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Sorghum head-bugs and grain molds in West and Central Africa: II. Relationships between weather, head-bug and mold damage on sorghum grains

A. Ratnadass[a,*], D.R. Butler[b], P.S. Marley[c], R. Bandyopadhyay[d,1], D.E. Hess[e,2], I. Akintayo[f]

[a] *ICRISAT-CIRAD, Samanko, BP 320 Bamako, Mali*
[b] *Cocoa Research Unit, University of the West Indies, St Augustine, Trinidad and Tobago*
[c] *IAR, Samaru, Ahmadu Bello University, PMB 1044, Zaria, Nigeria*
[d] *ICRISAT-Patancheru, Andhra Pradesh 502 324, India*
[e] *ICRISAT-Mali, Samanko, BP 320 Bamako, Mali*
[f] *WCASRN, s/c ICRISAT-Mali, Samanko, BP 320 Bamako, Mali*

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Abstract

A regional Sorghum Head-Bug and Grain Mold Trial was conducted in 1996 and 1997 by WCASRN in, respectively, 15 and 13 research stations in ten west and central African countries. Empirical relationships between weather factors and head-bug damage on the one hand, and between weather factors and grain mold damage on the other hand, were examined using the "Window" computer program. No significant correlation was found between head-bug damage and those weather factors examined. In the case of grain mold, high relative humidity (RH) during early plant growth (5–40 days after sowing, DAS) on the one hand, and between end of flowering and harvest (65–125 DAS) on the other hand, were the most strongly correlated with mold incidence. The relationships between maximum RH and grain mold scores in the scatter diagrams were clearly non-linear, showing a marked increase in grain mold scores when the RH exceeded a threshold of about 95%. These results are discussed and future research directions are proposed.

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1. Introduction

Sorghum [*Sorghum bicolor* (L.) Moench] is one of the most important food crops in the savanna areas of West and Central Africa (WCA). In this region, the mirid panicle-feeding bugs, particularly *Eurystylus oldi* Poppius, have recently become key-pests of sorghum (Ajayi and Ratnadass, 1998). They pose a major threat to increased sorghum production because of recent adoption of improved compact-headed cultivars of the caudatum race, which, although better yielding, are more susceptible to head-bug feeding and oviposition punctures than local loose-headed guinea landraces (Ratnadass et al., 1994, 1998). Grain molds are of major importance in the tropics and are comprised of: (a) specialized pathogens which invade developing or mature grain causing or not visible symptoms; (b) unspecialized pathogenic fungi that infect developing grain; and (c) unspecialized saprophytic fungi attacking mature grain (Williams and McDonald, 1983). Grain molds are of limited importance in local sorghum varieties which normally mature towards the end of the season when the risk of mold-conducive humid conditions is low. However, the disease has become a major problem with the introduction of early maturing compact-headed genotypes that fill grains during periods of relatively high rainfall (King, 1973; Denis and Girard, 1980; Williams and McDonald, 1983; Thomas, 1992).

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*Corresponding author. FOFIFA-CIRAD, BP 230, Antsirabe 110, Madagascar. Tel.: +261-20-4449236.
E-mail address: alain.ratnadass@cirad.fr (A. Ratnadass).

[1] Present address: IITA, PMB 5320, Ibadan, Nigeria.

[2] Present address: Agronomy Department, Purdue University, West Lafayette, IN 47907-1150, USA.

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While grain mold fungi may penetrate sorghum grain directly under high humidity conditions, infection by these fungi can be aided by biotic factors especially insects (Bandyopadhyay et al., 2000). Experiments carried out by the Institut d'économie rurale (IER) at Sotuba, Mali, demonstrated a strong relationship between head-bugs and grain molds (Ratnadass et al., 1995). Fungicide application only slightly affected bug damage, but grain mold damage was greater on unprotected than on fungicide-protected panicles. However, panicles protected from only bugs with a plastic bag had no more mold severity than panicles protected either by fungicide alone, or by both fungicide and a plastic bag (Ratnadass et al., 1995). Similar results were reported by Marley and Malgwi (1999) from Nigeria.

The relationship between head-bug infestation and mold infection was confirmed in the Regional Sorghum Head Bug and Grain Mold Trial, conducted in 1996 and 1997 under the West and Central African Sorghum Research Network (WCASRN) in 15 research stations across 10 countries participating in the Network. Two cultivars, IS 14384 and CGM 39/17-2-2, were identified with consistently high levels of resistance to head-bugs and grain molds over years and locations (Ratnadass et al., 2003).

Weather and plant disease are related, but for most diseases information is lacking as to how weather determines the course of the disease epidemic (Shaner, 1981). With respect to grain mold, little more is known than that "warm and wet or humid" conditions favor mold development (Williams and Rao, 1981; Forbes et al., 1992). Mold infection begins at flowering and continues throughout the grain development stages (Bandyopadhyay et al., 2000). Certain fungi may infect early but only develop near to grain maturity (Denis and Girard, 1980). The period from flowering to grain maturity is about 40 days under normal conditions. Weather factors during grain development vary and strongly influence mold damage. Consequently, there is need for additional studies relating weather throughout the cropping season to insect and disease incidence and grain mold severity at harvest. We comprehensively examined the empirical relationships between weather factors, head-bug damage and grain mold damage using the "Window" computer program (Coakley et al., 1988), in order to suggest hypotheses to explain these relationships.

2. Materials and methods

2.1. *Trial design and pest damage assessment*

The experimental procedure has been published by Ratnadass et al. (2003). The Regional Sorghum Head-Bug and Grain Mold Trial was conducted in 15 localities in 1996 and 13 in 1997, under natural infestation by head-bugs and infection by grain molds, with one date of sowing, in a split-plot design [main plots = insecticide treatment (insecticide-treated and untreated); subplots = varieties] with three replications (Tables 1 and 2). Before harvest, sorghum panicles were visually scored for head-bug damage and mold infection, using 1–9 rating scales (Ratnadass et al., 2002; Bandyopadhyay and Mughogho, 1988).

2.2. *Meteorological data collection*

Meteorological data were obtained from rain gauges and dry and wet bulb thermometers by each station

Table 1
Sowing date and local cultivars sown on the 16 stations where the WCASRN Regional Sorghum Head-Bug and Grain Mold Trial was conducted in 1996 and 1997

Country	Station	Longitude	Latitude	Sowing date		Local cultivar
				1996	1997	
Benin	Ina	02°44′E	09°58′N	01/07	22/07	Blanc de Karimana
Burkina Faso	Fada-Kouaré	0°10′E	12°05′N	27/07	—	Nongossomba
	Farako-bâ	04°20′W	11°06′N		16/07	Gnofing
Cameroon	Maroua	14°3′E	10°30′N	05/07	10/07	Damougari
CAR	Soumbé	17°36′E	06°29′N	22/07	—	Koï
	Poumbaïdi	16°25′E	07°05′N	—	21/07	IKI 164
Chad	Bébédjia	16°34′E	08°41′N	05/06	11/06	GOOP
Côte d'Ivoire	Ferkessédougou	05°12′W	09°36′N	29/07	05/08	NWS 63 D
Ghana	Nyankpala	0°58′W	09°25′N	11/07	11/07	Kapaala
Guinea	Bordo	09°18′W	10°23′N	19/07	09/07	Lombogbe
Mali	Cinzana	03°56′W	13°18′N	18/07	25/07	CSM 219^{E}
	Longorola	05°41′W	11°21′N	06/07	11/07	Locale Sikasso
	Samanko	08°07′W	12°32′N	10/07	09/07	CSM 388
Niger	Bengou	03°30′E	11°59′N	25/07	—	Local B.K.C.
Nigeria	Bagauda	08°30′E	11°40′N	08/07	07/07	Gaya Early
	Samaru	07°38′E	11°11′N	26/07	17/07	NR 71182

Table 2
Sorghum varieties tested in the WCASRN Regional Sorghum Head-Bug and Grain Mold Trial in 1996 and 1997

Head-bug resistant varieties	Grain mold resistant varieties	Controls
1. ICSV 905	9. IS 30469C-1526-4	19. S 34 (head-bug and grain mold susceptible)
2. M 943208-1	10. 10. IS 30469C-1518T-5	20. Naga White (regional standard check)
3. Malisor 84-7	11. IS 14384	21. Local check (cf. Table 1).
4. 87W810	12. IS 21658	
5. 91W113-2-1	13. CEM-328/1-1-1-2	
6. 82 Sel 1-Grain dur	14. CEM-328/3-3-1-1	
7. R 6078	15. CCGM-1/19-1-1	
8. 87-SB-F4-54-2	16. CGM-39/17-2-2	
	17. ICSV 1079	
	18. CEM-326/11-5-1-1	

collaborator. Daily values of total precipitation (TP), minimum and maximum temperature ($T_{\min}$ and $T_{\max}$), minimum and maximum relative humidity ($\mathrm{RH}_{\min}$ and $\mathrm{RH}_{\max}$) were collected from planting to harvest.

From these basic weather records, precipitation frequency (PF), consecutive days with precipitation (DWP), consecutive days without precipitation (DOP) and the daily temperature range (T_{range}) were derived and included as weather factors in the analyses. These derived weather factors were calculated for each time "Window" (see below).

2.3. "Window" analysis

The "Window" computer program (Coakley et al., 1988) was used to determine whether there were empirical relationships between weather, head-bug and grain mold damage scores. In this method, correlation analyses are based on individual weather factors, averaged or accumulated over different time windows, starting on different days throughout the crop-growing season. Missing values were ignored when calculating totals and means. Eight time windows were selected (5, 10, 15, 20, 25, 30, 35 and 40 days), and derived weather variables calculated for each day from the date of sowing.

The program calculates the means or totals of each weather variable over different periods or "windows of time", and correlates these with damage scores. Windows are chosen to begin on each day from the start of the growing season and vary in length, so that weather over the whole growing season is examined. The approach taken was to examine possible effects of the weather pattern throughout the growing season on disease incidence and insect infestation levels at grain maturity, in addition to weather conditions prevailing when damage assessments were made. Cut-off dates for the inclusion of weather data at the end of the growing season were determined from the mean time of 50% flowering for each genotype. The most significant correlations can be selected from a large matrix of results, to identify times when weather significantly affects disease or insect attack. Out of 25 location × year data sets for each primary weather variable, 25 data sets could be used for TP, 23 each for $T_{\max}$ and $T_{\min}$, and 16 each for $\mathrm{RH}_{\max}$ and $\mathrm{RH}_{\min}$. Other weather data sets were either not available or too unreliable to be of value in the analysis.

The program was run with the following assessments: head-bug damage score on unprotected plots, and threshed grain mold rating score (TGMR) on both unprotected and insecticide-protected plots. For each of these assessments, 15 analyses were conducted (namely the mean of all 21 genotypes, and values for 14 individual genotypes), with the nine (five primary and four derived) weather variables, for a total of 405 analyses.

3. Results

When considering trial means of all 21 genotypes in unprotected plots (Ratnadass et al., 2003), no highly significant correlations ($P<0.001$) were found between head-bug damage scores and any of the weather variables considered (data not shown). However, 116 significant correlations were found between mean mold score and maximum RH, for untreated plots. Only four significant correlations were found for treated plots. The number of such correlations increased dramatically for certain genotypes when considering them individually, notably on untreated plots (Table 3). In untreated plots, the two most mold-susceptible genotypes (87-SB-F4-54-2 and S 34) had the most significant correlations (>725), whereas the four most mold-resistant genotypes (IS 14384, IS 21658, CEM 39/17-2-2 and CEM 326/11-5-1-1) had no significant correlations (Table 3).

Table 3 also shows periods when the correlation coefficient (r) exceeded 0.7. These were all found either during the periods 5–40 or 65–125 DAS. In the untreated plots, there was a highly significant correlation ($r=0.771$, $P<0.001$) between mean grain mold scores and the number of highly significant weather correlations for the 14 cultivars.

Table 3
Correlations between maximum relative humidity and grain mold damage scores

Cultivar	Number of significant correlations[a]		Shortest periods with greatest absolute r value (>0.7)	
	Insecticide-treated	Untreated	Window start (DAS[b])	Window end (DAS)
87-SB-F4-54-2	26	726	8	13
			71	76
87W810	0	187	—	—
CGM 39/17-2-2	0	0	—	—
CEM 326/11-5-1-1	0	0	—	—
CEM 328/1-1-1-2	0	3	—	—
CEM 328/3-3-1-1	14	60	—	—
ICSV 1079	0	25	—	—
IS 14384	0	0	—	—
IS 21658	0	0	—	—
IS 30469C-1526-4	0	333	—	—
Malisor 84-7	0	712	9	14
			87	92
Naga White	0	155	—	—
S 34	11	755	94	99
Mean of genotypes	4	116	9	14

: no r value >0.7.

[a] Correlations ($P<0.001$) with windows of 5, 10, 15, 20, 25, 30, 35 and 40 days.

[b] DAS: number of days after sowing.

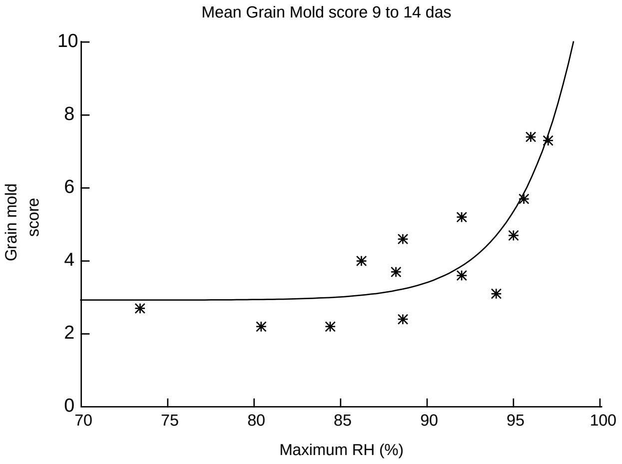
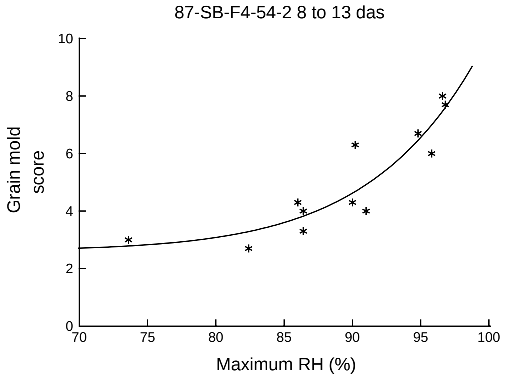
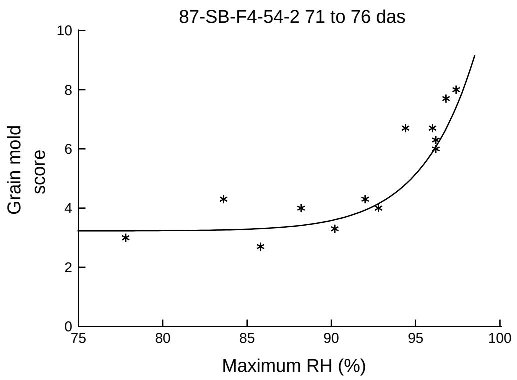


Fig. 1. Relationship between maximum RH and grain mold scores for the mean of 21 genotypes [9–14 DAS: equation of fitted line: $y = 11.13 * (x/100)29.84 + 2.93$ ($r^2 = 0.71$)].



(a) 9 to 14 DAS: equation of fitted line: $y = 7.45*(x/100)^{12.5} + 2.64$ ($r^2 = 0.84$).



(b) 71 to 76 DAS: equation of fitted line: $y = 9.44*(x/100)^{25.8} + 3.23$ ($r^2 = 0.87$).

Fig. 2. Relationship between maximum RH and grain mold scores for individual genotype 87-SB-F4-54-2.

Scatter diagrams between RH_{max} and grain mold scores for windows of time when the highest correlation coefficients were found are shown in Figs. 1 and 2. Non-linear equations fitted to the points using Systat (Wilkinson, 1990) are shown with the coefficient of determination (r^2).

4. Discussion

The variability in the entomofauna (Ratnadass et al., 2003) translated into the virtual absence of any significant correlation between head-bug incidence and those weather factors examined. This is not a surprise since even species belonging to the same mirid family such as *Eurystylus oldi* and *Creontiades pallidus* (which was dominant on some stations) can exhibit opposite relationships with weather (Ratnadass and Butler, 2003).

In the case of grain mold, high RH during early plant growth stages as well as between the end of flowering and harvest were most strongly correlated with mold incidence (TGMR).

The non-linear relationships between $\text{RH}_{\max}$ and grain mold scores in the scatter diagrams showed a marked increase in grain mold scores when the RH exceeded a threshold of about 95%. Based on the values of the coefficient of determination, the equations of the fitted lines explained between 60% and 86% of the total variance. The pattern was similar in both critical periods in the growing season; however, it was only in the second period that a direct effect of mold infection or sporulation on the grain was possible.

High RH can affect grain mold either by providing suitable conditions for infection, or by enhancing sporulation. Duration of wetness, a factor related to high humidity, has been demonstrated to have significant effect on infection of sorghum grain by mold fungi in controlled environment experiments (Bandyopadhyay et al., 2000). The requirement of wetness duration to give significant amounts of infection varied according to fungal species and grain development stages. Nearly 16 h of wetness duration was optimal for infection at physiological maturity, but at least 72 h wetness period was necessary for infection at flowering stage (Bandyopadhyay et al., 2000). It is also interesting to note that in controlled environment studies, significant sporulation (needed for the expression of grain mold symptoms) of major grain mold fungi was recorded only at $\geqslant 95\%$ RH (Butler and Bandyopadhyay, unpublished data). Therefore, the correlation studies reported in this paper from field experiments support the results of controlled-environment studies.

Many fungi causing grain mold are facultative parasites that colonize and sporulate on moribund plant tissues such as senescent or dead leaves and plant debris (Burgess, 1981; Williams and McDonald, 1983). Aerobiology studies in India have shown that spores of species of *Fusarium*, *Curvularia*, and *Alternaria* which cause grain mold were naturally available in the air over sorghum fields to initiate disease epidemics under favorable weather conditions (Bandyopadhyay et al., 1991).

High humidity during the first critical period may favor infection of young sorghum plants. *Leptosphaeria nodorum*, a wheat pathogen, frequently infects wheat seed. The fungus subsequently infects the growing host coleoptile. Subsequent sporulation on the coleoptile may provide secondary inoculum for infection of leaves (Hewett, 1975). The source of inoculum could be soil-borne fungi or plant debris on the soil surface. It might also originate on alternate hosts since grain mold fungi are non-host specific. At a later stage the initial infection sites could serve as a source of secondary inoculum for infection of panicles. It appears that such a mechanism of early colonization, although it is not routinely noted in pathology trials in the region, is nonetheless critical. Support for this hypothesis is given by the striking fact that correlations are not highly significant for weather periods from the DOS, but from about a week later, which corresponds to the time of emergence of sorghum seedlings.

Among the three cultivars for which the numbers of highly significant correlations were the highest, it is striking that it is only with S 34 for which correlations were not so high in the first critical period. S 34 is reported to be the most head-bug susceptible genotype, so it might be that the "secondary" assisted infection is so high as to mask any effect of early infection of grain. Actually, for head-bug resistant cultivars 87-SB-F4-54-2 and Malisor 84-7, it is the early colonization of leaves that seems to dominate (more and higher correlation coefficients).

The likely importance of head-bug-aided infection is supported by the timing of the second period that highly significant correlations were found. This was not from sorghum anthesis, but a few days later, corresponding to early milk stage of grains, when they emerge from the glumes and become accessible to head bugs. From early milk stage onwards, developing grains also prone to more infection compared to flowering stage (Bandyopadhyay et al., 2000).

While earlier studies using the "window" analysis (Ratnadass and Butler, 2003) have shown the influence of $\text{RH}_{\min}$ and $T_{\min}$ at the time of grain filling on *E. oldi* population dynamics, little was known about the epidemiology of grain mold (Forbes et al., 1992). Knowledge at the time of the review by Williams and Rao (1981) was probably well summarized by their comment, "generally it seems that wet weather following flowering is necessary for grain mold development and the longer wet period, the greater the mold development". Subsequently, greenhouse and field experiments were conducted at ICRISAT, India to study grain mold under various wetness, RH and temperature regimes during panicle development stages; some of this epidemiology research has been published (Bandyopadhyay et al., 2000).

From the present study, it is only possible to suggest hypotheses to explain relationships between head-bugs, grain molds and weather. Detailed greenhouse and field experiments are necessary to test these hypotheses by examining the relationships with wetness and RH at different stages of plant development, both on young plants and on the panicle. These controlled-condition studies could be conducted separately for several pathogenic species. Also, tests on the effectiveness of early foliar fungicide treatments in reducing later grain mold incidence could be conducted to determine the role of pathogen development on young plants, in providing a possible source of secondary inoculum for later infection of the panicle by mold fungi when leaves become senescent. The evidence presented here suggests that a closer look should be given to pathogens present on young sorghum plants early in the cropping season.

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