Quantifying Resistance of Sorghum Genotypes to the Sugary Disease Pathogen (*Claviceps africana*)

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ABSTRACT

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Sorghum lines were screened for resistance to the sugary disease pathogen (*Claviceps africana*) at two localities in South Africa. Of 71 lines that remained disease-free at Potchefstroom, only three remained disease-free at Bethlehem. Ranking of lines according to disease incidence was not correlated at the two localities, and the use of mean sugary disease incidence as a rating criterion was questioned. Nonlinear regression analysis was used to determine the relationship between disease potential associated with different inoculation dates and observed disease incidence within lines. Lines could be classified into three categories, i.e., those linearly related to disease potential, those highly susceptible even at low disease potentials, and those with various degrees of resistance despite increasing disease potentials. Lines in the latter group differed with respect to resistance breakdown points and the subsequent rate of resistance breakdown. These criteria proved to be useful for quantifying resistance as they are fixed values that are independent of fluctuations in flowering dates and variations in climatic conditions during flowering and infection.

The reaction of sorghum (*Sorghum bicolor* (L.) Moench) to sugary disease caused by *Claviceps africana* Frederickson, Mantle & De Milliano depends on cool, wet conditions during early flowering (4,5). A suggested method of screening for disease resistance is to plant so as to synchronize flowering and inoculation with the occurrence of such favorable conditions (5). In South Africa and other semiarid regions, climatic cycles are unpredictable, and synchronizing flowering with the desired climatic conditions is virtually impossible. Thakur and King (6) recommended sprinkler irrigation two to three times daily for 10–15 days after inoculation to standardize conditions for ergot development in millet. However, temperature variations of relatively small magnitude before flowering and during the first 4 days after pollen shed significantly affect sugary disease incidence, and genotypes differ in their response to changes in temperature (3,4). This, together with natural variation in flowering dates both within and across sorghum genotypes, has resulted in inaccurate comparisons of sugary disease incidences in resistance evaluation trials. The extent to which differences in disease incidences reflect the host genotype or the result of differences in climate associated with differing flowering dates is, therefore, questioned.

The need to develop a reliable scoring technique for sugary disease of sorghum was listed as a major priority by the international workshop on sorghum diseases in 1978 (2). The aim of this study was to determine a more absolute method of quantifying resistance to sugary disease that takes into account the host-pathogen-environment interaction.

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MATERIALS AND METHODS

Sugary disease evaluation blocks, consisting of 216 sorghum lines, were planted at Potchefstroom (Transvaal) and Bethlehem (Orange Free State). Each block contained approximately 60 plants per genotype, and three plantings were spaced from mid-November to early January. This ensured three primary flowering dates at each locality, ranging from early February to late March, to provide differing climatic conditions during flowering and inoculation. The choice of localities was based on long-term mean maximum temperatures of 25.8 and 24.5 C and 28.5 and 27.1 C for February and March at Bethlehem and Potchefstroom, respectively. Plots at both localities were fertilized with 300 kg ha^{-1} 2:3:2 (N-P-K [22% active ingredient]), and lines were planted in rows spaced 1.2 m apart, 6 m long, with 10-cm spacing between plants. Plots were maintained until flowering with insect and weed control and irrigation applied as required.

At flowering (± 10% pollen shed in male normal genotypes or stigma emergence in male sterile genotypes), sorghum heads were sprayed until runoff with a spore suspension of *C. africana* in water (approximately 10^4 spores per milliliter determined with a hemacytometer). Ten heads per genotype were inoculated on three to four different dates at each locality and marked accordingly. At the soft dough stage of grain development, the percentage of florets per head infected with sugary disease (i.e., secreting honeydew) was estimated visually. These ratings were used to calculate the mean sugary disease incidence per line at each locality and the mean disease incidence associated with each inoculation date, both within each line and across all lines.

RESULTS

Mean infection levels in lines differed considerably at Bethlehem (33.73%) and Potchefstroom (11.98%), both in terms of disease incidence per se and the ranking of lines (Spearman rank correlation, $r = 0.46$). Seventy lines remained disease-free at Potchefstroom, whereas all but three lines were susceptible to sugary disease at Bethlehem. Sugary disease incidence in these lines ranged from 0 to 64.6% (Fig. 1).

Regression analysis, using the model $Y = AX^b$, where X = mean sugary disease incidence over all lines associated with a specific inoculation date (indicative of the disease potential at a specific inoculation time) and Y = mean disease incidence within each line associated with a specific inoculation date, was used to quantify the variation in disease incidence. This yielded three types of relationships between sugary disease potential and observed sugary disease incidence (Fig. 2). These were defined by the b parameter. Where $b = 1$ (Fig. 2A), a linear relationship between sugary disease potential and observed sugary disease incidences within a line was indicated. Where $b > 1$ (Fig. 2B), initial resistance to the disease, despite increasing disease potential, was implied, whereas $b < 1$ (Fig. 2C) implied susceptibility despite a low disease potential. Applying calculated A and b parameters to the model, the sugary disease resistance breakdown point (SDBP) of each line could be determined for any arbitrary disease (Y) level; i.e., the disease potential required to produce a disease severity that would be regarded as the minimum acceptable level of infection. In the present study, this was calculated for $Y = 1\%$ (1% SDBP) and ranged from 0 to 28.2%. Only four lines had 1% SDBPs greater than 20%, whereas 187 lines had 1% SDBPs of less than 10%. A second criterion, the rate of resistance breakdown at 1% SDBP, could be determined by the model $dy/dx = AbX^{(b-1)}$. This ranged from 1,445% disease inci-

dence increase per potential unit in the extremely susceptible line Coes (P) to 0.10% in SA170. Results of the best 30 and the weakest five lines evaluated in the study are presented in Table 1. Also presented in Table 1 are the mean sugary disease incidences recorded at Bethlehem and Potchefstroom, respectively.

DISCUSSION

Seventy sorghum lines apparently were resistant to the sugary disease pathogen at Potchefstroom. The high disease incidence in these lines at Bethlehem, which has a milder climate, shows that a comparison of mean disease incidences, without clear definition of environmental conditions or disease potential, does not adequately reflect disease resistance. Similar observations have been recorded in pearl millet studies in which ergot resistance was not consistent (7). These observations suggest that environmental effects overshadow genetic effects on the phenotype. The present study shows that, with the exception of three, all lines evaluated were more or less susceptible to sugary disease at some stage, depending on disease potential. This finding agrees with those of Ajrekar (1), who tested numerous varieties of sorghum and found none to be totally resistant to infection by the sugary disease pathogen, and with Sundaram (5), who reported resistance was limited.

The primary points of difference between lines in the present study were the relationship between disease potential and observed disease incidence ($b < 1$, $b = 1$, or $b > 1$), the 1% SDBP and, to a lesser extent, the rate of resistance breakdown. Two of the three lines that remained disease-free (BTX602 and IA30) flowered at relatively low disease potentials (maximum potential = 10.1 and 21.68% at Potchefstroom and Bethlehem, respectively) and, as a result, were not subjected to disease pressure high enough to enable the calculation of SDBP. SA1304 was subjected to a maximum disease potential of 32.57%, at which point breakdown had not yet occurred. This disease potential is considerably higher than the breakdown point recorded for SD1/91, the best genotype presented in Table 1.

The importance of taking into account the rate of resistance breakdown is illustrated in SA170, with a rate of 0.1 per disease potential unit. This line had a 1% SDBP of 14.72% (Table 1) but a 5% SDBP of 43.25. In contrast, SD1/91, which had the highest 1% SDBP of 28.22, had a 5% SDBP of 35.21. SDBP should not be considered as a sugary disease evaluation criteria without taking into account the rate of disease resistance breakdown, and, ideally, a high SDBP and low subsequent rate of resistance breakdown should become primary breeding objectives.

This study illustrates the need for taking into account the dependence of sugary disease on fluctuations in climatic variables (3,4). The primary advantage of SDBP and rate of resistance breakdown as criteria are that they are fixed values and, therefore, independent of fluctuations in disease potential during disease development. The high coefficient of multiple correlation values obtained in the study, furthermore, suggest that they are reliable criteria for sugary disease measurement. However, the key to deter-

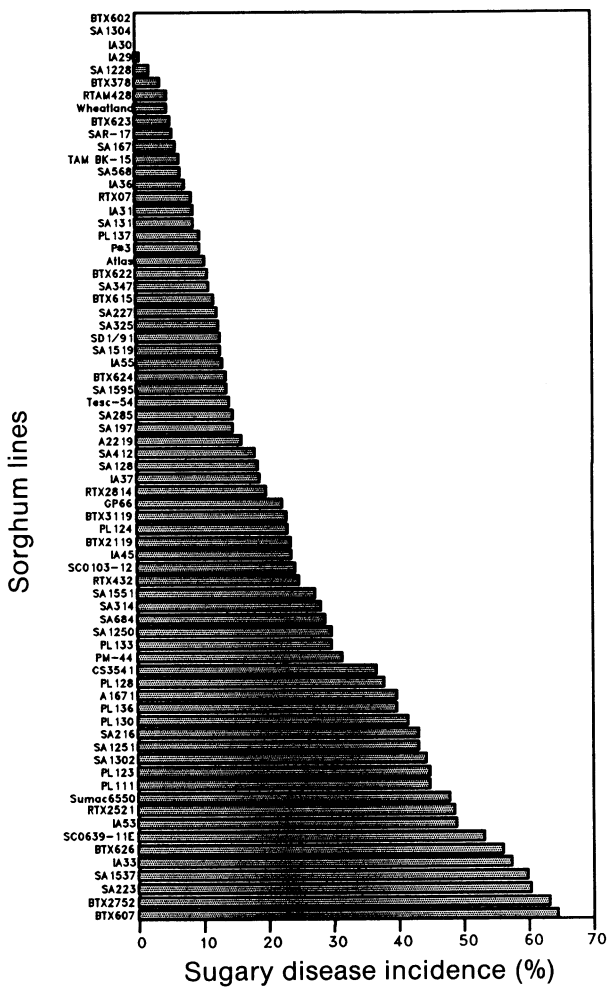

Fig. 1. Incidence of sugary disease in sorghum lines at Bethlehem that remained disease-free at Potchefstroom.

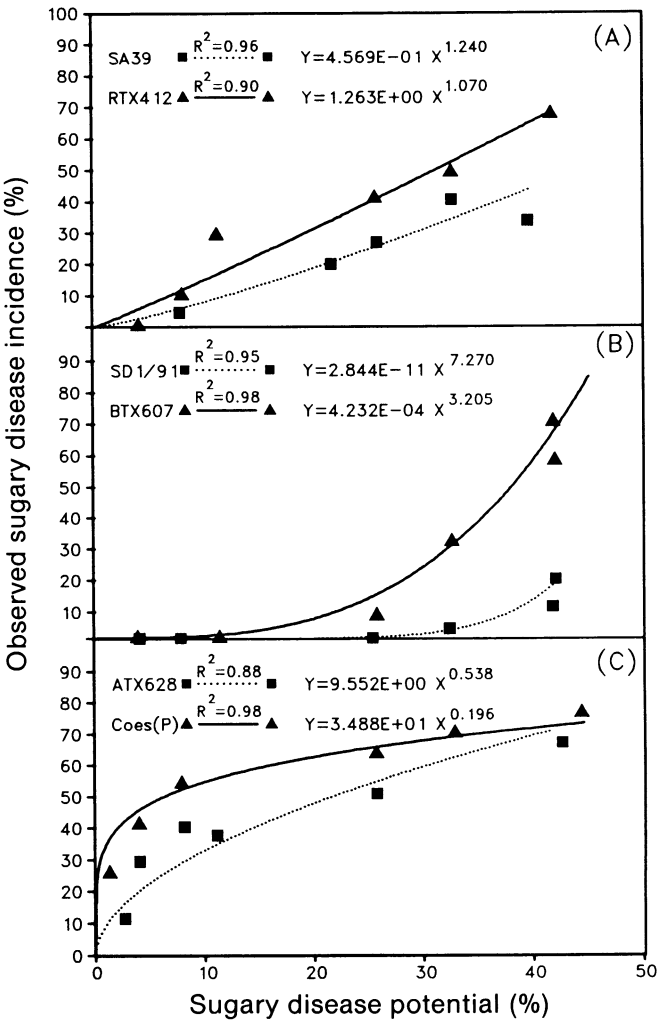

Fig. 2. Illustration of three relationships between sugary disease incidence in sorghum lines and sugary disease potential using $Y = AX^b$, where **(A)** $b = 1$, **(B)** $b > 1$, and **(C)** $b < 1$.

Table 1. Calculated parameters[a] for the relationship between sugary disease potential and sugary disease incidence in sorghum lines, 1% sugary disease resistance breakdown points (1% SDBP), rate of resistance breakdown, and sugary disease incidences at Bethlehem and Potchefstroom

Sorghum line	*A* parameter	*b* parameter	R^2	1% SDBP	Rate of breakdown	Disease incidence (%)	
						Bethlehem	Potchefstroom
30 best lines							
SD1/91	2.844E−11	7.27	0.95	28.22	0.26	13.20	0.00
SA1619	5.000E−07	4.61	0.99	23.23	0.20	5.83	0.00
SA197	5.000E−08	5.39	0.93	22.58	0.24	15.64	0.00
RTAM428	3.023E−05	3.45	0.99	20.51	0.17	5.00	0.00
Texioca-54	2.500E−07	5.14	0.91	19.20	0.27	14.38	0.00
SA314	2.910E−06	4.35	0.91	18.68	0.23	28.33	0.00
SA568	1.360E−05	3.87	0.85	18.11	0.21	7.00	0.00
IA36	1.172E−04	3.15	0.98	17.64	0.18	7.73	0.00
Wheatland	3.150E−06	4.42	0.99	17.62	0.25	4.39	0.00
SA1524	1.458E−05	3.97	0.96	16.53	0.24	41.04	3.32
QL-3	4.879E−05	3.56	0.76	16.22	0.22	23.75	2.12
SA325	9.011E−05	3.39	0.98	15.58	0.22	12.78	0.00
SA481	2.026E−04	3.11	0.57	15.37	0.20	27.86	3.06
SA170	1.801E−02	1.49	0.94	14.72	0.10	33.13	7.22
A3122	8.073E−09	7.00	0.97	14.33	0.49	7.14	11.82
IA37	2.167E−05	4.05	0.99	14.19	0.29	19.62	0.00
SA1508	6.774E−05	3.63	0.91	14.04	0.26	43.57	6.88
SA626	1.017E−04	3.50	0.81	13.84	0.25	37.22	4.48
IA55	1.990E−06	5.11	0.98	13.07	0.39	13.43	0.00
73K152	5.328E−03	2.05	0.99	12.84	0.16	5.12	2.86
SA131	7.313E−04	2.85	0.99	12.60	0.23	9.11	0.00
BTX630	3.672E−04	3.17	0.92	12.11	0.26	37.50	1.68
BTX622	2.591E−04	3.31	0.98	12.11	0.27	11.11	0.00
Spur Feter.	1.504E−03	2.65	0.99	11.57	0.23	30.00	0.00
BTX607	4.232E−04	3.21	0.98	11.28	0.28	64.55	0.00
GP-197	9.373E−04	2.96	0.97	10.55	0.28	41.43	4.09
SA1523	2.537E−03	2.56	0.95	10.36	0.25	27.50	32.86
RTX2737	5.372E−02	1.26	0.86	10.11	0.13	59.29	6.11
PL-137	6.668E−03	2.17	0.90	10.07	0.22	9.98	0.00
1268	4.433E−03	2.43	0.69	9.27	0.26	8.75	0.00
Five weakest lines							
ATX628	9.552E+00	0.54	0.87	0.02	35.66	68.00	34.22
PL-106	9.096E+00	0.48	0.73	0.01	47.52	48.13	19.96
ATX631	1.217E+01	0.47	0.85	0.00	99.16	67.10	49.51
IA43	1.039E+01	0.38	0.95	0.00	169.56	37.58	51.00
Coes (P)	3.488E+01	0.20	0.98	0.00	1,445.19	68.00	54.68

[a]For the function $Y = AX^b$ where X = sugary disease incidence over all lines associated with a specific inoculation date, Y = mean disease incidence within each line associated with a specific inoculation date, b parameter = relationship between sugary disease potential and observed sugary disease incidence, and A = expected disease incidence at $X = 0$.

mining these values is the creation of at least five epidemics that differ with respect to climatic conditions and that create a range of disease potentials from a low potential to beyond the highest expected breakdown point. Spacing of planting dates by 10–14 days throughout the season can ensure this. An added advantage of these criteria is that the reaction of sorghum genotypes to sugary disease infection can be compared over seasons if standard genotypes, planted at regular intervals throughout the season, are used to measure the disease potential of different flowering dates. Similarly, SDBP and rate of resistance breakdown comparisons over seasons could provide a useful measure of progress in a sugary disease resistance breeding program.

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