Effects of *Striga hermonthica* infestation on improved maize cultivars in Ghana

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SUMMARY

Four improved composite varieties of maize (*Zea mays* L.) grown by farmers in the savanna zones of Ghana and one striga-tolerant single-cross hybrid were screened under two levels of striga infestation in replicated field trials at Nyankpala in 1993 and 1994 to determine the effects and severity of striga infection on the varieties. Effects due to striga infestation and varieties were significant ($P<0.05$) for grain yield and some plant and ear traits. The striga infestation level × variety interaction was not significant for any of the traits. Striga infestation reduced plant height by 18.8 per cent, increased lodging by 136.9 per cent, but had no significant effect on the number of leaves per plant in the varieties. Ears per plant, ear weight, grain weight, ear acceptability, and grain yield declined by 22.9, 50.0, 16.5, 24.0, and 66.0 per cent, respectively, in the varieties in response to striga infestation. The results showed that (i) striga infestation had profound detrimental effects on growth and productivity of all the maize varieties, (ii) these effects were less severe in the striga-tolerant hybrid than in the composites, and (iii) breeding to improve cultivar tolerance to striga needs emphasis.

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RÉSUMÉ

SALLAH, P.Y.K. & AFRIBEH, D.: *Les effets de l'infestation de* Striga hermonthica *sur la variété du maïs-amélioré cultivé au Ghana.* Quatre variétés composées améliorées du maïs (*Zea mays* L.) cultivées par les cultivateurs dans les zones savanes du Ghana et un hybride de croisement unique tolérant à la strie étaient tournés au bout d'essai sous deux niveaux d'infestation dans les essais au champ à Nyankpala en 1993 et 1994 pour déterminer les effets et la sévérité d'infestation de strie sur les variétés. Les effets dû à l'infestation de strie et aux variétés étaient considérables ($P<0.05$) pour le rendement de graine et quelques traits de plante et d'épi. Le niveau d'infestation de strie × l'interaction de variété n'était pas considérable pour aucun des traits. L'infestation de strie reduisait la taille de plante par 18.8 pour cent, augmentait l'abattage par 136.9 pour cent mais n'avait aucun effet considérable sur le nombre de feuilles par plante dans les variétés. Les épis par plante, le poids d'épi, le poids de graine, l'acceptabilité d'épi et le rendement de graine déclinaient respectivement par 22.9, 50.0, 16.5, 24.0 et 66.0 pour cent dans les variétés en réponse à l'infestation de strie. Les résultats montraient que (i) l'infestation de strie avait des effets profondément nuisibles sur la croissance et la productivité de tous les variétés de maïs, (ii) Ces effets étaient moins sévères dans les hybrides tolérants à la strie que dans les composées, et (iii) la reproduction pour améliorer la tolérance de la variété à la strie exige l'insistance.

Introduction

Witchweeds (*Striga* spp.) are vascular plant-root parasites of maize (*Zea mays* L.), sorghum [*Sorghum bicolor* (L.) Moench], millet [*Pennisetum americanum* (L.) Leeke], and cowpea [*Vigna unguiculata* (L.) Walpers] in the savanna zones of Africa. Five important species in these zones are *S. hermonthica, S. asiatica* (L.) Kuntze, *S. aspera* (Willd.) Benth., *S. forbesii* Benth., and *S. gesnerioides* (Willd.) Vatke. The first four species infect cereal crops whereas the last attacks cowpea. *S. hermonthica* is the most important and widespread species in Africa (Aggarwal, 1991; Lagoke, Parkinson & Agunbiade, 1991; Musselman, 1987).

The mode of infection of host plants by striga has been reported (Ramaiah *et al.*, 1983). Striga produces several thousands of minute seeds, each measuring about 0.2 mm × 0.3 mm (Ramaiah *et al.*, 1983). Under optimum soil temperature and moisture conditions, striga seeds germinate in response to a stimulant produced by young host roots. The radicle of the striga seedling is transformed into a haustorium to penetrate the host root. After penetrating, the xylem of the parasite establishes connections with that of the host to complete successful attachment to the host. The parasite then becomes a metabolic sink for the carbohydrates produced by the host plant. Before emergence, young striga seedlings are completely parasitic on the host and cause the greatest damage at this stage. On emergence from the soil, the seedlings develop green leaves, are able to produce their own photosynthates, but may continue to depend on the host for water, assimilates, and other nutrients (Ramaiah *et al.*, 1983).

Maize is extremely susceptible to *Striga hermonthica* (striga) infection probably because it is relatively a new crop in the striga-endemic zone. The characteristic symptoms of striga infection on maize include leaf chlorosis, blotching, wilting, scorching, and general stunting (IITA, 1991; Kim, 1991). Highly susceptible maize genotypes show complete scorching of all leaves, severe stunting, and premature death. Striga may reduce the yield of maize by up to 100 per cent if the maize crop is infected at an early growth stage (Efron *et al.*, 1986; Kim *et al.*, 1984; Parkinson, 1985). Under heavy striga infection in an experiment, yield losses of susceptible and tolerant maize hybrids were 91 and 64 per cent, respectively (Kim, 1991). Sauerborn (1991) reported that striga reduced maize yields in farmers' fields by 16 per cent in northern Ghana.

Despite the huge economic losses caused by striga, practical methods for its effective control by small-scale, resource-poor farmers have not been developed. A combination of resistant/tolerant varieties and cultural practices such as rotation with non-host crops, manual and chemical means of preventing seed set in striga, and improved soil fertility have been suggested for striga control and are being investigated by researchers (Berner & Kling, 1997; Lagoke *et al.*, 1991, 1997; Kim, 1991; Ramaiah, 1987; Kim *et al.*, 1985).

Improved maize varieties currently grown by farmers in the striga-endemic zone of Ghana are Dodzi (extra-early maturing), Dorke SR (early maturing), Abeleehi and Obatanpa (medium maturing), and Okomasa (late maturing) (Sallah *et al.*, 1997; Badu-Apraku *et al.*, 1990, 1992; Twumasi-Afriyie *et al.*, 1992; GGDP, 1988). Information on the reaction of these varieties to striga infestation will, therefore, help farmers in choosing appropriate varieties for planting in striga-infested fields. Sallah, Badu-Apraku & Twumasi-Afriyie (1992) observed, in a preliminary study, that early (90-95 days) maize varieties were more tolerant to striga attack than late (115 - 120 days) varieties. However, no information is available for extra-early (75-80 days) and medium (105-110 days) maturing varieties in Ghana.

The study aimed to determine the effects and severity of striga infestation on agronomic performance of four improved cultivars, representing the four maturity groups of maize varieties grown by farmers in Ghana.

Materials and methods

Four open-pollinated maize varieties, Dodzi (extra-early maturing), Dorke SR (early), Abeleehi (intermediate), Okomasa (late), and one élite single cross hybrid 9022-13 (late) were evaluated under artificial striga infestation on a Chanayilli sandy-loam (Plinthaqualf) at Nyankpala in the Guinea savanna zone of Ghana in 1993 and 1994. The open-pollinated varieties are commercial cultivars released by the Crops Research Institute for planting in the major agro-ecologies of Ghana, including the striga zone (Sallah *et al.*, 1997; Badu-Apraku *et al.*, 1990, 1992; GGDP, 1988). The parental lines of the single cross hybrid are tolerant to *Striga hermonthica* and were developed by IITA (Kim, 1994). Table 1 shows other

TABLE 1

Characteristics of Five Varieties of Maize Evaluated Under Two Levels of Striga Infestation at Nyankpala in 1993 and 1994

Variety	Maturity group	Days to maturity	Endosperm+ type	Type of variety++	Parental source
Dodzi	Extra early	75 - 80	W, D/F	OP	TZEEW-SR
Dorke SR	Early	90 - 95	W, D	OP	Pool16-SR
Abeleehi	Medium	105 - 110	W. D	OP	Pop49-SR
Okomasa	Late	115 - 120	W/D	OP	Pop43-SR
9022-13	Late	115 - 120	W, F	Single cross	STRTZi 3 × STRTZi 12

+ W = White endosperm, D = Dent, F = Flint
++ OP = Open-pollinated

characteristics of the varieties.

Mature *Striga hermonthica* seed was harvested from farmers' fields from November to mid-December of 1992 and 1993. The seed was thoroughly sun-dried on the seed stalks before it was threshed. A 250-μm sieve was used to clean the threshed seed. The clean seed was stored in a sealed polyethylene bag at room temperature until June when the field was infested with striga seed harvested in the previous year.

The experimental field was ploughed, harrowed and ridged in both years. The experimental design was a randomized complete block arranged in a split-plot with four replications in each year. Striga infestation levels (control, infested) were randomized in the main plots, and the five maize varieties were randomized in the sub-plots. A sub-plot consisted of four 5-m rows of each variety. The rows were spaced at 0.75 m, and hills were spaced at 0.18, 0.20, 0.23, and 0.25 m for Dodzi, Dorke SR, Abeleehi, and Okomasa, respectively. The same row and hill spacings were adopted for Okomasa and the single-cross hybrid 9022-13.

Fine sand sieved through a 250-μm sieve was used to formulate a 1-per cent germinable striga seed-sand mixture, based on predetermined 70 per cent purity and 65 per cent germination of the striga seed, following the procedure of IITA (1991). The sand-striga mixture was applied at about 1,000 germinable striga seeds to each maize seed hole in the infested plots 2 weeks before sowing the maize (IITA, 1991). Three maize seeds were planted per hill, and the seedlings were thinned at 2 wk after planting to one plant per hill for the target populations of 76,000, 66 000, 56,000 and 53 000 plants ha^{-1} for the extra-early, early, intermediate, and late varieties, respectively.

Pre-emergence chemical weed (other than striga) control was practised and consisted of an application of a combination of Pendimethalin [N - (1-ethylpropyl) - 3, 4 - dimethyl - 2, 6 - dinitrobenzenamine] and Gesaprim [2 - chloro - 4 - (ethylamino) - 6 - (isopropylamino) - s - triazine] at 1.5 l and 1.0 l ha^{-1} a.i., respectively, at planting. Where weed growth before planting was heavy, Paraquat (1, 1' - dimethyl - 4, 4' - bipyridinium ion) was applied at 1.0 l ha^{-1} a.i. besides Pendimethalin and Gesaprim. Plots were also hand-weeded to eradicate weeds before striga emergence. Basal fertilizer was applied 2 weeks after planting at the rate of 30 kg N ha^{-1} and 60 kg P_2O_5 ha^{-1}, and top-dressed with additional N at 30 kg N ha^{-1} at 4 weeks after planting.

Data were recorded on competitive plants within the two middle rows of each sub-plot for days to 50 per cent silk emergence, plant height (cm), number of leaves per maize plant, number of striga plants which emerged per maize plant, striga symptom ratings of the maize varieties, percent total lodging, ears per plant, ear acceptability rating, ear weight (g), 1000 - grain weight (g), and for grain yield (t ha^{-1}) at 15 per cent moisture content. Ears were rated for acceptability on a 1-5 scale with 1 denoting very good ear and 5 denoting very poor ear, based on size and uniformity of ears, kernel arrangement, and grain filling on the ear. Striga symptom on maize plants was rated at 2 weeks after 50 per cent silk emergence on a scale of 1-9; with 1 denoting no symptom, normal maize growth (regarded as highly tolerant), and 9 denoting completely scorched, severely stunted, dead, or dying host plants (regarded as highly susceptible) (Kim, 1994). A variety rated 1-2 was considered highly tolerant, 3-4 was moderately tolerant, 5-6 was tolerant, 7-8 was susceptible, and 9 was highly susceptible.

The experiment was repeated at the same site during the second year. Analyses of variance were, therefore, computed according to split-plot arrangement for each year and combined over years, assuming the fixed effects model (Steel & Torrie, 1980). Phenotypic correlation coefficients were calculated across varieties for each level of striga infestation, using mean grain yield as the dependent variable (Y) and the other traits as the independent variables (X).

Results and discussion

Tables 2 to 4 show mean squares from the analyses of variance for 11 agronomic traits. The effects due to striga infestation were significant ($P<0.05$) for days to 50 per cent silking and ear acceptability rating; highly significant ($P<0.01$) for plant height, percent total lodging, ears per plant, ear weight, grain yield (Table 2), and for 1000-grain weight (Table 3). Striga infestation had no significant effect on number of leaves per plant in the maize varieties (Table 3).

Effects due to varieties were significant for 1000-grain weight and ear acceptability rating, and highly significant for days to 50 per cent silking, plant height, ears per plant, ear weight, and grain yield (Table 2). Varietal effects were also highly significant for number of leaves per maize plant (Table 3) and striga symptom ratings (Table 4). However, differences among the varieties for lodging (Table 2) and for striga emergence (Table 4) were not significant.

Year effects were significant for ear acceptability rating and highly significant for plant height, lodging, ears per plant (Table 2), and for striga symptom rating (Table 4). The year × striga infestation level interaction was significant only for plant height and ear weight (Table 2). The

TABLE 2

Combined Analyses of Variance for Seven Traits for Five Varieties of Maize Evaluated under Two Levels of Striga Infestation at Nyankpala in 1993 and 1994

Sources of variation	*df*	*Mid-silk (days)*	*Plant height (cm)*	*Total lodging (%)*	*Ears per plant (no.)*	*Ear⁺ rating (score)*	*Ear weight (g)*	*Grain yield (t ha⁻¹)*
Year	1	92.5	7182**	5374**	0.60**	7.81*	0.017	1 347367
Reps within year	6	11.4*	760	335	0.02	0.85	0.016	1 478537
Infestation	1	28.8*	18362**	4616**	0.98**	7.81*	0.166**	204 835104**
Year × infestation	1	2.5	3672*	498	0.09	0.31	0.039*	4 214918
Error (a)	6	2.2	434	203	0.02	0.60	0.005	2 326826
Variety	4	645.2**	3404**	82	0.04**	1.16*	0.01**	4 328410**
Year × variety	4	22.2**	268	54	0.04**	1.16*	0.002	74332
Infestation × variety	4	0.5	113	70	0.06**	0.72	0.002	225821
Year × infestation × variety	4	0.5	121	116	0.02	0.59	0.004*	213526
Error (b)	48	1.9	245	61	0.01	0.40	0.001	167713
Total	79							

+ Ear acceptability rating: 1 = very good ear, 5 = very poor ear.
*, ** Significant at 5 and 1 % levels of probability, respectively.

TABLE 3

Analyses of Variance for Two Traits for Five Varieties of Maize Evaluated under Two Levels of Striga Infestation at Nyankpala in 1994

Source of variation	*df*	*Leaves per plant (no.)*	*1000-grain weight (g)*
Replication	3	1.16	1112
Infestation	1	0.63	15960**
Error (a)	3	0.16	334
Variety	4	9.41**	3184*
Infestation × variety	4	2.31	745
Error (b)	24	0.93	933
Total	39		

* ** Significant at 5 and 1 % levels of probability, respectively.

TABLE 4

Combined Analyses of Variance for Two Striga Traits of Five Varieties of Maize Evaluated under Artificial Striga Infestation at Nyankpala in 1993 and 1994

Source of variation	*df*	*Striga emergence (no.)*	*Striga symptom rating+ (score)*
Year	1	9.54	27.23*
Reps. within years	6	2.91	2.89
Variety	4	2.82	3.41**
Year × variety	4	0.94	0.41
Error	24	1.08	0.75
Total	39		

+ Rating on 1-9 scale, 1 = very tolerant and 9 = highly susceptible.
*, **Significant at 5 and 1 % levels of probability, respectively.

year × variety interaction was significant for ear acceptability rating, and highly significant for days to 50 per cent silking and number of ears per plant.

The interaction between striga infestation level and variety was not significant for all the traits, except number of ears per plant. The year × striga level × variety interaction was significant for ear weight but not for the other traits (Tables 2 and 4). The lack of significant interaction between variety and striga infestation level for most of the traits implied striga infestation had similar detrimental effects on the maize varieties.

The number of emerged striga plants per maize plant ranged from three striga plants for hybrid 9022-13 to nine plants for Okomasa (Table 5). Though, differences among the varieties for this trait were not significant (Table 4), each variety supported about 35 striga plants m^{-2}. The striga population supported by a host crop is important, particularly in the quantity of striga seeds contributed to the soil striga-seed bank. Each striga plant can produce several thousands of seeds which can remain viable in the soil for 15 to 20 years even without a suitable host plant (Ramaiah *et al.*, 1983). It is, therefore, desirable that maize varieties that are grown in striga-endemic areas support little or no striga population.

Since the striga infestation level × variety interaction was not significant for most of the traits, the effects of striga infestation on the varieties can be deduced from the main effects of the two factors. Tables 5 and 6 show the effects of striga infestation on plant and ear traits of the maize varieties. On the average, striga infestation significantly delayed silk emergence in the maize varieties by one day, reduced height of maize plants by 18.8 per cent, increased lodging by 136.9 per cent, but had no significant effects on number of leaves per maize plant (Tables 5 and 6).

The significant reduction in height of maize plants observed in striga-infested plots indicated that striga infestation retarded plant growth in the maize varieties. Since the number of leaves per maize plant was not significantly affected by striga infestation, the number of nodes and internodes on the maize plants were similar in infested and un-infested plots. This would suggest that striga infestation retarded growth by suppressing internode elongation in the maize plants.

Fig. 1 presents striga symptom ratings which indicate the severity of infestation of each variety by the parasite. Mean scores (based on 1-9 scale) were 6.0, 6.4, 6.9, 7.2, and 7.6 for hybrid 9022-13, Abeleehi, Okomasa, Dorke SR, and Dodzi, respectively. Abeleehi had the lowest score among the open-pollinated varieties whereas

TABLE 5

Means of Five Agronomic Traits of Five Varieties of Maize Evaluated under Two Levels of Striga Infestation at Nyankpala in 1993 and 1994

	Mid-silk (days)		*Plant height (cm)*		*Leaves per plant (no.)*		*Total lodging (%)*		*Striga per*
Variety	*Control*	*Infested*	*Control*	*Infested*	*Control*	*Infested*	*Control*	*Infested*	*maize plant*+ *(no.)*
Dodzi	47	48	137	110	12.5	11.3	13.8	27.5	5.3
Dorke SR	57	59	168	129	14.[illegible]	13.3	8.6	26.4	6.5
Abeleehi	59	61	152	124	12.3	13.3	11.8	23.9	4.5
Okomasa	62	63	167	138	13.8	14.5	10.9	32.1	8.5
9022-13	63	64	175	148	14.8	14.3	10.3	22.2	2.8
Mean	58	59	160	130	13.6	13.3	11.1	26.3	5.5
LSD (*P*=0.05)	0.7	0.7	8	8	ns	ns	ns	5.5	ns
CV (%)	2.4	2.4	10.1	10.1	7.2	7.2	41.8	41.8	110

+ Observations made 2 weeks after 50 % silking

TABLE 6

Means of Four Agronomic Traits of Five Varieties of Maize Evaluated under Two Levels of Striga Infestation at Nyankpala in 1993 and 1994

	Ears per plant (no.)		*Ear rating*+ *(score)*		*Ear weight (g)*		*Grain weight (g)*	
Variety	*Control*	*Infested*	*Control*	*Infested*	*Control*	*Infested*	*Control*	*Infested*
Dodzi	0.99	0.67	3.0	3.5	146	76	214	175
Dorke SR	0.96	0.66	2.4	3.4	145	79	268	207
Abeleehi	0.96	0.81	2.4	2.8	196	87	266	210
Okomasa	0.94	0.66	2.1	3.3	216	118	241	226
9022-13	0.93	0.89	2.6	2.8	230	125	221	195
Mean	0.96	0.74	2.5	3.1	187	97	242	202
LSD (0.05)	0.04	0.06	0.3	8	19	16	22	13
CV (%)	10.3	10.3	12.6	12.6	28.1	28.1	13.7	13.7

+ Ear rating: 1 = very good ear, 5 = very poor ear.

Dodzi had the highest. On the tolerance/ susceptibility scale, the scores indicated that Abeleehi and the hybrid (9022-13) showed tolerance to while the other varieties showed susceptibility to the parasite.

Fig. 2 and 3 illustrate the effects of striga infestation on grain yields in the varieties. Striga infestation severely depressed yields in all varieties (Fig. 2). Percent yield declined by 57.9, 65.0, 68.5, 68.8, and 69.2 for hybrid 9022-13, Abeleehi, Dorke SR, Dodzi, and Okomasa, respectively. Percent yield reductions were similar, averaging 66.0 for the five varieties (Fig. 2). These yield losses due to striga infestation were comparable to those reported by Sallah, Badu-Apraku & Twumasi-Afriyie (1992) and Kim (1991).

Yield differences among the five varieties across the two levels of striga infestation were significant (Fig. 3). Hybrid 9022-13 significantly out-yielded the composites by 17.7-33.7 per cent. Yield differences between Dodzi and Dorke SR and between Abeleehi and Okomasa were not significant (Fig. 3). On the average, Abeleehi and Okomasa significantly out-yielded Dodzi and Dorke SR by 14.3 per cent. The hybrid consistently showed yield superiority over the open-pollinated varieties at both levels of striga infestation (Fig. 2 and 3).

The tolerance reaction of hybrid 9022-13 to striga infestation observed in this study confirmed

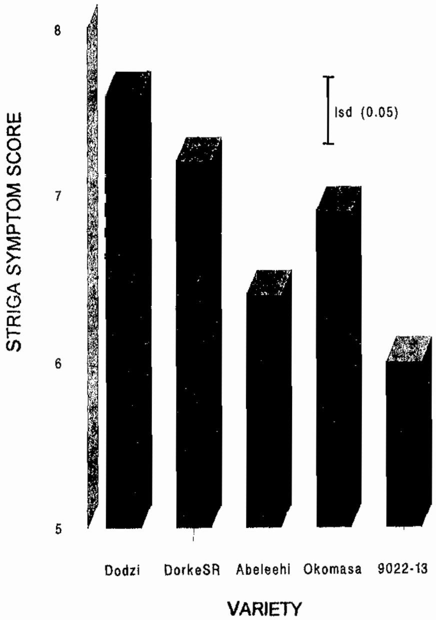

Fig. 1. Striga symptom ratings of five varieties of maize screened under artificial striga infestation at Nyankpala in 1993 and 1994.

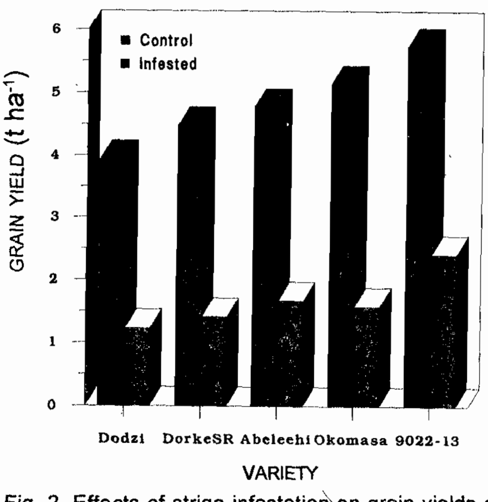

Fig. 2. Effects of striga infestation on grain yields of five varieties of maize screened at Nyankpala in 1993 and 1994.

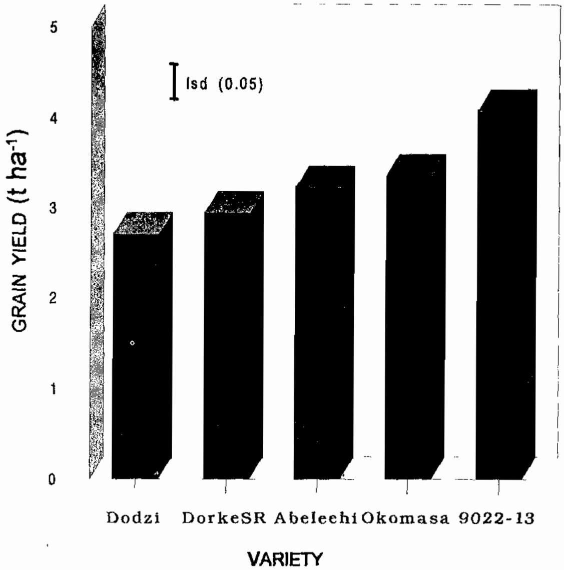

Fig. 3. Mean grain yields of five varieties of maize evaluated under two levels of striga infestation at Nyankpala in 1993 and 1994.

the results of previous studies (Adetimirin & Kim, 1997; Lagoke *et al.*, 1997). Hybrid 9022-13 was developed by IITA for high-yield potential as well as for tolerance to *S. hermonthica*. In contrast, the composites have not been bred for tolerance to the parasite and only one variety (Abeleehi) out of the four showed some tolerance to striga. However, this tolerance reaction did not reflect in the yield potential of Abeleehi under striga infestation.

Table 6 shows the effects of striga infestation on yield parameters. Striga infestation significantly reduced number of ears per maize plant by 22.9 per cent, ear weight by 50.0 per cent, 1000-grain weight by 16.5 per cent, and ear acceptability by 24.0 per cent. Yield losses observed in the varieties under striga infestation can be attributed to the adverse effects of the parasite on these yield components. There is, therefore, the need to develop maize varieties that combine high-yield potential with tolerance to striga to minimize yield losses in the striga zone.

Table 7 presents phenotypic correlation

TABLE 7

Phenotypic Correlations for Grain Yield (t/ha) with Agronomic Traits of Five Maize Varieties Evaluated underTwo Levels of Striga Infestation at Nyankpala in 1993 and 1994

Trait	*Correlation*	
	Control	*Infested*
Mid-silk	0.85	0.72
Plant height	0.77	0.85
Leaves per plant	0.59	0.67
Total lodging	-0.38	-0.58
Striga per maize plant	-	-0.93*
Striga symptom rating	-	-0.92*
Ears per plant	0.89*	0.88*
Ear weight	0.82	0.32
Ear acceptability rating	-0.35	-0.82
1000-grain weight	0.38	0.28

coefficients between grain yield and 10 plant and ear traits of the maize varieties at each level of striga infestation. Ear acceptability rating and total lodging were negatively correlated with grain yield under striga-infested and uninfested conditions. On the other hand, days to 50 per cent silk emergence, plant height, leaves per plant, ear weight, number of ears per plant, and 1000-grain weight showed positive correlations with yield. Number of striga plants per maize plant and striga symptom rating were also negatively correlated with grain yield under striga infestation. However, these correlations were significant only for ears per plant in the control and for number of striga plants per maize plant, striga symptom ratings, and ears per plant under striga infestation. Total lodging, ear rating and grain weight for the control, and ear weight and grain weight under striga infestation showed the least relationship with grain yield.

It was concluded from the study that (1) striga infestation had detrimental effects on growth and productivity of all the maize varieties studied, (2) these effects were less severe in the striga-tolerant hybrid than in the composite varieties, and (3) breeding to improve striga tolerance in maize needs emphasis.

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