l'Ouest. Synthese des travaux realises de 1961 a 1984. Premier seminaire de lutte integree contre les principaux ravageurs des cultures vivrieres, 4-8 Dec. 1984, Niamey, Niger. Ouagadougou, Burkina Faso: Direction Regionale du Projet CILSS/FAO/ USAID de lutte integree. 9 pp.

**FAO and ICRISAT. 1996.** The world sorghum and millet economies: Facts, trends and outlook. Rome, Italy: Food and Agriculture Organization of the United Nations (FAO) and Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), 72 pp.

ITCF. 1991. STAT-ITCF Version 5. Manuel d'utilisation.

**Nwanze, K.F. 1988.** Distribution and seasonal incidence of some major insect pests of sorghum in Burkina Faso. Insect Science and Its Application 9: 313-321.

**Sharma, H.C., Taneja, S.L., Leuschner, K., and Nwanze, K.F. 1992.** Techniques to screen sorghums for resistance to insect pests. Information Bulletin no. 32. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 48 pp.

**Sharma, H.C., Mukuru, S.Z., Manyasa, E., and Were, J.W. 1999.** Breakdown of resistance to sorghum midge, *Stenodiplosis sorghicola.* Euphytica 109: 131-140.

## Inheritance of Resistance to Sorghum Midge and Leaf Disease in Sorghum in Kenya

**H C Sharma[1], S Z Mukuru[2], H Gugi[2], and S B King[2]** (1. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru 502 324, Andhra Pradesh, India; and 2. ICRISAT PO Box 39063, Nairobi, Kenya)

### Introduction

Sorghum [*Sorghum bicolor*(L.) Moench] is one of the most important cereal crops in the semi-arid tropics (SAT). Of the over 150 species of insects that damage the sorghum crop, the sorghum midge *(Stenodiplosis sorghicola* Coquillett), is the most important pest in the Lake Victoria basin area of eastern Africa. Leaf diseases such as anthracnose [*Colletotrichum graminicola* (Cesti.) Wilson], zonate leaf spot [*Gloeocercospora sorghi* (Bains and Edgerton)], leaf blight *[Exserohilum turcicum* (Pass.) Leonard and Suggs.], and rust (*Puccinia purpurea* Cooke) also constitute important constraints to increasing the production and productivity of sorghum in this region.

Nearly 15,000 sorghum germplasm accessions have been screened for resistance to sorghum midge at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, India; and 25 lines have been found to be resistant across seasons and locations in India (Sharma et al. 1993). Most of the high-yielding, midge-resistant lines derived from cv DJ 6514 have shown a susceptible reaction to sorghum midge at Alupe, Kenya (Sharma et al. 1998). To investigate the interactions between midge-resistant and midge-susceptible cytoplasmic male-sterile (cms) lines and restorers for expression of resistance to sorghum midge and leaf diseases, a set of 36 $F_1$ hybrids and their parents [12 restorers showing resistance to sorghum midge in India, and three cms lines (ICSA 88019 and ICSA 88020—resistant to sorghum midge in India, and ICSA 42—a susceptible control)] were tested at Alupe, Kenya in 1994 to determine whether the restorers showing resistance to sorghum midge/leaf diseases combined with the cms lines to produce hybrids with resistance to these pests. Such information is important when selecting parents for transferring resistance into high-yielding varieties and hybrids to increase the production and productivity of sorghum in eastern Africa.

### Materials and methods

Gene action for sorghum midge resistance was studied on two midge-resistant (ICSA 88019 and ICSA 88020) (Agrawal et al. 1996) and one commercial midge-susceptible (ICSA 42) cms lines. Twelve genotypes identified as resistant to sorghum midge in India (Sharma et al. 1993) were used as restorers. Thirty-six $F_1$ hybrids and their parents were sown in a randomized complete block design at Alupe, Kenya during the 1994 short rainy season, in three replications. Each entry was sown in a 4-m long, two-row plot. The experiment was sown twice at an interval of 10 days to avoid escapes, and maximize insect/ disease incidence on the crop. The crop was raised following normal agronomic practices. No insecticide was applied during the reproductive phase of the crop. At maturity, the panicles were evaluated visually for sorghum midge damage (damage rating, DR) on a 1 to 9 scale (1 = <10%, 2 = 11-20%, 3 = 21-30%, 4 = 31-40%, 5 = 41-50%, 6 = 51-60%, 7 = 61-70%, 8 = 71-80%, and 9 = >80% midge-damaged spikelets). Leaf disease (anthracnose, rust, leaf blight, and zonate leaf spot) severity (LDS) was evaluated on a 1 to 9 scale (1 = <10%, 2 = 11-20%, 3 = 21-30%, 4 = 31-40%, 5 = 41-50%, 6 = 51-60%, 7 = 61-70%, 8 = 71-80%, and 9 = >80% of the leaf area infected). Overall LDS was recorded in both the sowings, while individual LDS was recorded only in first sowing, when the LDS was greater than that in the second sowing. The material was also evaluated for agronomic desirability (agronomic score, AS) on a 1-5 scale (1 = agronomically desirable phenotype with high yield potential, 2 = agronomically desirable plant type with moderate yield potential, 3 = tall plant type with moderate yield potential, 4 = tall plant type with low yield potential but acceptable grain quality, and 5= tall plant type with poor yield potential and/or grain quality).

Data on sorghum midge damage (DR), and LDS were subjected to analysis of variance. Significant differences between the treatment means were judged by the F-test, and the treatment means were compared using least significant difference (LSD) at $P<0.05$. Combining ability analysis was carried out according to Kempthorne (1957). The sums of squares due to $F_1$ hybrids was partitioned into the sums of squares due to lines, testers, and their interaction. The F-test was applied to test the significance of line x tester interaction, and if significant, mean squares for the line x tester interaction was used to test the significance of the lines and the testers. The contribution of lines, testers, and their interactions to the total variability for each character was computed to assess their relative importance. The main effects of the lines and testers were equal to general combining ability (GCA), and female interaction with a specific tester was equivalent to specific combining ability (SCA) (Hallauer and Miranda 1981). The standard errors of GCA for the lines and testers were calculated to test the significance of these effects.

## Results

**Sorghum midge.** Restorers IS 22778, IS 18698, and IS 8891 showed moderate levels of resistance to sorghum midge (DR 3.0-5.4 compared with 9.0 in IS 12608C) (Table 1). IS 27103 and DJ 6514 showed moderate levels of susceptibility to sorghum midge (DR 6.3-7.0). B-lines ICSB 88019 and ICSB 88020 also showed moderate levels of susceptibility (DR 5.7-7.7), but ICSB 42 was highly susceptible (DR 9.0). Sorghum midge damage in the hybrids was generally high. Hybrids ICSA 88019 x IS 21703, ICSA 88019 x IS 8891, ICSA 88019 x ICSV 197, ICSA 88019 x DJ 6514, and ICSA 88020 x IS 27103 showed moderate levels of susceptibility to sorghum

**Table 1. Sorghum midge damage, leaf diseases severity, and agronomic score of maintainers of three cytoplasmic male-sterile sorghum lines and 12 restorers over two sowings at Alupe, Kenya, short rainy season, 1994**

| | DR[1] | | LDS[2] | | | | OLDS[3] | | AS[4] | |
|---|---|---|---|---|---|---|---|---|---|---|
| Genotypes | S1[5] | S2 | ANTH | LB | ZLS | RUS | S1 | S2 | S1 | S2 |
| Restorers | | | | | | | | | | |
| IS 2579C | 8.0 | 7.0 | 4.7 | 7.1 | 4.4 | 5.1 | 8.7 | 8.0 | 4.3 | 4.3 |
| IS 27103 | 7.0 | 6.7 | 1.0 | 1.3 | 2.7 | 3.0 | 2.3 | 3.3 | 3.7 | 4.7 |
| IS 21881 | 7.5 | 6.3 | 5.7 | 6.3 | 5.7 | 3.2 | 8.7 | 9.0 | 4.0 | 3.0 |
| IS 8721 | 8.7 | 7.7 | 7.3 | 6.0 | 3.3 | 4.7 | 7.7 | 7.0 | 2.7 | 2.0 |
| IS 8100C | 7.3 | 7.7 | 4.3 | 6.3 | 3.7 | 4.7 | 6.0 | 6.7 | 3.0 | 3.0 |
| IS 22778 | 5.4 | 5.3 | 6,0 | 5.0 | 6.3 | 6.7 | 6.3 | 8.7 | 5.0 | 5.0 |
| IS 12608 | 9.0 | 9.0 | 6.7 | 7.0 | 6.0 | 7.0 | 8.7 | 9.0 | 3.0 | 2.7 |
| IS 8891 | 4.3 | 4.0 | 1.3 | 4.7 | 5.0 | 5.0 | 4.7 | 5.0 | 5.0 | 4.3 |
| IS 18698 | 3.0 | 3.3 | 1.0 | 8.7 | 4.3 | 3.2 | 5.0 | 5.0 | 5.0 | 3.3 |
| ICSV 197 | 8.7 | 7.7 | 1.3 | 6.0 | 3.7 | 5.7 | 4.7 | 4.0 | 2.0 | 3.0 |
| DJ 6514 | 7.0 | 6.3 | 1.3 | 2.0 | 3.7 | 5.7 | 3.0 | 3.3 | 3.0 | 4.7 |
| ICSV 745 | 8.7 | 8.3 | 1.3 | 4.7 | 3.3 | 5.3 | 6.3 | 6.7 | 3.3 | 2.3 |
| Maintainer lines | | | | | | | | | | |
| ICSB 88019 | 7.7 | 7.3 | 1.0 | 3.0 | 3.3 | 3.0 | 4.4 | 3.7 | 4.3 | 4.0 |
| ICSB 88020 | 7.0 | 5.7 | 1.3 | 3.0 | 3.3 | 3.3 | 3.7 | 4.0 | 4.3 | 3.3 |
| ICSB 42 | 9.0 | 9.0 | 1.7 | 3.3 | 4.3 | 4.7 | 7.3 | 7.3 | 2.0 | 1.7 |
| Mean | 8.1 | 7.6 | 2.2 | 4.0 | 4.4 | 5.1 | 7.8 | 5.4 | 2.9 | 2.7 |
| SE | ±0.33 | ±0.53 | ±0.76 | ±0.68 | ±0.50 | ±0.71 | ±0.32 | ±0.51 | ±0.38 | ±0.36 |

1. DR = Midge damage rating (1 = < 10% midge damage, and 9 = >80% midge damage)
2. LDS = leaf diseases severity (ANTH = anthracnose. LB = leaf blight, ZLS = zonate leaf spot, and RUS = rust) (1 = <10% leaf area infected, and 9 = >80% leaf area infected)
3. OLDS = overall leaf diseases severity
4. AS = agronomic score (1 = good, and 5 = poor)
5. SI = crop sown on 21 September 1994; S2 = crop sown on 29 September 1994.

**Table 2. Mean squares for lines X testers analysis for sorghum midge damage, leaf diseases severity, and agronomic expression at Alupe, Kenya, short rainy season, 1994**

| Sources of variation | | DR[1] | | LDS[2] | | | | OLDS[3] | | AS[4] | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | df | S1[5] | S2 | ANTH | LB | ZLS | RUS | S1 | S2 | S1 | S2 |
| Parents | 14 | 9.2**[6] | 8.2** | 17.2** | 13.0** | 3.8** | 6.2** | 13.3** | 13.4** | 3.2** | 3.2** |
| Lines | 2 | 6.4* | 8.1** | 9.2** | 41.6** | 8.2** | 27.8** | 15.0** | 22.6** | 2.5** | 0.6 |
| Testers | 11 | 1.5** | 2.4** | 8.7** | 6.0** | 9.4** | 7.6** | 7.3** | 11.4** | 4.9** | 4.3** |
| Lines x testers | 22 | 0.8* | 1.3[a] | 2.6** | 1.7 | 1.00 | 2.3 | 2.5** | 2.9** | 0.6 | 0.7* |
| Error | 152 | 0.3 | 0.8 | 1.8 | 1.4 | 0.8 | 1.5 | 0.8 | 0.6 | 0.4 | 0.4 |
| Proportional contribution to the total variance (%) | | | | | | | | | | | |
| Lines | | 27.6 | 23.0 | 10.8 | 44.8 | 11.1 | 29.2 | 18.1 | 19.4 | 7.0 | 1.8 |
| Testers | | 35.5 | 36.6 | 56.0 | 35.3 | 72.9 | 44.2 | 48.7 | 53.6 | 75.9 | 73.3 |
| Lines x testers | | 36.9 | 40.5 | 33.2 | 19.9 | 15.5 | 26.6 | 33.2 | 27.0 | 17.1 | 24.9 |

1. DR = Midge damage rating (1 <10%, and 9 = > 80% midge damage)
2. LDS = leaf diseases severity (ANTH = anthracnose, LB = leaf blight. ZLS = zonate leaf spot, and RUS = rust) (1 = <10% leaf area infected, and 9 = >80% leaf area infected)
3. OLDS = overall leaf diseases severity
4. AS = agronomic score ( 1 = good, and 5 = poor)
5. S1 = crop sown on 21 September 1994; S2 = crop sown on 29 September 1994
6. Mean squares significant * $P<0.05$ and ** $P<0.01$, a = significant at $P<0.07$.

midge. Mean squares for parents, lines, testers, and lines x testers were significant (Table 2). The relative contribution of lines x testers and the testers to observed variation was higher (35.5-40.5%) than the lines (23.0-27.6%). The contribution of GCA effects was greater than that of the SCA effects. GCA effects were significant and positive for susceptibility to midge in 1CSA 42, while such effects were significant and negative for ICSA 88019 (Table 3). Amongst the testers, the GCA effects were significant and positive for IS 12608C, IS 2579C, IS 8721, and ICSV 745, and significant and negative for IS 27103, IS 21881, and ICSV 197 in one or both sowings. SCA effects for sorghum midge damage were significant and positive for ICSA 88019 x IS 22778, ICSA 88020 x IS 8721, ICSA 88020 x DJ 6514, and ICSA 42 x IS 8100C, and significant and negative for ICSA 42 x IS 8721. Resistance to midge was predominantly governed by additive gene action.

**Leaf diseases.** Overall leaf diseases severity (OLDS) was low (≤5) in IS 27103, IS 8891, IS 18698, ICSV 197, DJ 6514, ICSB 88019, and ICSB 88020 (Table 1). Restorers IS 27103, IS 8891, ICSV 197, and DJ 6514, in combination with all three cms lines, resulted in hybrids resistant to leaf diseases. Genotypes ICSB 88019, ICSB 88020, IS 27103, IS 8891, ICSV 197, and DJ 6514 were resistant to anthracnose, zonate leaf spot, leaf blight, and rust. Mean squares for parents, lines, testers, and lines x testers (for overall LDS only) were significant (Table 2). The contribution of GCA effects was greater than that of SCA effects (except for anthracnose and zonate leaf spot, where restorers showed greater contribution than the lines and the lines x testers). The proportional contribution of the testers was greater than that of the lines (except for leaf blight as expected) since the number of testers was four times that of the lines. GCA effects were significant and negative for ICSA 88019, while such effects were positive for ICSA 42 (except for zonate leaf spot and rust) (Table 3). GCA effects of ICSA 88020 were significant and positive for zonate leaf spot and rust. GCA effects were significant and negative for DJ 6514, IS 27103, IS 8727 (except for rust), IS 18698, ICSV 197 and ICSV 745 (except for leaf blight), and IS 12608C (for leaf blight only), while such effects were positive for IS 21881 (except for rust), IS 8100C (except for anthracnose), IS 22778, and IS 12608C. SCA effects were significant for ICSA 42 x IS 18698. Resistance to OLDS was governed by additive gene action. Nonadditive gene action was important for resistance to anthracnose and zonate leaf spot, while there was a preponderance of additive of gene action for resistance to leaf blight and rust.

**Agronomic desirability.** Restorers IS 8721, IS 8100C, IS 22778, IS 12608, ICSV 197, and ICSV 745 showed moderate levels of agronomic desirability (AS 2.0-3.3) over the two sowings. Of these, only IS 22778 also showed

**Table 3. General combining ability (GCA) effects of three cytoplasmic male-sterile sorghum lines and 12 restorers for sorghum midge damage, leaf diseases, and agronomic expression at Alupe, Kenya, short rainy season, 1994**

| | DR[1] | | LDS[2] | | | | OLDS[1] | | AS[4] | |
|---|---|---|---|---|---|---|---|---|---|---|
| Lines/restorers | S1[5] | S2 | ANTH | LB | ZLS | RUS | S1 | S2 | S1 | S2 |
| Lines | | | | | | | | | | |
| ICSA 88019 | -0.45*[6] | -0.31* | -0.55* | -0.91* | -0.50* | -0.71* | -0.72* | -0.81* | 0.18 | -0.01 |
| ICSA 88020 | 0.07 | -0.23 | 0.11 | -0.27* | 0.43* | 0.98* | 0.20 | 0.03 | 0.13 | 0.13 |
| ICSA 42 | 0.38* | 0.55* | 0.44* | 1.19* | 0.07 | 0.27 | 0.52* | 0.78* | -0.31* | -0.12 |
| SE(gi) | ±0.097 | ±0.152 | ±0.220 | ±0.196 | ±0.145 | ±0.206 | 0.147 | ±0.128 | 0.108 | ±0.103 |
| SE (gi-gj) | ±0.137 | ±0.215 | ±0.311 | ±0.276 | ±0.206 | ±0.412 | 0.208 | ±0.182 | 0.154 | 0.146 |
| Restorers | | | | | | | | | | |
| IS 2579C | 0.46* | 0.60* | 2.22* | 0.62* | -0.54 | 0.54 | -0.33 | 0.14 | -0.26 | 0.10 |
| IS 27103 | -0.54* | -0.40 | -0.44* | -1.16* | -1.32* | -0.68 | -1.22* | -1.41* | 0.07 | 0.10 |
| IS 21881 | -0.42* | -0.40 | 1.00* | 0.84* | 0.57 | -0.74 | 0.99* | 1.03* | -0.96* | -0.23 |
| IS 8721 | 0.47* | 0.49* | -0.69* | 0.01 | -0.64* | 1.26* | -0.03 | -0.19 | 0.23 | -0.45* |
| IS 8100C | 0.24 | -0.51 | -0.33 | 0.94* | 2.24* | 0.65 | 0.89* | 1.25* | -0.71* | -0.79* |
| IS 22778 | -0.32 | -0.18 | 0.56* | -0.27 | 0.35 | 1.54* | 0.78* | 1.03* | 1.74* | 1.32* |
| IS 12608 | 0.57* | 0.05 | 1.11* | -0.83* | 1.24* | 0.87* | 0.89* | 1.92* | -0.82* | -1.01* |
| IS 8891 | -0.21 | 0.05 | -0.55* | 0.28 | 0.46 | -0.13 | 0.01 | -0.08 | 0.41 | 0.66* |
| IS 18698 | -0.32 | 0.94* | -0.66* | 0.62* | -0.20 | -1.13* | 0.45 | -0.42 | 0.18 | 0.44* |
| ICSV 197 | -0.21 | -0.84* | -0.78* | 0.28 | -0.98* | -0.57 | -0.89* | 1.19* | 0.41 | 0.10 |
| DJ 6514 | -0.21 | -0.06 | -0.66* | -1.61* | -0.31 | -0.69 | -1.77* | -1.64* | 0.29 | 0.55* |
| ICSV 745 | 0.46 | 0.27 | -0.78* | 0.28 | -0.87* | -0.91* | 0.23 | -0.41 | -0.59* | 0.78* |
| SE(gi) | ±0.194 | ±0.304 | ±0.220 | ±0.392 | ±0.291 | ±0.412 | ±0.295 | ±0.257 | ±0.217 | ±0.207 |
| SE (gi-gj) | ±0.274 | ±0.430 | ±0.623 | ±0.554 | ±0.412 | ±0.582 | ±0.416 | ±0.363 | ±0.307 | ±0.292 |

1. DR = Midge damage rating (1 = <10%, and 9 = >80% midge damage)
2. LDS = leaf diseases severity (ANTH = anthracnose, LB = leaf blight, ZLS = zonate leaf spot, and RUS = rust severity (1 = <10% leaf area infected, and 9 = >80% leaf area infected)
3. OLDS = overall leaf diseases severity
4. Agronomic score (1 = good, and 5 = poor)
5. S1 = crop sown on 21 September 1994; S2 = crop sown on 29 September 1994
6. * = GCA effects significant at $P<0.05$.

moderate levels of resistance to midge. The agronomic expressions of ICSB 88019 and ICSB 88020 were poorer than those of ICSB 42. Mean squares for parents, lines (in first sowing), testers, and lines x testers (in second sowing) were significant. Combining ability for agronomic desirability varied considerably over the two sowings. The proportional contribution of the testers was maximum (73.3-75.9%), followed by lines x testers (17.1-24.9%), and the lines (1.8-7.0%). GCA effects of the lines for AS were nonsignificant. Significant and positive GCA effects were observed for AS in the case of IS 8891, IS 18698, IS 22778, and DJ 6514; while IS 22881, IS 8100C, and IS 12608 showed significant and negative GCA effects in one or both the sowings.

## Discussion

Of the 12 genotypes used as restorers that are resistant to sorghum midge at ICRISAT, Patancheru, India (Sharma et al. 1993), IS 22778, IS 18698, and IS 8891 showed moderate levels of resistance to sorghum midge in Kenya in this study. Genotypes DJ 6514, ICSV 197, and ICSV 745; that are highly resistant to sorghum midge in India, showed a susceptible reaction at Alupe, Kenya. The B-lines ICSB 88019 and ICSB 88020-resistant to sorghum midge in India (Agrawal et al. 1996), also showed a susceptible reaction in Kenya. The GCA effects of ICSA 88019 and ICSA 42 for susceptibility to midge were similar to those observed at ICRISAT, Patancheru, India (Sharma et al. 1996), while those of ICSA 88020 were in the opposite direction. Differences in the reactions of midge-resistant lines across locations may be partly due to the influence of the environment on the expression of resistance to midge, and/or the possible occurrence of a new biotype of sorghum midge in the region (Sharma et al. 1998). Resistance to midge was predominantly governed by additive gene action as observed earlier (Widstrom et al. 1984, Agrawal et al. 1988, Sharma et al. 1996). Restorers that showed resistance to midge at Alupe did not combine with midge-resistant cms lines ICSA 88019 and ICSA 88020 to produce midge-resistant hybrids. Therefore, it is essential to transfer resistance to sorghum midge into both parents to produce midge-resistant hybrids for eastern Africa. A start has been made in this direction by screening and selecting the sorghum head pest population (developed at ICRISAT, Patancheru, India) at Alupe. Most of the lines identified as resistant to midge have been introgressed into this population, and there is a good possibility of deriving progenies from this gene pool with resistance to midge at Alupe.

Restorer lines IS 27103, IS 8891, ICSV 197, and DJ 6414 produced leaf disease resistant hybrids in combination with all the three cms lines, indicating that resistance to some of the leaf diseases is dominant. Resistance to anthracnose was governed by nonadditive gene action. Earlier studies have shown that resistance to anthracnose is controlled by a single dominant gene (Reddy and Singh 1992), and that cytoplasm has no influence on expression of resistance. Resistance to leaf blight is polygenic—characterized by few small lesions, and monogenic—characterized by hypersensitive fleck and little or no lesion development. Drolson (1954) reported that resistance to leaf blight is polygenic and recessive, while Frederickson et al. (1978) and Tarumoto et al. (1977) observed that resistance was monogenic and dominant. Cytoplasm has no influence on the expression of resistance to leaf blight (Sifuentes et al. 1992). Resistance genes from different sources behave differently, and are not allelic. The reported studies showed that resistance to leaf blight is controlled by additive gene action. Indira et al. (1983) reported that tan x tan crosses are more resistant to rust than the tan x purple, and purple x purple crosses. Resistance is dominant and is governed by one or two major genes (Anahosur 1992). The present studies showed that resistance to rust can also be inherited additively. Genotypes ICSB 88019, ICSB 88020, IS 27103, IS 8891, ICSV 197 (except for leaf blight), IS 18698 (except for leaf blight), and DJ 6514 were resistant to leaf diseases, and can be used as sources of multiple resistance to sorghum midge and leaf diseases in sorghum improvement programs.

**Acknowledgments**

We thank E Manyasa and J Were for their help in carrying out these experiments, M V Sathyanarayana for statistical analysis, and H D Upadhayaya for his comments on the manuscript.

## References

**Agrawal, B.L., Abraham, C.V., and House, L.R. 1988.** Inheritance of resistance to midge, *Contarinia sorghicola* Coq. in *Sorghum bicolor* (L.) Moench. Insect Science and its Application 9: 43-45.

**Agrawal, B.L., Sharma, H.C., Abraham, C.V., Nwanze, K.F., Reddy, B.V.S., and Stenhouse, J.W. 1996.** Registration of ICS 88019 and ICS 88020 grain sorghum A and B parental lines. Crop Science 36: 825.

**Anahosur, K.H. 1992.** Sorghum diseases in India: knowledge and research needs. Pages 45-46 *in* Sorghum and millet diseases: a second world review (de Milliano, W.A.J., Frederickson, R.A., and Bengston, G.D., eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

**Drolson, P.N. 1954.** Inheritance of leaf blight reaction in Sudangrass. Agronomy Journal 46: 329-332.

Frederickson, R.A., Rosenow, D.T., and Foster J.H. 1978. Inheritance of resistance to *Exserohilum turcicum. In* Proceedings of Sorghum diseases and insect resistance workshop. Publication MP 1373. College Station, Texas. USA: Texas A&M University System. 74 pp.

**Hallauer, A.R. and Miranda, J.B. 1981.** Quantitative genetics in maize breeding. Ames, Iowa, USA: Iowa State University Press.

**Indira, S., Rana, B.S., Rao, V.J.M., and Rao, N.G.P. 1983.** Host plant resistance to rust in sorghum. Indian Journal of Genetics and Plant Breeding 43: 193-199.

**Kempthorne, O. 1957.** An introduction to genetic statistics. New York, USA: John Wiley and Sons.

Reddy, B.V.S. and Singh, S.D. 1992. Sorghum anthracnose (*Colletotrichum graminicola*)— breeding for resistance. Page 17 *in* Cereals Program Annual Report 1992. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. (Limited distribution)

**Sharma, H.C., Abraham, C.V., Vidyasagar, P., and Stenhouse, J.W. 1996.** Gene action for resistance in sorghum to midge, *Contarinia sorghicola.* Crop Science 36: 259-265.

Sharma, H.C., Agrawal, B.L., Vidyasagar, P., Abraham. C.V., **and Nwanze, K.F. 1993.** Identification and utilization of resistance to sorghum midge, *Contarinia sorghicola* (Coquillett), in India. Crop Protection 12: 343-351.

**Sharma, H.C., Mukuru, S.Z., Hari Prasad, K.V., Manyasa, E., and Pande, S. 1998.** Identification of stable sources of resistance in sorghum to midge and their reaction to leaf diseases. Crop Protection 18: 29-37.

**Sifuentes, J.A., Mughogho, L.K., and Thakur, R.P. 1992.** Inheritance of resistance to sorghum leaf blight. Pages 16-17 *in* Cereals Program Annual Report. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. (Limited distribution)

**Tarumoto, I., Isawa, K., and Watanbe, K. 1977.** Inheritance of resistance in sorghum-Sudangrass and sorghum hybrids. Japan Journal of Plant Breeding 27: 216-222.

**Widstrom, N.W., Wiseman, B.R., and McMillian, W.W. 1984.** Patterns of resistance to sorghum midge. Crop Science 24: 791-793.

## Color Variation in the African Sorghum Head Bug

**H C Sharma[1] and A Ratnadass[2]** (1. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru 502 324, Andhra Pradesh, India. 2. ICRISAT-Centre de cooperation internationale en recherche agronomique pour le development (CIRAD), BP 320, Bamako, Mali)

Sorghum [*Sorghum bicolor* (L.) Moench] is an important cereal crop in West Africa. It is damaged by over 150 species of insects worldwide, of which *Eurystylus oldi* Poppius (Heteroptera: Miridae) is one of the most damaging pests in West and Central Africa (Ratnadass et al. 1994). Published reports of *Eurystylus* spp. on sorghum suggest a complex of species are involved in West Africa. *Eurystylus marginatus* Odh. was recorded as the dominant species in Mali (Doumbia and Bonzi 1985), *E. rufocunealis* Poppius in Nigeria (MacFarlane 1989), *E. risbeci* Sch. in Senegal (Risbec 1950), *E. marginatus* in Niger (Steck et al. 1989), and *E. immaculatus* Odh. in Nigeria and Mali (Sharma et al. 1992, 1994; Ratnadass et al. 1994). However, based on head bug collections from several locations in West Africa, Stonedahl (1995) reported that the major head bug species infesting sorghum in West Africa is *E. oldi* Poppius, with *E. bellevoyei* Reuter sometimes occurring as a minor pest. Previous identifications of *E. marginatus* were misidentifications, while *E. risbeci* and *E. immaculatus* are synonyms of *E. oldi.* This confusion about species identity has, to an extent, been due to various color morphs of *E. oldi,* and to different names being assigned by taxonomists at different times/locations.

Few farmers recognize head bugs on sorghum, and most are not familiar with the nature of the damage these insects cause. Agronomists and breeders in general are unaware of head bugs, and their damage potential. This ignorance is attributable to the relatively small size of the insects, and the fact that both nymphs and adults tend to assume the same color as that of the panicle/grain. There is therefore a need to educate farmers/extension workers, agronomists, and breeders on the identification and pest status of *E. oldi* in West and Central Africa. In this paper color variation in *E. oldi* in relation to panicle/grain color in sorghum is reported.

In 1989, first- and second-instar head bug nymphs collected from sorghum panicles in the field in Nigeria and Mali, were sorted into red, red-brown, and green color morphs. The nymphs were reared on green or red-colored sorghum grain, corresponding to 'white' and 'brown' grain classes. Red-colored nymphs reared on red grain developed into reddish adults with bluish-green undersides, while the green nymphs reared on green grain developed into greenish-brown adults with bluish-green undersides. Red-brown nymphs reared on green grain became brown-black adults, with light green undersides. Red nymphs reared on green grain became light green or red, while green nymphs reared on red grain developed into light green adults. Dark brown nymphs reared on green grain became brown-red adults.

Observations on the changes in color of the nymphs and adults were confirmed during the 1999 rainy season at Samanko, Mali. The green first-instar nymphs collected from white- or tan-grained sorghum cultivars S 34 or ICSV 197, that have green immature grain, developed into greenish-brown adults with bluish-green undersides when reared on the maturing green grains of the same white- or tan-grained cultivars, or of chalky-grained cv Nagawhite. The green first-instar nymphs collected from white- or tan-grained sorghum cultivars, S 34 or ICSV 197, developed into reddish-brown adults with bluish-green undersides with distinct red markings on their abdominal segments, when reared on the maturing red grains of Sorvato 28 or Framida (which is actually brown-grained: its grain has both a pigmented testa and a red pericarp).

The green third-instar nymphs collected from panicles of the tan-grained sorghum cultivar ICSH 89002 developed into greenish-brown adults with bluish-green undersides when reared on the maturing green grains of the same tan-grained cultivar. However, the nymphs developed into light green adults when reared on the maturing red-brown grains of Framida. The red third-instar nymphs collected from panicles of the red-brown grained sorghum Framida developed into reddish-brown adults with light green undersides in males, and bluish-green females with red markings on their abdominal segments, when reared either on the maturing red grains of