Bird and Rust Damage and Seed Molds in 30 Sorghum, *Sorghum bicolor* (L.) Moench., Lines in Mayagüez, Puerto Rico[1]

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ABSTRACT

Thirty sorghum lines were evaluated under humid tropical conditions in Mayagüez, Puerto Rico in 1980. In order of importance, bird damage, seed molds, and rust were the major constraints to optimum yields and seed quality. Finches (Fringillidae) mostly *Tiaris bicolor* and black birds (Icteridae) mostly *Quiscalus niger* were the most common sorghum eating birds. Seed losses from birds varied from 0 to 97.3% depending on the sorghum line. The mean loss from birds over all lines was 50.7%. Only two sorghum lines, IS 7013 der (0%) and SC0414-12 (ADN 252) (3%) suffered less than 10% seed losses. Over all sorghum lines a strong positive correlation (r = 0.81**) was found between severity of bird damage and the length of the period between 50% flowering and 50% physiological maturity. A low correlation (r = 0.39*) was found between the 125-seed weight and the severity of bird attack. Twenty-five genera of fungi were found on sorghum seeds. Clean seed frequency (seeds without signs of fungi) was highly correlated with seed germination in in vitro tests (r = 0.89**). During delayed harvest, visible mold on seeds increased markedly. Significant losses in seed germination were found at 1 and 2 weeks delayed harvest. Seeds infected with *Fusarium moniliforme* and *Curvularia lunata* were 60% lower in viability than noninfected seeds. *Phoma* spp. and *Nigrospora* sp. were associated with 20 to 40% reductions in seed viability. *Colletotrichum graminicola* did not lower seed viability of infected seeds. Sorghum rust severity varied from 0.6 to 46.6% among lines. All but 6 lines showed rust severity of less than 15%. Over all lines there was no significant correlation between rust severity and yield. Six rust susceptible lines (15 to 46.6% rust severity) yielded 63.8% ± 22.6 g/m^2, whereas 6 of the most resistant lines (rust severity of less than 3%) yielded 126.6 ± 46.4 g/m^2. Based on pest resistance, rapid grain fill and yield, IS 12610 der, IS 12661 der, and SCO(414-12) (ADN 252) appear to be excellent candidates for further testing at Mayagüez. In avoiding seed pests, sorghum lines appeared to benefit from a rapid germination and emergence, a comparatively long vegetative growth period, and a short uniform grain filling period.

INTRODUCTION

Throughout much of the world, sorghum—(*Sorghum bicolor* (L.) Moench.)—is an important crop used as food and feed. Compared with other cereals, only wheat, maize, rice and barley exceed the world production of sorghum. Based on sorghum's high yield, versatility in cropping systems, and drought tolerance, it may be useful as a field crop in Puerto Rico on land previously devoted to sugarcane. Sorghum plantings for forage and grain are expanding on the north and south coasts.

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Animal production (dairy, poultry, meat, and pork) have been strong agricultural commodities in Puerto Rico and constitute the backbone of the local agricultural economy. The vast majority of feeds for these industries is imported from abroad, mostly from the mainland United States. Imported feed maize (*Zea mays* L.) exceeds 600,000 tons and has an estimated value of about $30 million per annum. Sorghum could substitute for maize in most feeds. Over 70% of the cost of poultry production in Puerto Rico is based on feed costs. Certainly, for this industry to remain competitive and thrive, increased local production of animal feeds is necessary to improve feed availability and lower costs.

Pests are major constraints on the production of field crops worldwide. The importance of specific pests varies depending on climatic, seasonal, and geographic conditions. For this reason, successful production usually depends on dynamic local programs to control pests. A key to effective pest control in field crops is the development of disease and insect resistant cultivars and hybrids and their deployment. This effort usually demands input from plant breeders and crop protection specialists.

Sotomayor-Ríos (9) and Hepperly et al. (6, 7) have reported birds and seed molds as major constraints to high yield and quality of sorghum in Puerto Rico. The purpose of this study was to explore more deeply and quantify losses in sorghum in Mayagüez, Puerto Rico. Studies were focused on the variability among sorghum lines for resistance to pests and on host factors, such as length of developmental stages, which may be associated with pest resistance and yield.

MATERIALS AND METHODS

The experimental field was located at the Tropical Agriculture Research Station of the United States Department of Agriculture, Agricultural Research Service, at Mayagüez, Puerto Rico, and laboratory analyses were conducted at the Department of Crop Protection, College of Agricultural Sciences, University of Puerto Rico, Mayagüez Campus. Soil of the experimental field was of Consumo-Humatas association. This association is characterized by its formation under constant high rainfall and temperatures (humid tropical conditions). The resulting soil is a heavy kaolinitic clay with a sticky plastic texture, medium low nutrient availability and acid pH. The farm is located at approximately 200 m above sea level with a yearly temperature range from 16.0 to 34.4° C, and a yearly rainfall of about 1930 mm. Monthly rainfall during the experimental months of February, March, April, and May were 42, 89, 119, and 215 mm, respectively.

Thirty sorghum entries were supplied by Dr. D. T. Rosenow, Texas Agricultural Experiment Station, Lubbock, Texas. Names and codes of these are as follows.

Entry No.	Designation
1	IS 12602C
2	IS 12661 der
3	IS 7419 C
4	IS 7254 C
5	IS 3552 der
6	74 PR 759
7	IS 1269 der
8	IS 7013 der
9	IS 12610 der
10	CS 3541
11	B 2219
12	TP 3 RO3-316-3
13	TP 4- -5-
14	TP 9 RO ms-2-86
15	IS 2856
16	71 SLT 113-8
17	TP 2 RO2-318-21
18	IS 9530
19	(4283 X Gb 7000)
20	IS (3271) (Homo wx)
21	IS (3318,19) (Sg wx)
22	IS (3323) (Homo wx)
23	IS 10542
24	IS 413
25	IS 412
26	IS 3349 (ADN 116)
27	SCO414-12 (ADN 252)
28	SCO599-6-3 (9247)
29	Tx 2536
30	(SCO110-9XSCO120-6) (4130)

Entries were planted January 26, 1980 and the last harvest was completed June 10, 1980. Entries were planted in a randomized complete block design with three replications. Experimental plots consisted of three 11.5 m long rows with one meter between rows. The center row of each plot was harvested. On the basis of harvest date, the plots were split equally. Plots were harvested at physiological maturity, harvest maturity, 1 week following harvest maturity and 2 weeks following harvest maturity. Harvest maturity was considered as the time when grain moisture was 15 to 20%.

Sorghum was grown under intensive management. All plots were fertilized with 561 kg/ha of 15-5-10 fertilizer which was broadcast and incorporated prior to planting. Thirty days after emergence an equal amount of fertilizer was banded alongside sorghum rows. The planting was irrigated as needed to maintain vigorous growth. Weeds were controlled by pre- and post-emergent herbicide applications and by mechanical and hand weeding. Propazine,[3] Milogard^{RT}—(2-chloro-4,6-bis(isisopropylamine s-triazine a.i.), CIBA Geigy Corp., Greensboro, North Carolina)— was applied at 2.8 kg/ha as a pre-emergent herbicide and 20 days after emergence as a post-emergent herbicide. Insects were controlled by weekly sprays of carbaryl, Sevin^{RT} (1-naphthyl methylcarbamate a.i., Union Carbide Chemical Co., Salinas, California) at a rate of 0.56 kg/ha. To discourage finches insecticide dosages were increased to 4.94 kg/ha during grain fill. To enhance foliar coverage and retention, 0.5% polysorbate was included in the insecticide preparation as a spreader-sticker. Sorghum panicles were harvested by hand and dried under greenhouse conditions to 12% moisture.

Data were collected on length of sorghum development stages: 1) time to 50% emergence; 2) time to 50% flowering; and 3) time to physiological maturity. Emergence was checked on experimental plots every other day following planting for three weeks. Half flowering was noted when the plot had over 50% in flower. To determine physiological maturity five plants in the center row of each plot were evaluated. Panicles were observed at their equatorial area and seeds were examined for black layer formation.

Bird attack was recorded by visually rating percentages of eaten grain in plants at physiological maturity. Foliar diseases were visually rated based on subjective estimation of the percentage of necrotic area on foliage at physiological maturity.

Seed dried to 12% moisture threshed and cleaned was weighed to determine experimental yields. Seeds were mixed thoroughly and then randomly sampled for seed analyses. From each sub-plot two 50-seed lots were sampled. Seed from all seedlots was observed under the dissecting microscope for presence of visible fungal growth. Seeds were planted on moist cellulose pads, clean seed separated from seed with fungal signs, and those with fungal signs were grouped according to the type of fungal sign present. Seeds were incubated for 7 to 14 days at 25° C and 95% RH after which germination and fungal growth was recorded. The other 50-seed lot was not observed under the dissecting scope, but instead submerged in 0.5% NAOCl for 4 minutes, rinsing in sterile distilled water and their aseptic transfer to sterile potato dextrose agar (Difco Brand). These seeds were incubated 7 to 14 days at 25° C before data on microorganisms and germination were recorded.

[3] Trade names in this publication are used only to provide specific information. Mention of a trade name does not constitute a warranty of equipment or materials by the Agricultural Experiment Station of the Univesity of Puerto Rico, nor is this mention a statement of preference over other equipment or materials.

RESULTS

Sorghum entries varied in the length of their developmental stages (table 1). There was more variation among sorghum entries for length of the emergence period and grain filling period than for the length of the vegetative cycle and total life cycle. Emergence time varied from 5.7 to 11.0 days and grain filling period from 23.7 to 45.3 days; vegetative periods ranged from 52.7 to 67.0 days.

TABLE 1.—*Variability among 30 sorghum lines in days to 50% emergence, days from 50% emergence to 50% flowering, days from 50% flower to 50% physiological maturity, and total field time to physiological maturity*

Entry No.	Days			
	Planting to 50% emergence	50% Emergence to 50% flowering	50% Flowering to 50% physiological maturity	Total cycle
1	9.0	54.3	45.3	108.6
2	7.7	66.3	30.3	104.3
3	9.3	53.0	41.7	104.0
4	6.3	54.0	44.0	104.3
5	5.7	58.3	37.0	101.0
6	9.0	56.3	35.7	104.4
7	9.0	56.3	39.3	104.6
8	7.7	52.7	23.7	84.1
9	7.3	66.7	35.0	109.0
10	8.3	62.3	34.0	104.0
11	6.7	61.3	39.3	107.3
12	8.7	55.0	36.7	100.4
13	5.7	63.7	31.7	101.1
14	7.7	62.3	34.0	104.0
15	9.7	53.3	41.3	104.3
16	7.7	55.3	41.5	104.5
17	6.3	59.0	36.0	101.3
18	9.7	53.3	41.3	104.3
19	8.0	66.0	33.0	107.0
20	10.0	60.7	33.3	104.0
21	6.0	59.7	38.7	104.4
22	7.0	65.0	29.0	101.0
23	10.0	61.0	35.7	106.7
24	8.0	58.0	36.5	102.5
25	8.3	54.7	39.0	102.0
26	7.3	60.7	36.0	104.0
27	6.3	67.0	30.7	104.0
28	6.0	59.7	37.7	101.4
29	11.0	63.0	35.0	109.0
30	7.7	59.3	33.3	100.3
Range	5.7–11.0	52.7–67.0	23.7–45.3	84.1–109.0
Mean	7.91	59.20	36.19	103.39
S.E.	0.26	0.82	0.84	0.80
(S.E./mean)100	3.28	1.38	2.32	0.77

TABLE 2.—*Bird damage, rust severity, seed size and grain yield for 30 sorghum lines grown under humid tropical conditions in Mayagüez, Puerto Rico in 1980.*

Entry No.	Percentage		125-seed weight (g)	Grain yield (g/m²)
	Bird damage	Rust severity		
1	97.3	5.7	ND[1]	ND
2	22.5	10.0	2.77	207.1
3	82.5	18.3	ND	ND
4	87.5	11.7	3.43	18.9
5	42.5	3.3	3.15	237.1
6	51.7	31.6	2.71	145.5
7	63.3	16.7	4.66	112.0
8	0.0	5.0	2.88	97.9
9	12.0	3.0	3.10	290.3
10	24.3	3.3	3.80	138.5
11	36.7	15.0	1.88	42.0
12	59.4	2.7	3.94	43.6
13	70.0	6.0	3.25	139.9
14	58.3	6.7	2.72	96.4
15	78.3	8.3	4.18	39.4
16	94.7	1.7	3.76	35.2
17	47.5	1.8	3.63	286.4
18	96.3	46.6	3.40	20.8
19	25.0	11.0	3.30	219.0
20	14.0	2.0	3.44	240.1
21	83.3	5.7	3.39	88.8
22	14.9	6.0	2.88	168.1
23	34.4	7.3	3.60	156.6
24	34.2	13.3	3.26	123.6
25	71.7	28.3	3.44	63.0
26	34.2	11.7	2.91	219.0
27	3.0	5.7	2.74	274.9
28	72.5	0.6	3.17	68.5
29	60.0	1.7	3.34	46.2
30	50.0	10.3	4.18	267.7
Range	0.0–97.3	0.6–46.6	1.88–4.66	18.9–290.3
Mean	50.73	10.03	3.31	138.8
S.E.	5.28	1.85	0.11	16.7
(S.E./mean)100	10.4	18.4	3.3	12.0

[1] ND = no data due to insufficient harvest.

Losses from birds ranged from 0 to 97.3% (table 2). Estimated losses from birds were highly correlated to entry yields (r = 0.68**) (fig. 1). Over the 30 entries length of grain filling periods were highly correlated with estimated losses from birds (r = 0.81**) (fig. 2).

The following tabulation shows the 25 genera of fungi identified as seed molds based on the assay of four 50-seed samples from each of 28 sorghum lines at each of four harvests starting at physiological maturity and ending at 2 weeks after normal harvest.

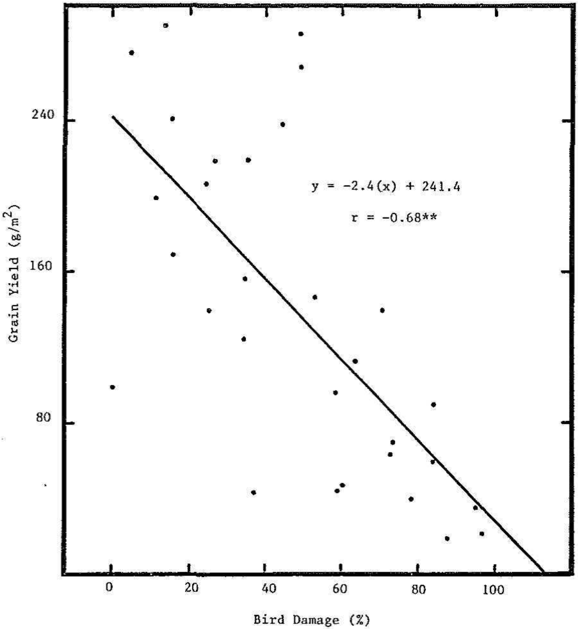

FIG. 1.—Relationship of bird damage to sorghum grain yield in 28 sorghum lines grown under humid tropical conditions in Mayagüez, Puerto Rico.

Alternaria	*Drechslera*	*Penicillium*
Aspergillus	**Epicoccum*	**Periconia*
**Bactrodesmium*[4]	*Fusarium*	*Phoma*
**Briosia*	*Giberella*	**Rhinocladiella*
Cephalosporium	*Gloeocercospora*	*Rhizopus*
Choanephora	*Gonatobotrys*	**Torula*
Cladosporium	**Metarrhizium*	**Trichoderma*
Colletotrichum	*Nigrospora*	**Verticillium*
Curvularia		

[4] Asterisk denotes genus of fungi not previously reported from sorghum seed.

Nine of these genera were not previously reported as seed molds in sorghum. *Phoma* spp. and *Colletotrichum graminicola* were the predominant fungi found externally on sorghum seeds (table 3). *Curvularia* spp., *Fusarium moniliforme* and *Phoma* spp. were the dominant fungi found internally in the seed. The dominant internally seed-borne fungi were all associated with reduced levels of seed viability. On the other hand, *Colletotrichum graminicola* which appeared mostly externally, was not

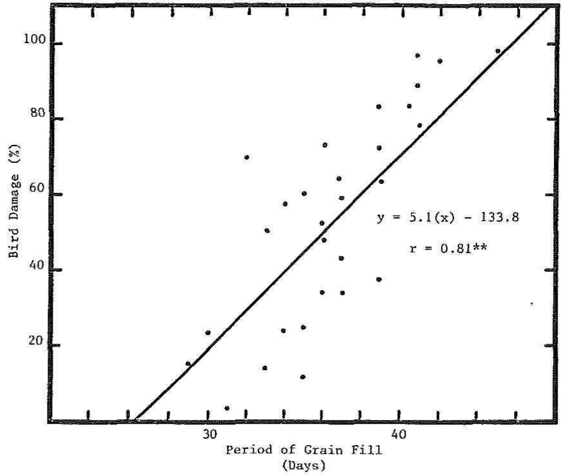

FIG. 2.—Relationship of bird damage to period of sorghum grain fill for 30 sorghum lines grown under humid tropical conditions in Mayagüez, Puerto Rico.

associated with reduction in seed viability compared to seed without fungal signs.

Time of harvest was an important determinant of sorghum seed quality and viability (fig. 3). Marked increases in visible seed mold and reduced seed viability was noted at 14 and 21 days after physiological maturity. Over all entries seed viability was never over 75% even at physiological maturity. Viability of seed dropped to less than 50% 21 days after physiological maturity.

Based on visible seed quality differences, 28 of the 30 entries were classified into four groups (fig. 4). Two lines, IS 12602C and IS 7416C did not yield sufficient seeds for testing. In all groups a similar rate of deterioration was noted as indicated by similar slope values in regression lines of harvest maturity days versus clean seed frequency. There was a marked difference in the y-intercepts of the reaction groups. Period of grain fill of the reaction groups was highly correlated with clean seed frequency ($r = 0.95^{**}$) (fig. 5).

Most sorghum lines had a rust severity of less than 15% (table 2). There was no significant overall correlation between rust severity and yield; nevertheless, lines with high rust severity (greater than 15%) had low yield compared to the most resistant entries. Seed weight varied from 1.88 to 4.16 g/125 seed. Seed size was negatively associated with grain yield ($r = 0.41^{*}$). Based on yield, bird resistance, seed viability, rapidity

TABLE 3.—*The comparative frequencies of the dominant field fungi identified as external molds or internally borne in sorghum seeds from 30 sorghum lines grown under humid tropical conditions in Mayagüez, P. R.*

Fungi	Percentage[1]	
	External Signs[2]	Isolated Internally[3]
Phoma spp. (*P. glomerata* and *P. lingam*)	18.8	22.0
Curvularia spp. (*C. lunata* and *C. brachyspora*)	5.6	29.5
Fusarium moniliforme	4.6	27.5
Colletotrichum graminicola	10.4	3.0
Nigrospora sp.	1.5	7.5

[1] Based on the evaluation of four 50-seed samples for each of 28 sorghum lines planted in Mayagüez and harvested at normal harvest maturity in 1980.

[2] Seeds were examined under the stereoscope to determine frequency of fungal signs.

[3] Seeds were surface disinfected in 0.5% NaOCl, plated on potato dextrose agar, and incubated at 95% RH and 27 C to determine internal infections.

of grain fill, and rust resistance, sorghum lines IS 12610 der, IS 12661 der, and SCO(414-12) (ADN 252) appear excellent candidates for further testing.

DISCUSSION

In our study, birds were by far the most constraining factor to sorghum production. An abundance of bird habitat probably contributes to the local importance of birds. Doggett (2) espoused elimination of birds and their habitat as a valid control of grass seed eating birds on major crops. We question the elimination of hedge rows, bush, and shrub lands in semi-arid zones where sorghum is a major crop since these are instrumental in controlling excessive wind and water erosion of soil resources. Mismanagement of fragile semi-arid zones can easily lead to increased desertification as is now occurring in Africa.

Finches were the principal consumers of sorghum grain in our study. Observation of other workers have shown distinctive birds as sorghum pests on each continent (3). In none of these reports were finches cited

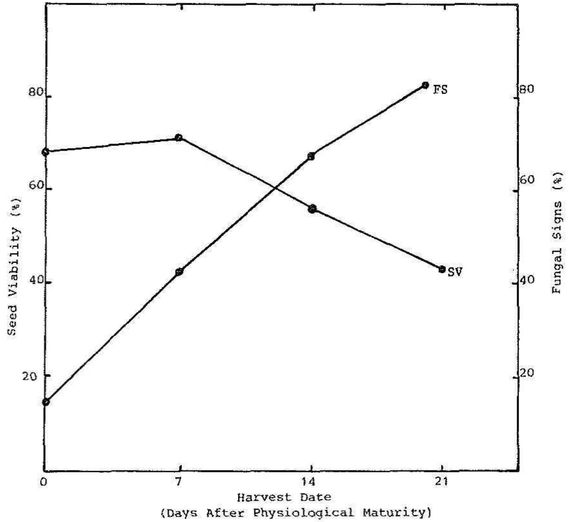

FIG. 3.—Frequencies of fungal signs on sorghum seed and sorghum seed viability as influenced by harvests at physiological maturity and at 7, 14, and 21 days thereafter. Means are based on visual assay and germination tests of four seedlots of 50 seed each, for each of 29 sorghum lines at each harvest date.

as a major pest as we have found in Puerto Rico. The distinctive populations of birds between regions suggests that means of controlling them or avoiding their damage may also be distinctive and vary between regions. Increased knowledge of the biology of local finches may be important in effectively controlling them or avoiding losses in Puerto Rico. We found that local finches mainly attacked sorghum grains in the "milk stage" similar to the attack of sorghum by sparrows in North America (3). Time from flowering to physiological maturity in the sorghum lines we studied was strongly associated with the extent of bird damage. We suggest that a short grain filling period limits losses by birds in sorghum because the most attractive stage, the milk stage, is reduced. Breeding sorghum for short uniform grain filling periods and synchro-

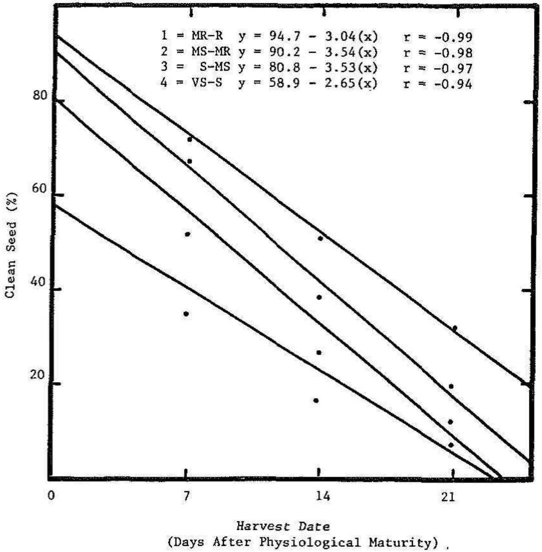

FIG. 4.—Relationship of period of sorghum grain fill to the frequency of clean sorghum seed (seed without fungal signs) in 28 sorghum lines grouped in four categories based on variable deterioration of seed under delayed harvest.

nization of sorghum plantings on a regional scale would likely reduce potential losses in sorghum from birds.

Two sorghum lines IS 7013 der and SCO(414-12) (ADN 252) suffered less than 10% bird losses in our studies. IS 7013 der is a brown seeded astringent sorghum. Voigt (12) and Harris (5) reported that sorghum lines with brown seeds and high levels of polyphenols were resistant to birds. Doggett (2) criticized use of bird resistance in sorghum based on the low nutritional value and palatability of brown astringent sorghums. McMillan et al. (8) found diverse sources of bird resistance not related to dark color or astringency. In our studies levels of bird damage were not strictly related to sorghum color or astringency. This suggests that further work on development of bird resistant sorghum is indeed war-

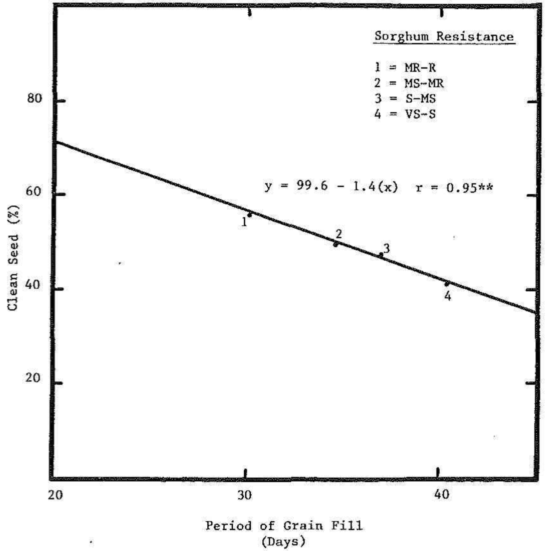

FIG. 5.—Clean sorghum seed (seed without visible fungal signs) in four categories of sorghum lines (seven lines per category). Separation based on variable field deterioration at harvest, at physiological maturity and at 7, 14 and 21 days thereafter under humid tropical conditions in Mayagüez, Puerto Rico in 1980.

ranted.

In the past, sorghum grain mold has been considered a minor disease (10, 13). Recent questionaires from the International Crops Institute for the Semi-Arid Tropics (ICRISAT) have shown that sorghum breeders and pathologists throughout the tropics consider grain molds of major economic importance in sorghum (14). Williams and Rao (14) suggest that the increasing tendency to plant sorghum under more humid environmental conditions is mainly responsible for the increasing importance of grain molds. Older sorghum cultivars were photoperiod sensitive and tended to avoid grain molds by maturing in the dry season. Work in Puerto Rico shows that under humid conditions grain molds are major factors limiting quality and yield (6, 7).

Thirty fungal genera are reported worldwide from sorghum seeds (14). In our studies, 25 genera were found, 10 of which were not previously reported from sorghum seed. These results suggest that the microflora of sorghum seed is still incompletely known and deserves further study.

Of the genera encountered *Fusarium* and *Curvularia* were the most commonly internally borne in sorghum seed, and had the greatest association with reduced seed viability and decreased seedling vigor. Castor and Frederiksen (1) noted *Alternaria* and *Helminthosporium* as major grain molds in Texas. In Puerto Rico, we found low incidences of these fungi both internally and externally on sorghum seeds.

We are not aware of any published studies on the epidemiology of sorghum grain molds. Among 28 diverse sorghum lines harvested, seed appearance and visible seed quality varied markedly within each harvest date. When sorghum lines were classified into four appearance groups, all groups showed the same rate of seed decline over delayed harvests. Van der Plank (11) equated disease losses with rate or velocity of disease increase, timing of the initial infection, level of initial inoculum, or period of disease progress. Because all sorghum lines appeared to decline at similar rates, observed differences in quality are probably related to differences in either amount or timing of initial infections or the period of disease progress. Chemical control studies have indicated that flowering is the most critical stage for the fungicidal protection of sorghum grain from seed molds (Hepperly et al., unpublished). In the present study, length of grain filling has been associated with the extent of bird damages, and losses in seed appearance. We believe that further work should focus on how host factors limit initial infections to understand how sorghum lines vary in severity of fungal decay.

Rust was the most widespread foliar disease. Only six lines had rust severity of over 15%, but their yield was considerably less than that of most of the resistant lines. Frederiksen and Rosenow (4) noted that sorghum reactions to rust were somewhat different between Texas and Puerto Rico. Rust is generally more severe in Puerto Rico. Several factors may contribute to the rust problem in Puerto Rico, but the constant presence of infected weed sorghums and continuous favorable conditions for rust are probably foremost. In Texas and in tropical areas with a well defined dry season natural factors may curtail rust development. Use of resistant varieties is crucial to adequate control of sorghum rust in the humid tropics.

The results of our study indicate that pests may severely limit the expansion of sorghum production in humid areas of Puerto Rico. A coordinated and continuous effort of crop breeders and protection specialists is needed for the successful introduction of sorghums in humid areas in Puerto Rico. To become economically viable, sorghum production in the humid tropics will require improved control of major pests. The current low yields of sorghum under humid tropical climates may be associated with the greater importance of pests under these conditions.

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