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SORGHUM HEAD BUG INFESTATION AND MOULD INFECTION ON THE GRAIN QUALITY OF SORGHUM IN NORTHERN GHANA

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ABSTRACT

Sorghum (*Sorghum bicolor*) panicle is reported to be attacked by a myriad of insect pest species, whose infestation predisposes the grains to fungal infection, thereby compromising their quality. A complex of bugs has been reported to infest sorghum, thereby affecting quality of grains in West Africa. The objective of this study was to investigate the effect of head bug (*Eurystylus oldi* (POPPIUS) infestation and mould infection on sorghum grain quality. An experiment consisting of eight sorghum breeding lines (two parental checks and six F₈ derivatives), was carried out in fields at three Agro-ecological Zones (Nyankpala, Damongo and Manga) in Northern Ghana. Results showed that damage caused by head bug populations per panicle were not significant (P>0.05). Head bug damage was, however, found to be highly correlated with panicle grain mould ratings (PGMR) at all three locations. This points to the significant roles head bug damage plays in fungal infection of sorghum grains. The derivatives, on the other hand, suffered less PGMR than the compact headed Kapaala, across the three locations. The three dominant fungi isolated at Manga and Nyankpala included those of the genera *Curvularia* sp. (31.6 and 31.4%, respectively), *Fusarium* sp. (22.3 and 27.6%, respectively) and *Thielaviopsis* sp. (20.3 and 20.9%, respectively). At Damongo, *Fusarium* sp. (29.6%), *Curvularia* sp. (23.6%) and *Mucor* sp. (17.2%) were dominant. Grain quality, in terms of head bug and mould damage ratings, showed the following lines emerging superior at Manga (SARSORG-MRG-2011-3, SARSORG-SBG-2011-5 and SARSORG-SRG-2011-6), at Damongo (SARSORG-TRG-2011-1, SARSORG-SBG-2011-5 and SARSORG-MBG-2011-4) and at Nyankpala (SARSORG-MBG-2011-4, SARSORG-MRG-2011-3 and SARSORG-TRG-2011-1) and; thus suggest they may possess some desirable traits for which they could be selected for further improvement.

Key Words: *Curvularia*, *Eurystylus oldi*, *Sorghum bicolor*

RÉSUMÉ

La panicule du sorgho (*Sorghum bicolor*) a été rapportée d'être attaquée par une multitude d'espèces d'insectes pestes, dont l'infestation prédispose les grains à l'infection des champignons, par conséquent compromet leur qualité. Un complexe de punaises a été rapporté d'infester le sorgho, donc affecte la qualité des grains en Afrique de l'Ouest. L'objectif de cette étude était d'investiguer l'effet de l'infestation des punaises de tête (*Eurystylus oldi*, POPPIUS) et des moisissures sur la qualité des grains du sorgho. Une expérimentation comportant huit lignées améliorées du sorgho (deux contrôles parentaux et six F₈ dérivées), était conduite au champ en trois zones agro-écologiques (Nyankpala, Damongo et Manga) au Nord du Ghana. Les résultats ont montré que les dommages

causés par les populations de punaises de tête sur la panicule n'étaient pas significatifs ($P > 0,05$). Le dommage de la punaise de tête était, toutefois, retrouvé hautement corrélé avec les scores de panicule de grains moisies (PGMR) à toutes les trois locations. Ceci montre le rôle significatif que joue la punaise de tête dans l'infection fongique des grains du sorgho. Les dérivées, d'autre part, ont souffert moins de PGMR que le Kapaala à tête compacte, à travers les trois locations. Les trois champignons dominants isolés à Manga et Nyankpala comprennent ceux du genre *Curvularia* sp. (31,6 et 31,4%, respectivement), *Fusarium* sp. (22,3 et 27,6%, respectivement) et *Thielaviopsis* sp. (20,3 et 20,9%, respectivement). A Damongo, *Fusarium* sp. (29,6%), *Curvularia* sp. (23,6%) et *Mucor* sp. (17,2%) étaient dominants. La qualité du grain, en termes des scores du dommage de punaise de tête et des moisissures, a montré que les lignées suivantes étaient supérieures à Manga (SARSORG-MRG-2011-3, SARSORG-SBG-2011-5 et SARSORG-SRG-2011-6), à Damongo (SARSORG-TRG-2011-1, SARSORG-SBG-2011-5 et SARSORG-MBG-2011-4) et à Nyankpala (SARSORG-MBG-2011-4, SARSORG-MRG-2011-3 et SARSORG-TRG-2011-1) et ; donc suggère qu'ils pourraient posséder quelques traits désirables pour lesquels ils pourraient être sélectionnés pour une meilleure amélioration.

Mots Clés: *Curvularia*, *Eurystylus oldi*, *Sorghum bicolor*

INTRODUCTION

Sorghum (*Sorghum bicolor* Moench) is Africa's second most important cereal crop after maize (*Zea mays* L.), but the most important cereal in the Guinea and Sudan savannah regions of West Africa (Mishra *et al.*, 2008). In Ghana, sorghum is mainly grown in the semi-arid zones, comprising of the three Northern regions usually characterised by erratic and low rainfall.

Despite the important role that the crop plays in the livelihood of populations in the country (Kudadjie *et al.*, 2004), production is constrained by a myriad of biotic and abiotic factors, including insect pests, of which head bugs (*Eurystylus oldi*) constitute a major entity (Atokple, 1993; Gerda and Christopher, 2007; Ochieng *et al.*, 2011).

The sorghum head bug (*Eurystylus oldi* POPPIUS) belongs to the family Miridae. It is one of the most renowned panicle feeding insect pests that feeds on sorghum grains in West and Central Africa. Female adults deposit eggs on the panicles, soon after booting, and both adults and nymphs suck sap from the developing grain, causing it to shrink, thus reducing yield (Sharma, 1985; Rana and Singh, 1995; Kudadjie-Freeman *et al.*, 2008). Little information is available on head bugs and their activities in Ghana, since their presence in the country was first reported by Ratnadass *et al.* (2003).

Ratnadass and Ajayi (1995b) linked head bugs to compact headed sorghum types. Ajayi *et al.* (2001) established that head bugs were less abundant on landraces than on improved cultivars. This assertion was based on the fact that most landraces have long glumes, which cover the grains until the endosperm becomes hard enough to resist oviposition and feeding by head bugs. Many improved varieties of sorghum, for example the Caudatum types, have compact panicles, which create a relatively stable and humid micro-climate for the bug (Sharma *et al.*, 1994; Ratnadass and Ajayi, 1995; Kudadjie *et al.*, 2008). Head bugs, thus pose a major threat to increased sorghum production in Africa, since the damage they inflict on the grains predisposes them to mould infection (Marley and Ajayi, 1999).

Grain moulds are of limited importance in local sorghum varieties, which normally mature towards the end of the growing period when the risk of mould-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 (Williams and McDonald, 1983; Thomas, 1992). Infected seeds of low quality are not good for brewing local beer, 'pito', possess low food value and have poor germination quality.

Ratnadass *et al.* (1995a) demonstrated a relationship between head-bug infestation and

grain mould infection, during experiments at the Institut d'économie Rurale (IER) at Sotuba in Mali. Bandyopadhyay *et al.* (2000) stated that while grain mould fungi may penetrate sorghum grain directly under high humidity conditions, infection by these fungi can be aided by biotic factors especially insects.

Kudadjie *et al.* (2004) noted that in the Upper East Region of Ghana, three sorghum varieties, namely Naga white, Framida and Kapaala, from the savannah Agricultural Research Institute (SARI) were introduced to farmers. A number of reasons, however, discouraged farmers from growing these improved varieties. Although Kapaala was high yielding among the sorghum cultivars introduced, to farmers' its major problem was its compact headed nature which made it a favourable host for head bugs leading to severe damage, thus affecting the quality of the grains. Kudadjie *et al.* (2004) indicated that breeders were already aware of the problem associated with Kapaala's susceptibility to head bug infestation and a hybridisation programme was being carried out to open up its panicle. The Savannah Agricultural Research Institute initiated a breeding programme and developed six open panicle derivatives of Kapaala that will be both high yielding and tolerant to head bug infestation and damage. The objective of this study was to investigate the effect of head bug infestation and mould infection on the grain quality of the breeding lines in the field.

MATERIALS AND METHODS

Experimental sites. A multi-locational study was conducted in Savannah Agriculture Research Institute (SARI), at Nyankpala, Damongo and Manga sites. The Nyankpala and the Damongo sites lie in the Guinea savannah zone of Northern Ghana about 124 Km apart. Nyankpala is located on latitude 9° 25' 41" N and 0° 58' 42" W and at altitude 183 m above sea level. The mean annual rainfall of Nyankpala is about 1000 mm and the mean annual temperature is 28.3°C. Damongo lies on

Latitude 8° 32' and 10° 2' N and longitude 1° 5' and 2° 58' W and experiences an annual rainfall of 1144 mm and a mean annual temperature of 27°C.

Manga, is located on latitude 10°15" and 11°10" N and 0° and 1°0" W. It lies in the semi-arid part of the Volta Basin, falling in the transitional zone of the Sudan savannah Agro-ecological Zone. The area is characterised by a uni-modal rainfall pattern with a mean annual rainfall of 950 mm.

The vegetation of these locations, except Damongo, comprises scattered trees and shrubs with grass under-growths. Due to increasing population; coupled with low crop yields, fallows are now almost non-existent at all three locations

Experimental materials. The plant materials used for this study (Table 1) were obtained from the Savannah Agriculture Research Institute in Ghana. They consisted of two parental checks and six F_8 derivatives with varying panicle shapes obtained by repeated backcrossing to Kapaala as the recurrent parent. The aim was to maintain the good qualities and high yield of Kapaala; while opening the panicle shape for reduced head bug infestation.

Experimental design and crop management. The lines were sown in a randomised complete block design (RCBD), with four replications. Plot size consisted of 6 ridges, which were 5 m long and 0.75 m apart.

Four seeds were planted per hill at 0.30 m spacing on ridges, and were thinned to two plants per hill, two weeks after emergence. NPK 15: 15: 15 fertiliser was applied at 250 kg ha⁻¹ two weeks after sowing and sulphate of ammonia 150 kg ha⁻¹, two weeks after the first fertiliser application. Weeds were controlled by hand weeding at three and five weeks after crop emergence at all locations.

Head bug field infestation and grain damage. To determine *Eurystylus oldi*

TABLE 1. Description of experimental materials (sorghum) used in the study, sourced from the Savanna Agriculture Research Institute in Ghana

Lines	Description
Kadaga	Grain colour is brown with black glumes. Average height is 3.0 m. Panicle is very loose
Kapaala	Grain colour is white. Has an average height of 2.5 m. Plant type is tan and panicle is compact
SARSORG-MBG-2011-4	F ₈ derivative of Kapaala and Kadaga crosses. It is a medium maturing line. The plant type is tan, with white grain covered with brown glumes. Panicle type is semi-loose
SARSORG-MRG-2011-3	F ₈ derivative of Kapaala and Kadaga crosses. It is a medium maturing line. The plant type is tan, with white grain covered with red glumes. Panicle type is semi-loose
SARSORG-SBG-2011-5	F ₈ derivative of Kapaala and Kadaga crosses. It is a short maturing line. The plant type is tan, with white grain covered with brown glumes. Panicle type is very loose
SARSORG-SRG-2011-6	F ₈ derivative of Kapaala and Kadaga crosses. It is a short maturing line. The plant type is tan, with white grain covered with red glumes. Panicle type is semi-loose
SARSORG-TBG-2011-2	F ₈ derivative of Kapaala and Kadaga crosses. It is a tall maturing line. The plant type is tan, with white grain covered with brown glumes. Panicle type is semi-loose
SARSORG-TRG-2011-1	F ₈ derivative of Kapaala and Kadaga crosses. It is a tall maturing line. The plant type is tan, with white grain covered with red glumes. Panicle type is loose with drooping primary branches

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infestation and grain damage scores, bug population was assessed at the dough stage; three weeks after flowering. The number of head bugs was obtained from the ten tagged plants by lowering the panicle for each plant into a polyethylene bag large enough to accommodate the panicle and shaken vigorously by hand (Ratnadass *et al.*, 2003). The bagged samples were preserved at 0°C. Samples were later defrosted in the laboratory for one hour and inspected in small portions in a glass petri dish, to facilitate counting of the head bugs.

Feeding damage was scored on a 1 to 9 rating scale (Sharma *et al.*, 1997); where 1 = all grains fully developed with a few feeding punctures; 2 = grain fully developed, with feeding punctures; 3 = grains showing slight tanning or browning; 4 = most grains with feeding punctures, and a few showing slight shriveling; 5 = grains showing slight shriveling and browning; 6 = grains showing more than 50% shriveling and turning brown or tanned; 7 = most of the grain highly shriveled and dark brown coloration; 8 = grain highly shriveled and slightly visible outside the glumes; and 9 = most of the grains highly shriveled and slightly visible outside the glumes. Correlation between head bug infestation and damage scores was then determined using Pearson's correlations analysis.

Mould infection. Grain mould scores were taken twice, first in the field at physiological maturity where panicle grain mould rating (PGMR) was scored on a 1 to 5 scale where, 1 = grains on panicle has no mould, 2 = 1-10 % of grains on panicle has mould, 3 = 11-25 % of grains on panicle has mould, 4 = 26-50 % of grains on panicle has mould, and 5 > 50 % of grains on panicle has mould in the field.

The second scoring was done after harvesting, manual threshing by putting them into a mini-sacks and beaten with stick until all grains were removed from the panicle, and conventional sun drying for about 12 hr three days before storage. Twenty grammes of threshed grain sample from the bulk of the 10

panicles was collected per plot, and spread evenly in petri dishes. The samples were then scored for threshed grain mould rating (TGMR) using the above-1 to 5 severity rating (Thakur *et al.*, 2006). Correlation between head bug damage scores and PGMR and TGMR were then determined.

Infection by mould. The test to determine the mycoflora associated with sorghum seed was undertaken in the Plant Pathology Laboratory at the University of Ghana. Petri dishes with cotton-blotting paper were prepared under aseptic conditions. The lower lids were lined with a thin layer of absorbent cotton, followed by two layers of blotter paper. The entire assembly was placed in a stainless steel sterilising container, and sterilised in an autoclave at 121°C and 15 PSI for 15 min. The cotton-blotting paper was then wetted with 15 ml of distilled water, in a petri dish, to serve as a humidity chamber.

Twenty five grains from each harvested plot were surface sterilised in 1% sodium hypochlorite, for three minutes, and rinsed with three washes in sterile distilled water. The grain samples were transferred onto the sterilised Petri dish humidity chambers, under aseptic conditions. The plates were then incubated at $28 \pm 1^\circ\text{C}$ for 5 days; and seeds were examined for the presence of fungi.

For easy identification of the various fungal colonies associated with seeds of the breeding lines, slides of the fruiting structures of the fungi were prepared with the help of a sterilised incubating needle, and examined under a compound microscope. The various fungi species were then identified on the basis of morphology of mycelia, conidia and fruiting structure as described by Navi *et al.* (1999) and Barnett and Hunter (2006). The relative frequency of occurrence of particular fungi was calculated using the formula of Ghiasian *et al.* (2004).

Grain quality. High performing breeding lines were selected by ranking the lines' in terms of head bug and mould damage ratings (PGMR

and TGMR). Breeding lines with low average values were considered more desirable.

Climatic data. Data on temperature and rainfall were obtained from weather stations established by SARI at the three locations of this study.

Data analysis. Prior to analysis, head bug counts were square root transformed; whereas percentage fungi occurrence was arcsine transformed. Data were subjected to analysis of variance for each parameter using the GenStat 12th edition. Treatment differences were compared using the Least Significant Difference (LSD) at $P < 0.05$ level of probability. Data were also subjected to correlation analyses on locational basis to elucidate the relationship among the selection indices.

RESULTS AND DISCUSSIONS

Head bug infestation. The number of head bugs per 10 panicles observed at Manga,

Damongo and Nyankpala is presented in Figure 1. Highly significant ($P < 0.01$) differences were observed among the breeding lines at Manga and Damongo. At Manga, assessment was done in September, when the temperatures ranged between 22.3 - 31.1 °C. The lowest head bug population (9.5 per 10 panicles) was recorded on SARSORG-TRG-2011-1, while Kapaala, Kadaga and SARSORG-TBG-2011-2 recorded very high bug populations of 15.2, 14.7 and 12.2, respectively which did not differ significantly from each other (Fig. 1). At Damongo, bug population assessment was done in late August when minimum and maximum temperatures ranged between 21.5 and 30.3°C. The highest and lowest numbers of bugs were recorded on SARSORG-TBG-2011-2 (3.9) and Kadaga (1.6) (Fig. 1).

Assessment at Nyankpala was done in September with temperatures ranging between 23.1 - 30.5°C. Significant ($P < 0.05$) differences among the head bug populations were observed for the breeding lines evaluated. The bug numbers ranged from 2.3 (Kadaga) to 5.0 (Kapaala) per 10 panicles (Fig. 1).

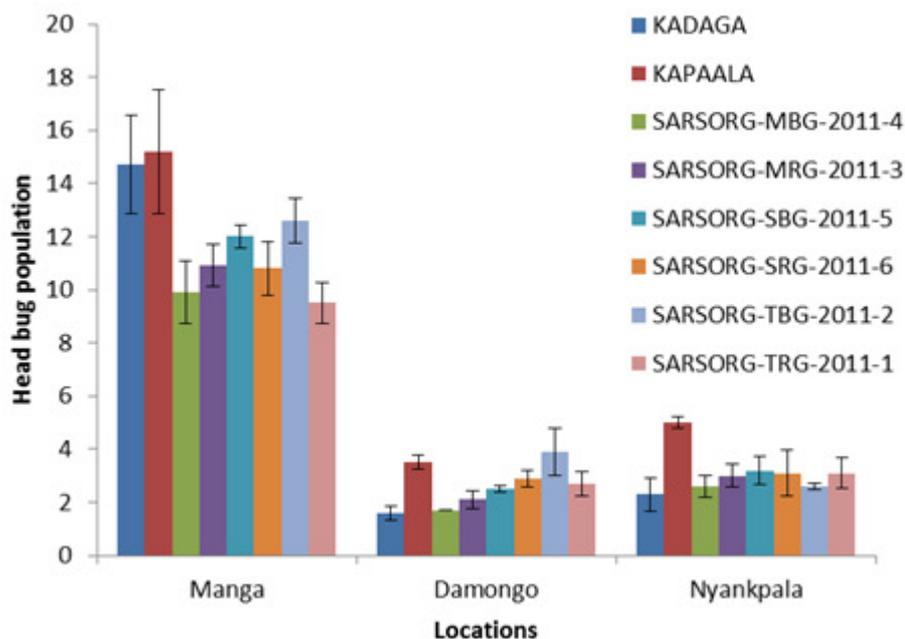


Figure 1. Head bug population on eight sorghum lines grown at Manga, Damongo and Nyankpala in Ghana.

A study of the insect fauna sampled across all three locations; however, revealed that Manga supported the largest head bug population density, followed by Nyankpala (Fig. 1). The high level of population build-up observed in Manga may be attributed to the fact that the location and its surrounding communities support large scale production of the host plant. The population of bugs on individual breeding lines also revealed that apart from Kapaala, which provided a better lodging for the highest bug number in Manga and Nyankpala, the rest of the open-panicle derivatives equally harboured significantly higher numbers of bugs.

While head bugs have been reported to express preference for compact headed sorghum lines for favouring their feeding activities, survival, development and fecundity (Sharma *et al.*, 1994; Showemimo *et al.*, 2011), the huge bug numbers observed in Kadaga and the rest of the open panicle

derivatives at Manga might be linked to head bug population exceeding the threshold for resistance among the lines and, hence did not reflect in the differences in insect numbers recorded.

The economic threshold of head bugs on sorghum has been reported to vary from 4 (Hiremath, 1981) to 15 bugs per panicle (Natarajan and Sundarbabu, 1988). That notwithstanding, high numbers exceeding 200 bugs per panicle have also been reported (Hiremath, 1995). The very loose and slightly drooping seed primary branches of Kadaga which closes up when the head drops may perhaps aid in providing a favourable lodging for the bugs.

Head bug damage. Highly significant ($P < 0.01$) differences among the breeding lines for head bug damage were observed at Manga and Damongo, but not at Nyankpala (Fig. 2). At Manga, Kapaala suffered the most damage

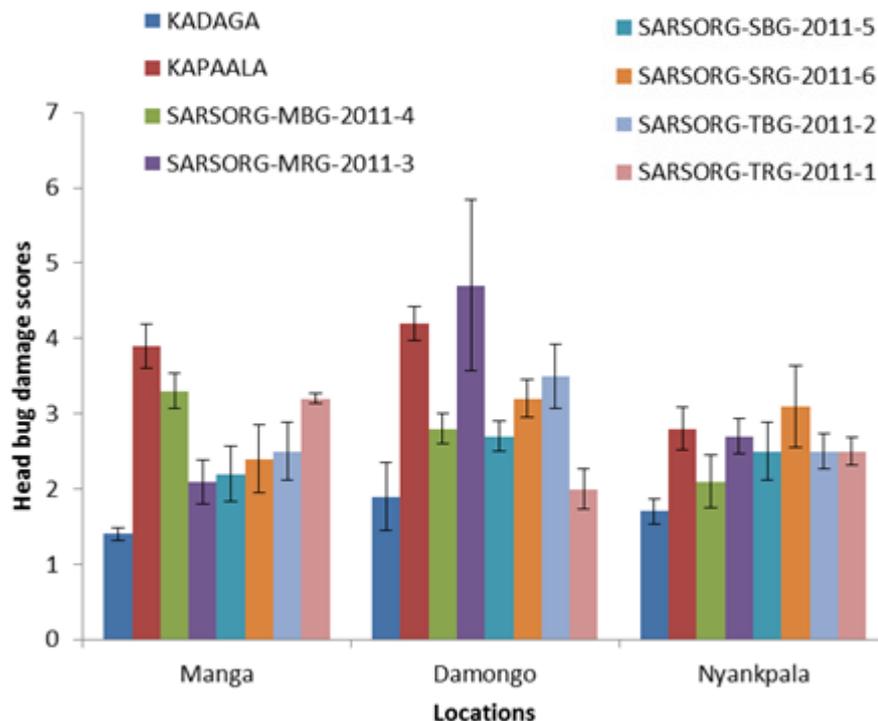


Figure 2. Head bug damage of eight sorghum lines grown at Manga, Damongo and Nyankpala in Ghana.

with a score of 3.9. However, this was not significantly different from the damage scores recorded by SARSORG-MBG-2011-4 (3.3) and SARSORG-TRG-2011-1 (3.2). The least damaged line was Kadaga with mean damage score of 1.4.

At Damongo, SARSORG-MRG-2011-3 and Kapaala recorded the highest mean damage scores of 4.7 and 4.2, respectively (Fig. 2). The least damaged lines were Kadaga and SARSORG-TRG-2011-1 each obtaining mean damage scores of 1.9 and 2.0, respectively.

Although the breeding lines showed no significant differences for damage at Nyankpala, damage ratings ranged from 1.7 to 3.1 and were recorded by Kadaga and Sarsorg-srg-2011-6, respectively.

The compact head shape of Kapaala has been reported by Ratnadass and Ajayi (1995b) to favour head bug infestation and damage; whereas the very loose head shape of Kadaga, according to ICRISAT (1995), supports lower bug numbers hence suffer less grain damage. This could be the reason why Kapaala did not only provide better lodging for the head bugs

across locations, but also favoured higher grain damage.

Mould infection. Assessment of panicle grain mould rating (PGMR) at the three locations revealed highly significant ($P < 0.01$) differences among the breeding lines (Table 2). At Manga, although the derivative SARSORG-TRG-2011-1 obtained a higher rating of 2.4, it was not significantly different from the rest of the lines apart from Kadaga, SARSORG-MRG-2011-3 and Kapaala which recorded 1.0, 1.8 and 3.1, respectively.

The lowest and highest panicle mould infection scores at Damongo were recorded on the two parental checks, Kadaga and Kapaala with mean scores of 1.2 and 3.5, respectively. Some of the derivatives also recorded relatively high mould infection scores. SARSORG-MRG-2011-3 for instance recorded a high score of 3.0, but did not vary significantly from the 3.5 obtained on Kapaala

Panicle grain mould ratings (PGMR) at Nyankpala ranged from 1.2 to 2.5 (Table 2). The resistant and susceptible parents, Kadaga

TABLE 2. Scores of grain mould infection on eight genotypes of sorghum at physiological maturity (PGMR) and on threshed grain (TGMR) across three locations in Ghana

Genotypes	PGMR				TGMR			
	Mga	Dgo	Nkla	Mean	Mga	Dgo	Nkla	Mean
Kadaga (res. Check)	1.0	1.2	1.2	1.1	1.0	1.0	1.0	1.0
Kapaala (sus. Check)	3.1	3.5	2.5	3.0	3.5	3.0	3.0	3.2
Sarsorg-mbg-2011-4	2.1	2.4	1.9	2.1	2.8	3.8	2.3	2.9
Sarsorg-mrg-2011-3	1.8	3.0	1.9	2.2	2.8	4.0	2.3	3.0
Sarsorg-sbg-2011-5	2.1	2.4	2.3	2.3	3.3	4.0	3.0	3.4
Sarsorg-srg-2011-6	2.0	2.6	2.4	2.3	2.3	3.5	3.3	3.0
Sarsorg-tbg-2011-2	2.1	2.7	2.2	2.4	3.5	4.3	3.0	3.6
Sarsorg-trg-2011-1	2.4	2.1	2.2	2.2	2.5	3.0	2.3	2.6
Mean	2.1	2.5	2.1	2.2	2.7	3.3	2.5	2.8
SE(m) \pm	0.2	0.2	0.2		0.3	0.3	0.4	
LSD _{0.05}	0.6	0.7	0.5		0.8	0.8	1.1	
CV (%)	18.5	18.6	16.9		21.3	16.0	29.3	

Dgo = Damongo, Mga = Manga, Nkla = Nyankpala res. Check = resistant check, sus. Check = susceptible check

and Kapaala showed the lowest and highest ratings of 1.2 and 2.5, respectively. The derivative with the highest rating was SARSORG-SRG-2011-6 (2.4).

The high panicle grain mould ratings (PGMR) values obtained at Damongo may be the direct influence of rainfall (134.7 mm) recorded in September, preceding harvest. The minimum level of PGMR observed on the derivatives, including Kadaga corroborates the assertions of Khaing *et al.* (2013) that open-panicle cultivars of sorghum lines serve as an adaptive trait to allow quick drying of panicles in high-humidity environments.

Threshed grain mould rating (TGMR) also showed highly significant ($P < 0.01$) differences across the three locations (Table 2). At Manga, threshed grain mould ratings varied from 1.0 to 3. However, Kapaala SARSORG-TBG-2011-2 and SARSORG-SBG-2011-5 recorded very high ratings of 3.5, 3.5 and 3.3, respectively which did not differ from each other

Threshed grain mould ratings (TGMR) at Damongo ranged from 1.0 to 4.3. The line with the most TGMR was SARSORG-TBG-2011-2 (4.3) followed by SARSORG-MRG-2011-3 and SARSORG-SBG-2011-5, both recording a score of 4.0. The line with the least TGMR was Kadaga with a score of 1.0

At Nyankpala, SARSORG-SRG-2011-6 recorded the highest TGMR of 3.3 which varied from the 1.0 obtained by Kadaga but not Kapaala which recorded a rating of 3.0. The overall TGMR scores from all three

locations showed that SARSORG-TBG-2011-2 (3.6) and SARSORG-SBG-2011-5 (3.4) were the most damaged breeding lines.

Based on these results and other by Thakur *et al.* (2007), one can suggest that scoring for grain mould severity at physiological maturity in the field was more reliable than on threshed grain, since prevailing humidity conditions may influence threshed grain mould ratings (TGMR) data which is usually taken several days after panicle grain mould ratings (PGMR).

Correlation of traits. At Manga, panicle grain mould rating (PGMR) correlated positively ($r = 0.91$; $P < 0.001$) with head bug damage (Table 3). There was also a positive correlation ($r = 0.78$; $P < 0.02$) between PGMR and TGMR. On the contrary, head bug population and head bug damage produced a negative correlation $r = -0.09$ ($P > 0.82$ (Table 3). At Damongo, head bug damage and PGMR produced a significant ($r = 0.87$; $P < 0.01$) positive correlation. On the other hand, head bug population and head bug damage did not produce a significant correlation ($r = 0.385$; $P > 0.347$). There was also no significant correlation between PGMR and TGMR (Table 4). At Nyankpala a significant positive correlation ($r = 0.85$; $P < 0.01$) between head bug damage and PGMR, and between head bug damage and TGMR ($r = 0.85$; $P < 0.01$) were recorded. Unlike at Damongo, correlation between PGMR and TGMR was highly significant ($r = 0.95$; $P < 0.001$) (Table 5).

TABLE 3. Correlation coefficient among agronomic parameters of sorghum lines evaluated at Manga in Ghana

	Grain yield	Panicle weight	Bug population	Bug damage	PGMR	TGMR
Grain yield	1.000					
Panicle weight	0.929**	1.000				
Bug population	-0.438	-0.455	1.000			
Bug damage	0.662 ^{ns}	0.447 ^{ns}	-0.092	1.000		
PGMR	0.747*	0.508 ^{ns}	-0.009	0.913**	1.000	
TGMR	0.555 ^{ns}	0.256 ^{ns}	-0.056	0.597 ^{ns}	0.778*	1.000

** = indicates significance at $P < 0.01$; * = significance at $P < 0.05$ and ns = non-significance at $P < 0.05$

TABLE 4. Correlation coefficient among agronomic parameters of sorghum lines evaluated at Damongo in Ghana

	Grain yield	Panicle weight	Bug population	Bug damage	PGMR	TGMR
Grain yield	1.000					
Panicle weight	0.973**	1.000				
Bug population	0.296 ^{ns}	0.218 ^{ns}	1.000			
Bug damage	0.172 ^{ns}	0.069 ^{ns}	0.378 ^{ns}	1.000		
PGMR	0.341 ^{ns}	0.185 ^{ns}	0.598 ^{ns}	0.873**	1.000	
TGMR	0.071 ^{ns}	0.017 ^{ns}	0.414 ^{ns}	0.532 ^{ns}	0.659 ^{ns}	1.000

** = indicates significance at $P < 0.01$; and ns = non-significance at $P < 0.05$

TABLE 5. Correlation coefficient among agronomic parameters of sorghum lines evaluated at Nyankpala in Ghana

	Grain yield	Panicle weight	Bug population	Bug damage	PGMR	TGMR
Grain yield	1.000					
Panicle weight	0.971**	1.000				
Bug population	-0.473 ^{ns}	-0.522 ^{ns}	1.000			
Bug damage	-0.094 ^{ns}	-0.200 ^{ns}	0.561 ^{ns}	1.000		
PGMR	-0.180 ^{ns}	-0.312 ^{ns}	0.659 ^{ns}	0.852**	1.000	
TGMR	-0.281 ^{ns}	-0.414 ^{ns}	0.489 ^{ns}	0.851**	0.947**	1.000

** = indicates significance at $P < 0.01$; and ns = non-significance at $P < 0.05$

The highly significant correlations between head bug damage and PGMR identified across the three locations is a clear indication of the significant roles head bug damage plays in grain mould infection, an emphasis which was also strongly advocated by Sharma *et al.* (2000). Furthermore, the non-significant correlation between head bug population and damage recorded across the three locations suggests that high bug numbers are not a prerequisite for significant level of grain damage to occur; which is in line with the findings of Harris (1995). For instance, a field visit at noon at Manga revealed high bug presence in both compact and semi-compact panicles; and some bugs hiding underneath the leaves to avoid direct contact with the hot sun. This phenomenon thus suggests that the presence of bugs do not necessarily result in severe feeding damage although some level of feeding will occur.

Despite showing a significant correlation at Nyankpala ($r = 0.85$), the relationship between head bug damage and TGMR was not significant at Manga ($r = 0.59$) and Damongo ($r = 0.53$). These low correlations may suggest that in the absence of high humidity and suitable temperature, as major abiotic factors, bug damage alone may not impose high level of mould infection on stored grains. The significant relationship observed between PGMR and TGMR at Manga and Nyankpala, but not at Damongo suggests that scoring for grain mould severity at physiological maturity in the field was more reliable than on threshed grain since prevailing humidity conditions could influence TGMR data, which is usually taken several days after PGMR (Thakur *et al.*, 2007). Thus, for all grain mould screening, the PGMR scores alone are enough to set apart lines into resistant and susceptible classes (Thakur *et al.*, 2007).

Fungal profiles. A total of six fungal genera, namely, *Aspergillus*, *Curvularia*, *Fusarium*, *Thielaviopsis*, *Exserohilum* and *Rhizopus*, were isolated from the infected seeds at Manga (Table 6). *Curvularia* recorded the highest percentage frequency of isolation (31.6 %), followed by *Fusarium* (22.3 %). Other fungal species with lesser frequencies identified included *Exserohilum* (2.4 %) and *Rhizopus* (1.6 %) (Table 6). A total of five fungi genera were identified at Damongo. These included *Fusarium* (29.6%) and *Curvularia* (23.6%) producing the highest scores with *Epicoccum* (13.6) having the least frequency (Table 6). *Curvularia* was the dominant fungus isolated at Nyankpala with a frequency of 31.4% followed by *Fusarium* (27.6 %) (Table 6).

Field assessment for grain mould infection identified that mould contamination was widespread in the three locations (Table 6). The high mould incidence might be due to the occurrence of rainfall and favourable temperatures days preceding harvest which creates the ambient conditions for fungal growth. This high level of grain contamination could result in severe yield and quality losses as was indicated by Das and Govardhan (2015).

An earlier study by Nutsugah *et al.* (2003) identified *P. sorghina* and *Fusarium moniliforme sensu lato* as the most frequently isolated seed-borne fungi associated with

sorghum. The high presence of these fungi, especially *Curvularia* and *Fusarium*, corroborates the findings of Forbes *et al.* (1992), Singh and Bandyopadhyay (2000) and Prom *et al.* (2011) who also identified *Curvularia* as the major pathogen responsible for grain mould throughout sorghum producing regions. Sharma *et al.* (2010), on the other hand also, cited *Fusarium* as the dominant fungi in sorghum caryopsis

Grain quality. The derivatives recorded lower panicle grain mould ratings (PGMR) (<2.5); while more than 3.0 was obtained for Kapaala at Manga (Table 7). Ranking the breeding lines for grain quality suggests that the breeding lines vary significantly. The average values depicted that SARSORG-MRG-2011-3, SARSORG-SRG-2011-6 and SARSORG-SBG-2011-5 were superior. The least desired line was the commercial susceptible parent, Kapaala, and three derivatives, SARSORG-TRG-2011-1, SARSORG-TBG-2011-2 and SARSORG-MRG-2011-3.

The breeding lines evaluated at Damongo recorded higher PGMR (>2.5), except for SARSORG-TRG-2011-1 (2.1), SARSORG-SBG-2011-5 and SARSORG-MBG-2011-4, both rating 2.4 (Table 8). Kapaala on the other hand recorded a high mean PGMR of 3.5. These reflect the direct influence of rainfall (134.7 mm) recorded in September, preceding harvest.

When sorghum lines were ranked on the bases of grain quality, Kadaga (resistant parent) again emerged the best. The following lines, SARSORG-TRG-2011-1, SARSORG-MBG-2011-4 and SARSORG-SBG-2011-5 were the best 3 derivatives for desired qualitative traits. The least desired lines were SARSORG-TBG-2011-2, SARSORG-MRG-2011-3 and the susceptible parent, Kapaala (Table 8).

At Nyankpala, the derivatives recorded lower mean PGMR (<2.5) (Table 9). For the average values based on the qualitative performance of the breeding lines using bug damage, PGMR and TGMR showed Kadaga

TABLE 6. Frequency of occurrence of fungi isolated from seeds of eight sorghum lines in Ghana

Fungi	Frequency of isolation from seeds (%)		
	Manga	Damongo	Nyankpala
<i>Curvularia</i>	31.6	23.6	31.4
<i>Fusarium</i>	22.3	29.6	27.6
<i>Rhizopus</i>	1.6	-	-
<i>Thielaviopsis</i>	20.3	-	20.1
<i>Aspergillus</i>	21.8	16.0	-
<i>Exserohilum</i>	2.4	-	20.9
<i>Epicoccum</i>	-	13.6	-
<i>Mucor</i>	-	17.2	-

TABLE 7. Ranking of the performances of sorghum lines for quality using head bug and mould damage at Manga in Ghana

Lines	Bug damage	Rank	PGMR	Rank	TGMR	Rank	Rank sum	Average value
Kadaga	1.4	1	1.0	1	1.0	1	3	1
Kapaala	3.9	8	3.1	8	3.5	7	23	8
SARSORG-MBG-2011-4	3.3	7	2.1	4	2.8	4	15	5
SARSORG-MRG-2011-3	2.1	2	1.8	2	2.8	4	8	3
SARSORG-SBG-2011-5	2.2	3	2.1	4	3.3	6	13	4
SARSORG-SRG-2011-6	2.4	4	2.0	3	2.3	2	9	3
SARSORG-TBG-2011-2	2.5	5	2.1	4	3.5	7	16	5
SARSORG-TRG-2011-1	3.2	6	2.4	7	2.5	3	16	5

Breeding lines with less average values are considered more preferred

TABLE 8. Ranking of the performances of sorghum lines for quality using head bug and mould damage at Damongo in Ghana

Lines	Bug damage	Rank	PGMR	Rank	TGMR	Rank	Rank sum	Average value
Kadaga	1.9	1	1.2	1	1.0	1	3	1
Kapaala	4.2	7	3.5	8	3.0	2	17	6
SARSORG-MBG-2011-4	2.8	4	2.4	3	3.8	5	12	4
SARSORG-MRG-2011-3	4.7	8	3.0	7	4.0	6	21	7
SARSORG-SBG-2011-5	2.7	3	2.4	3	4.0	6	12	4
SARSORG-SRG-2011-6	3.2	5	2.6	5	3.5	4	14	5
SARSORG-TBG-2011-2	3.5	6	2.7	6	4.3	8	20	7
SARSORG-TRG-2011-1	2.0	2	2.1	2	3.0	2	6	2

Breeding lines with less average values are considered more preferred

TABLE 9. Ranking of the performances of sorghum lines for quality using head bug and mould damage at Nyankpala in Ghana

Lines	Bug damage	Rank	PGMR	Rank	TGMR	Rank	Rank sum	Average value
Kadaga	1.7	1	1.2	1	1.0	1	3	1
Kapaala	2.8	7	2.5	8	3.0	5	20	7
SARSORG-MBG-2011-4	2.1	2	1.9	2	2.3	2	6	2
SARSORG-MRG-2011-3	2.7	6	1.9	2	2.3	2	10	3
SARSORG-SBG-2011-5	2.5	3	2.3	6	3.0	5	14	5
SARSORG-SRG-2011-6	3.1	8	2.4	7	3.3	8	23	8
SARSORG-TBG-2011-2	2.5	3	2.2	4	3.0	5	12	4
SARSORG-TRG-2011-1	2.5	3	2.2	4	2.3	2	9	3

Breeding lines with less average values are considered more preferred

as the superior parent with average value of 1. However, among the derivatives, the ranking was SARSORG-MBG-2011-4, SARSORG-MRG-2011-3 and SARSORG-TRG-2011-1 as the lines with higher quality.

Crop production can be sustained when breeders do not only focus on yield, but also on other measurable traits such as insect and disease resistance (Sharma *et al.*, 2005). Use of these traits in breeding will considerably increase breeding progress, compared to selection for yield alone (Edmeades *et al.*, 1997). The low PGMR levels observed for the derivatives, including Kadaga, corroborates with the assertions of Khaing *et al.* (2013) that open-panicle cultivars of sorghum lines might have originated as an adaptive trait to allow quick drying of panicles in high-humidity environments in order to minimize insect and mould damage. The loose nature of the branches of the open panicles may allow those panicles with long primary branches to be tossed to and fro, especially as the wind blows thus disrupting oviposition activities of the head bugs.

The findings in the present study suggest that all three locations were considerably diverse from each other in terms of grain mould development due to their varying agro-climatic conditions such as rainfall and temperature during the growing season (Kibebe, 2015).

The performances of the following lines at Manga (SARSORG-MRG-2011-3, SARSORG-SBG-2011-5 and SARSORG-SRG-2011-6); (SARSORG-TRG-2011-1, SARSORG-SBG-2011-5 and SARSORG-MBG-2011-4) at Damongo; and (SARSORG-MBG-2011-4, SARSORG-MRG-2011-3 and SARSORG-TRG-2011-1) at Nyankpala on the basis of their grain quality suggest they may possess some desirable traits for which they could be selected for further improvement at the specific environments.

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