performance under borer-infested and uninfested conditions, when screening and breeding for resistance to *C. partellus*.

Acknowledgements

We thank Messrs. K.V. Hari Prasad, G. Pampapathy, V. Venkateswara Rao, S.V.N. Chandra, J. Raja Rao, Mrs. Ponnamma and Mrs. Vimala for their help in insect rearing and field observations. We also thank Mr Suraj Prasad Sharma for his help in drawing the graphs.

References

Ajala S.O., Odulaja A. and Saxena K.N. (1993). Assessing tolerance to stem borer attack in maize: basic considerations and views, pp. 71-74. In *Beneficial African Insects: A Renewable Natural Resource*. Proceedings of the 10^{th} Meeting and Scientific Conference of the African Association of Insect Scientists. 5-10 September 1993, Mombasa, Kenya.

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

Alghali A.M. (1985). Insect-host plant relationships. The spotted stalk borer, *Chilo partellus* (Swinhoe) (Lepidoptera: Pyralidae) and its principal host, sorghum. *Insect Science and its Application* 6, 315-322.

Alghali A.M. (1987). Effect of time of *Chilo partellus* Swinhoe (Lepidoptera: Pyralidae) infestation on yield loss and compensatory ability in sorghum cultivars. *Tropical Agriculture (Trinidad)* 64, 144-148.

Ampofo, J.K.O. (1986). Maize stalk borer (Lepidoptera: Pyralidae) damage and plant resistance. *Environmental Entomology* 15, 1124-1129.

Anglade P. (1992). Selection pour la resistance et la tolerance du mais a la pyrale, pp. 105-109. In A. Gallais et H. Bannerot (Eds.), *Amelioration des Especes Vegetales Cultivees, Objecstifs et Criteres de Selection*. Institut National de Recherches Agronomiques, Paris, France.

Anglade P., Gouesnard B., Boyat A. and Panouille A. (1996). Effects of multitrait recurrent selection for European corn borer tolerance and for agronomic traits in FS 12 maize synthetic. *Maydica* 41, 97-104.

Bardner R. and Fletcher K.E. (1974). Insect infestation and their effects on the growth and yield of field crops: a review. *Bulletin of Entomological Research* 64, 141-179.

Blum, A. (1996)**.** Crop responses to drought and the interpretation of adaptation. *Plant Growth Regulators* 20, 135-148.

Clarke J.M., Depauw, R.M. and Fred Townley-Smith, T. (1992). Evaluation of methods for quantification of drought tolerance in wheat. *Crop Science* 32, 728-732.

Dabrowski Z.T. and Kidiavai E.L. (1983). Resistance of some sorghum lines to the spotted stalk borer, *Chilo partellus*, under western Kenya conditions. *Insect Science and its Application* 4, 119-126.

Davies J.C. (1981). Pest losses and control of damage on sorghum in developing countries – the realities and myths, pp. 215-223. In *Sorghum in the Eighties: Proceedings of the International Symposium on Sorghum,* 2-7 Nov 1981. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh 502 324, India.

Farshadfar E. and Sutka J. (2003). Screening drought tolerance criteria in maize. *Acta AgronomicaHungarica* 50, 411-416.

Fereres E., Gimenez C. and Fernandez J.M. (1986). Genetic variability in sunflower cultivars under drought I. Yield relationships. *Australian Journal of Agriculture Research* 37, 573-582.

Fernandez C.G.J. (1993). Effective selection criteria for assessing plant stress tolerance, pp. 257-270. In C. George Kuo (Ed.), *Adoption of Food Crops to Temperature and Water Stress: Proceedings of an International Symposium*, 13-18 August 1992. Asian Vegetable Research and Development Center (AVRDC), Taiwan.

Fischer K.S., Edmeades G.O., and Johnson E.C. (1989). Selection for the improvement of maize yield under moisture-deficits. *Field Crops Research* 22, 227-243.

Fischer R.A. and Maurer R. (1978). Drought resistance in spring wheat cultivars. I. Grain yield responses. *Australian Journal of Agriculture Research* 29, 897-912.

Fischer K.S., Johnson E.C., and Edmeades G.O. (1983). *Breeding and selection for drought resistance in tropical maize*. Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT), Mexico D.F., Mexico.

Flattery K.E. (1982). An assessment of pest damage of grain sorghum in Botswana. *Experimental Agriculture* 18, 319-328.

Golabadi, M., Arzani A., Maibody S.A.M. 2006. Assessment of drought tolerance in segregating populations in durum wheat. *African Journal of Agricultural Research* 5, 162-171.

Graham R.D. (1984). Breeding for nutritional characteristics in cereals. *Advances in Plant Nutrition* 1, 57-102.

Hamdi A. and Erskine, W. (1986). Reaction of wild species of the genus *Lens* to drought. *Euphytica* 92, 175-183.

Harris K.M. (1962). Lepidopterous stem borers of cereals in Nigeria. *Bulletin of Entomological Research* 53, 139-171.

Heinrich G.M., Francis, C.A. and Eastin J.D. (1983). Stability of grain sorghum yield components across diverse environments. *Crop Science* 23, 209-212.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics), 1992. *Medium Term Plan 1992*. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh, India.

Jarvis J.L., Zeigler K.E. and Guthrie W.D. (1986). European corn borer (Lepidoptera: Pyralidae) yield losses and damage in popcorn in relation to hybrid and stage of plant development. *Journal of Economic Entomology* 79, 764-768.

Jotwani M.G., Young W.R. and Teetes G.L. (1980). Elements of integrated control of sorghum pests. *FAO Plant Production and Protection Paper No. 39*. Food and Agricultural Organization, Rome, Italy. 159 pp.

Klenke J.R., Russell W.A. and Guthrie W.D. (1986). Recurrent selection for resistance to European corn borer in a corn synthetic and correlated effects on agronomic traits. *Crop Science* 26, 864-868.

Kumar H. (1994). Components of resistance in maize (*Zea mays* L.) to first and second generation *Chilo partellus* (Swinhoe). *Maydica* 39, 165-170.

MacFarlane J.H. (1990). Damage assessment and yield losses in sorghum due to the stem borer, *Buseola fusca* (Fuller) (Lepidoptera: Noctuidae) in northern Nigeria. *Tropical Pest Management* 36, 131-137.

Morgan J., Wilde G. and Johnson D. (1980). Greenbug resistance in commercial sorghum hybrids in the seedling stage. *Journal of Economic Entomology* 73, 51-514.

Ortega A., Vasal S.K. Mihm J. and Hershey, C. (1980). Breeding for insect resistance in maize, pp. 371-419. In F.G. Maxwell and P.R. Jennings (Eds.) *Breeding Plants Resistant to Insects.* John Wiley and Sons, New York, USA.

Panda N. and Heinrichs E.A. (1983). Levels of tolerance and antibiosis in rice varieties having moderate resistance to the brown planthopper, *Nilaparvata lugens* (Stal) (Hemiptera: Delphacidae). *Environmental Entomology* 12, 1204-1214.

Panthuwan G., Fukai S, Cooper M., Rajatasereekul S., O'Toole J.C. 2002. Yield response of rice genotypes to different types of drought under rainfed lowlands. Part 1: Grain yield and yield components. *Field Crops Research* 41, 45-54.

Ramirez, P. and Kelly, J.D. (1998). Traits related to drought resistance in common bean. *Euphytica* 99, 127-136.

Rana B.S., Singh B.U., Jaya Mohan Rao V., Reddy B.B., and Rao N.G.P. (1984). Inheritance of resistance to stem borer in sorghum. *Indian Journal of Genetics & Plant Breeding* 44, 7-14.

Rana B.S., Singh B.U. and Rao N.G.P. (1985). Breeding for shoot fly and stem borer resistance in sorghum. pp. 347-360. In *Proceedings of the International Sorghum Entomology Workshop*, July 15-21, 1984, Texas A&M University, College Station, Texas, USA; International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh 5021 324, India. .

Rosales-Serna R., Ramirez-Vallejo P., Acosta-Gallegos J.A., Castillo-Gonzalez F. and Kelly J.D. (2000). Grain yield and drought tolerance of common bean under field conditions. *Agrociencia* 34, 153-165.

Rosielle A.A. and Hamblin J. (1981). Theoretical aspects of selection for yield in stress and non-stress environments. *Crop Science* 21, 943-945.

Samper C. (1984). *Effect of water stress imposed at mid-pod filling upon yield and dry matter partitioning in dry bean* (Phaseolus vulgaris). M.S. thesis, Michigan State University, East Lansing, Michigan, USA. 131 pp.

Samper C. and Adams M.W. (1985). Geometric mean of stress and control yield as a selection criterion for drought tolerance. *Annual Report of Bean Improvement Cooperative* 28, 53-54.

Saxena K.N. (1990). Mechanisms of resistance/susceptibility of certain sorghum cultivars to the stem borer, *Chilo partellus*: role of behavior and development. *Entomologia Experimentalis et Applicata* 55, 91-99.

Schneider K.A., Rosales-Serna R., Ibarra-Perez F., Cazares-Enriquez B., Acosta-Gallegos J.A., Ramirez-Vallejo P., Wassini N. and Kelly J.D. (1997). Improving common bean performance under drought stress. *Crop Science* 37, 43-50.

Sharma H.C. (1993). Host plant resistance to insects in sorghum and its role in integrated pest management. *Crop Protection* 12, 11-34.

Sharma H.C. (2002). Effect of stem borer damage on fodder quality in sorghum. In *Stakeholders Workshop on Evaluation of the Effects of Plant Diseases on the Yield and Nutritive Value of Crop Residues used for Peri-Urban Dairy Production on the Deccan Plateau in India*, 19 - 22 Feb 2002. International Crops Research Institute for the Semi-Arid Tropics, Patancheru, Andhra Pradesh, India.

Sharma H. C. and Nwanze K. F. (1997). *Mechanisms of Resistance to Insects in Sorghum and Their Usefulness in Crop Improvement*. Information Bulletin no. 45. International Crops Research Institute for the Semi-Arid Tropics, Patancheru, Andhra Pradesh, India. 51 pp.

Sharma H.C., Dhillon, M.K., Pampapathy, G. andReddy B.V.S. (2007).Inheritance of resistance to spotted stem borer, *Chilo partellus* in sorghum, *Sorghum bicolor*. *Euphytica* 156, 117-128.

Sharma H.C., Singh, F. and and Nwanze K.F. (ed.) (1997). *Plant Resistance to Insects in Sorghum.* International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh, India. 205 pp.

Sharma H.C., Taneja S.L., Leuschner K. and Nwanze K.F. (1992). *Techniques to Screen Sorghum for Resistance to Insects.* Information Bulletin no. 32. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh, India. 48 pp.

Singh, B.U. and Rana B.S. (1984). Influence of varietal resistance on oviposition and larval development of stalk-borer, *Chilo partellus* Swin., and its relationship to field resistance in sorghum. *Insect Science and its Application* 5, 287-296.

Singh B.U. and Rana B.S. (1989). Varietal resistance in sorghum to spotted stem borer, *Chilopartellus* (Swinhoe). *Insect Science and its Application* 10, 3-27.

Singh B.U., Rana B.S., Reddy B.B. and Rao N.G.P. (1983). Host plant resistance to stalk-borer, *Chilo partellus* Swin., in sorghum. *Insect Science and its Application* 4, 407-414.

Taneja S.L. and Leuschner K. (1985). Methods of rearing, infestation, and evaluation for *Chilo partellus* resistance in sorghum, pp. 175-188. In *Proceedings of the International Sorghum Entomology Workshop*, 15-21 July 1984, College Station, Texas, USA. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh, India.

Taneja S.L. and Nwanze K.F. (1989). Assessment of yield loss of sorghum and pearl millet due to stem borer damage, pp. 95-104. In *International Workshop on Sorghum Stem Borers*, 17-20 Nov 1987. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh, India.

Thome C.R., Smith M.E. and Mihm J.A. (1994). Yield reduction in a maize diallel under infestation with Southwestern corn borer. *Crop Science* 34, 1431-1435.

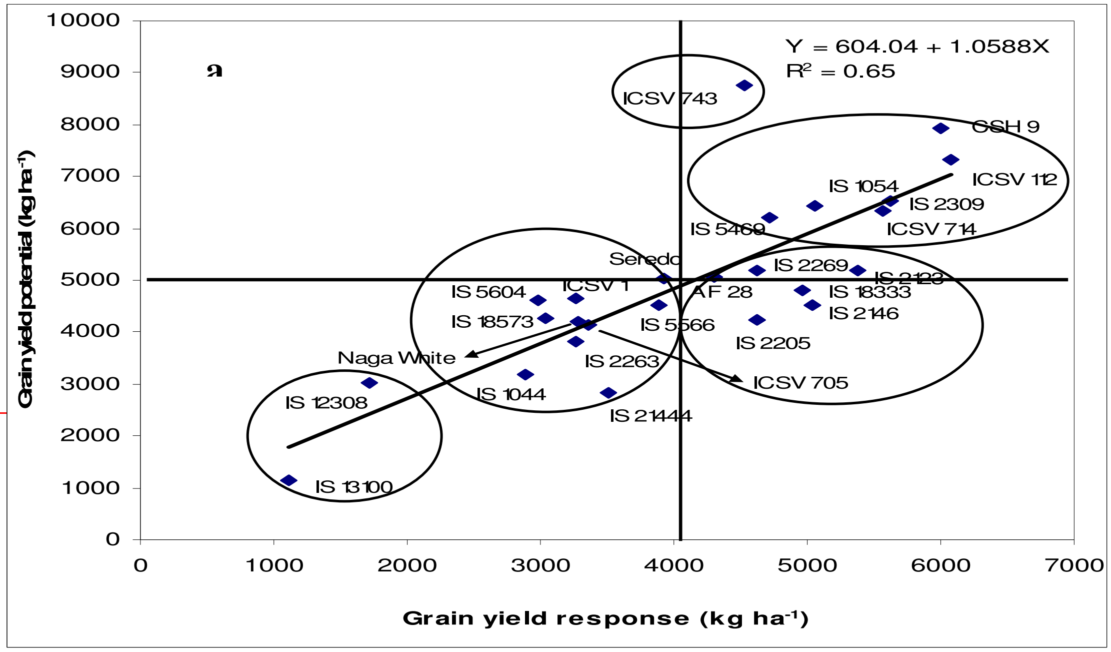
van den Berg J., van Rensburg J.B.J. and Pringle K.L. (1990). Damage caused by *Chilo partellus* (Swinhoe) (Lepidoptera: Pyralidae) to various cultivars of grain sorghum, *Sorghum bicolor* (L.) Moench. *South African Journal of Plant and Soil* 7, 192-196.

Walker P.T. (1981). The relation between infestation by lepidopterous stem bores and yield in maize: methods and results. *EPPO Bulletin* 11, 101-106.

Walker P.T. (1983). The assessment of crop losses in cereals. *Insect Science and its Application* 4, 97-104.

White J.W. and Singh S.P. (1991). Breeding for adaptation to drought, pp. 501-551. In A. van Schoonhoven and O. Voysest (Eds.), *Common Beans: Research for Crop Improvement*. CAB International, Wallingford, UK/Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia.

Fig.1. Relationship between grain yield potential (uninfested conditions) and grain yield response (under stem borer infestation) during the rainy (a) and postrainy (b) seasons.



b

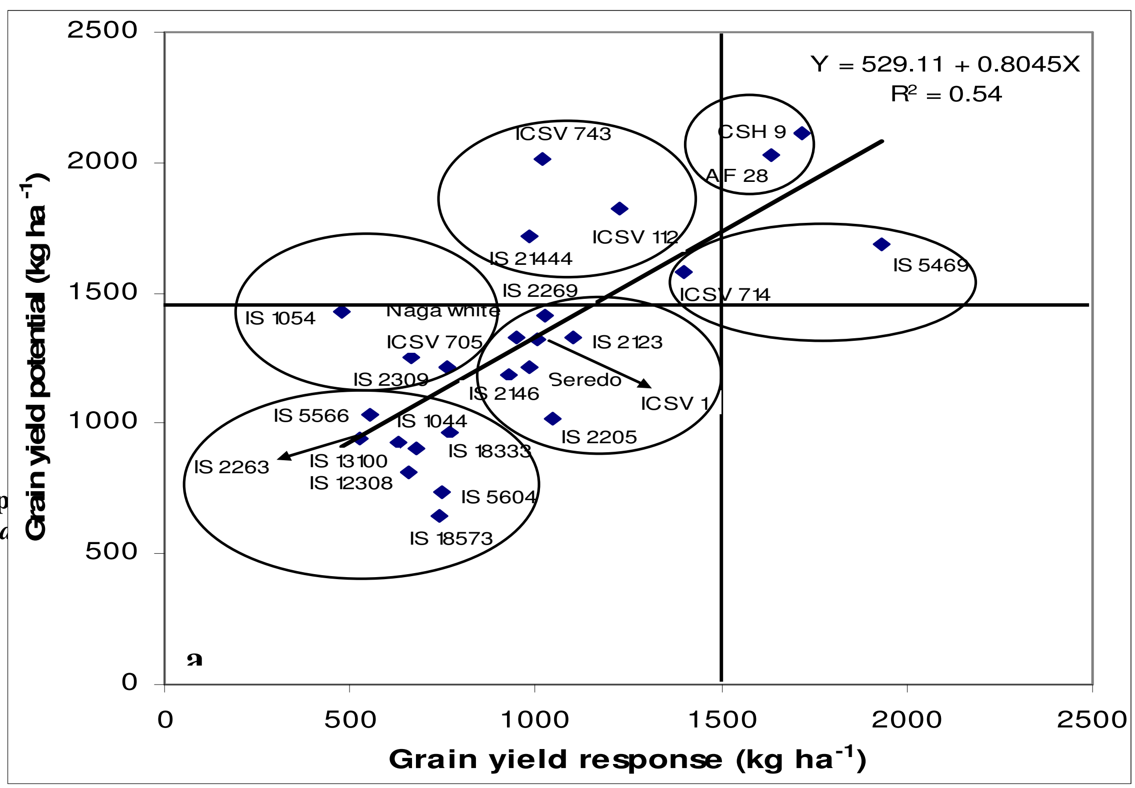
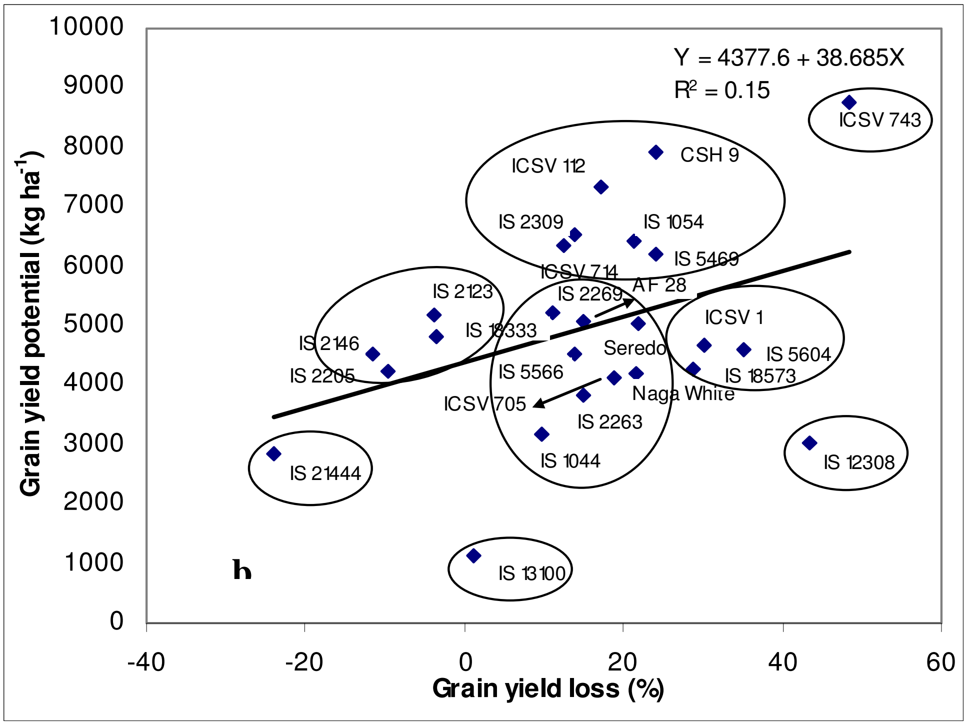
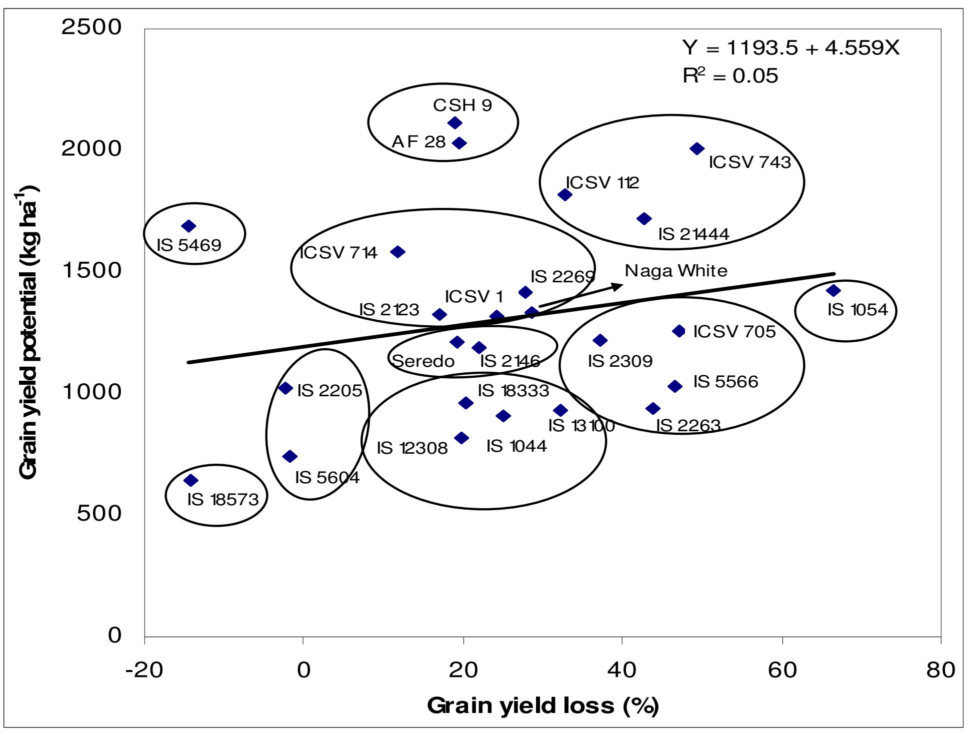


Fig. 2. Relationship
stem borer, *Chilo pa*


Y = 4377.6 + 38.685X
R2 = 0.15
ICSV 743
CSH 9
ICSV 112
IS 2309
IS 1054
IS 5469
ICSV 714
AF 28
IS 2269
IS 2123
IS 18333
ICSV 1
IS 5604
IS 2146
Seredo
IS 5566
IS 18573
IS 2205
Naga White
ICSV 705
IS 2263
IS 1044
IS 21444
IS 12308
h
IS 13100
Grain yield potential (kg ha-1)
Grain yield loss (%)


Y = 1193.5 + 4.559X
R2 = 0.05
CSH 9
AF 28
ICSV 743
ICSV 112
IS 5469
IS 21444
ICSV 714
Naga White
IS 2269
ICSV 1
IS 1054
IS 2123
ICSV 705
Seredo
IS 2146
IS 2309
IS 2205
IS 5566
IS 18333
IS 13100
IS 2263
IS 12308
IS 1044
IS 5604
IS 18573
Grain yield potential (kg ha-1)
Grain yield loss (%)