VARIATION FOR ANTHRACNOSE (*Colletotrichum sublineolum*) RESISTANCE WITHIN THE SORGHUM [*Sorghum bicolor* (L.) Moench] GERMPLASM COLLECTION FROM THE KAYES REGION OF MALI, WEST AFRICA

by

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A thesis submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE
In
AGRONOMY

UNIVERSITY OF PUERTO RICO
MAYAGÜEZ CAMPUS
2006

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ABSTRACT

Anthracnose, caused by *Colletotrichum sublineolum*, is considered one of the most important diseases of sorghum. The pathogen is highly variable; therefore, additional sources of host plant resistance are needed for the development of anthracnose resistant hybrids to prevent crop losses. West African countries such as Mali may provide new sources of resistance. Environmental conditions in the region are favorable for the pathogen, which could contribute to selection of host plant resistance in sorghum landraces. The objectives of this research were to evaluate the variation in disease response to anthracnose infection and to identify stable sources of resistance within the sorghum germplasm collection from the Kayes region of Mali. During 2003 (wet season) and 2004 (dry season) anthracnose evaluations were conducted at the USDA-ARS-TARS at Isabela, Puerto Rico. From 277 accessions evaluated, a resistant response was observed for 140 accessions in the wet season and 131 accessions in the dry season. Stable resistance over seasons was observed for 120 accessions. Association between anthracnose disease response and sorghum germplasm phenotypic characteristics and climatic conditions in the country of origin were also evaluated to determine if resistance was influenced by these factors. Significant differences were observed between the anthracnose disease response within administrative districts of the Kayes region of Mali and for rainfall pattern, indicating that disease response of the germplasm accessions varied from north to south. More accessions were resistant in the south as compared to the north. We assume that this is due to the rainfall pattern present in the region contributing to greater selection pressure under the wetter conditions of the south. Significant differences were also observed between disease response and sorghum races grown in the region. We assume that these differences in disease response were due to race durra

commonly grown in drier regions whereas race guinea is more associated with wetter regions. Plant color and rust disease response were not associated with anthracnose disease response. The response of rust, caused by *Puccinia purpurea*, was not influenced by the climatic conditions present in the Kayes region of Mali, as compared to anthracnose response. Since rainfall pattern in the Kayes region was associated with anthracnose disease response, this would indicate that environmental conditions such as annual rainfall pattern could be used to help identify germplasm collections that may contain new sources of anthracnose resistance. Approximately 50% of the sorghum accessions from the Kayes region showed a resistant disease response, suggesting that the sorghum germplasm collection from Mali would be a valuable source of anthracnose resistance for sorghum improvement.

RESUMEN

La antracnosis, causada por *Colletotrichum sublineolum*, es considerada una de las enfermedades más importantes en sorgo. El patógeno es muy variable, por lo tanto, se necesitan fuentes adicionales de resistencia para el desarrollo de híbridos con resistencia a antracnosis para prevenir las pérdidas del cultivo. Países en el oeste de Africa, como Mali, pueden proveer nuevas fuentes de resistencia. Las condiciones ambientales en la región son favorables para el patógeno, lo cual puede contribuir a la selección de la resistencia en plantas huésped. Los objetivos de esta investigación fueron la evaluación de la variación en la respuesta a la infección de antracnosis y la identificación de fuentes estables de resistencia dentro de la colección de germoplasma de sorgo de la región Kayes en Mali. Durante el 2003 (época lluviosa) y 2004 (época seca), se condujeron las evaluaciones para antracnosis, USDA ARS-TARS en Isabela, Puerto Rico. De un total de 277 accesiones evaluadas, se observó una respuesta resistente para 140 accessiones en la epoca de siembra lluviosa y 131 accessiones en la epoca de siembra seca. Resistencia estable fue observada para 120 accessiones. Asociación entre las características fenotípicas del germoplasma de sorgo y las condiciones climáticas en el país de orígen también fueron evaluadas para determinar si la resistencia es influenciada por estos factores. Se observaron diferencias significativas entre la respuesta a antracnosis y los distritos administrativos y los patrones de lluvia de la región de Kayes de Mali, indicando que la respuesta a antracnosis varía de norte a sur en las accessiones del germoplasma. Un número mayor de accessiones resistentes proviene del sur al compararlas con el norte. Asumimos que estas diferencias se deben al patrón de lluvia presente en la región, el cual contribuye a una mayor presión de selección bajo las condiciones humedas del sur. Se observaron diferencias significativas también entre la respuesta a

antracnosis y las razas de sorgo cultivadas en la región. Asumimos que estas diferencias en la respuesta a la enfermedad se deben a que la raza durra es cultivada comúnmente en las regiones secas mientras que la raza guinea se encuentra mayormente asociada a regiones lluviosas. El color de la planta y la respuesta a la roya no estuvieron asociados con la respuesta a antracnosis. La respuesta a la roya, causada por *Puccinia purpurea,* no estuvo influenciada por las condiciones climáticas en la región de Kayes en Mali, a diferencia de la respuesta a antracnosis. Los patrones de lluvia en la región de Kayes estuvieron asociados a la respuesta a antracnosis, esto nos indica que las condiciones ambientales como los patrones de lluvia anuales pueden ser utilizadas en la selección de colecciones de germoplasma para identificar nuevas fuentes de resistencia a antracnosis. Aproximadamente el 50% de las accessiones de sorgo de la región de Kayes mostraron una respuesta resistente a la enfermedad, lo que sugiere que la colección de germoplasma de sorgo de Mali puede ser una valiosa fuente de resistencia a antracnosis para el mejoramiento de sorgo.

To my family . . .

ACKNOWLEDGMENTS

To Dr. John E. Erpelding for all his knowledge, time and patience. He has been a source of inspiration and an excellent educator.

To Dr. James S. Beaver for accepting me as a student and for his guidance through all these years.

To Dr. Lydia I. Rivera for her interest in this research.

To all the employees of the USDA-ARS, Tropical Agriculture Research Station for helping me and providing me the facilities to perform this research.

To my parents for their unending support through all these years.

To the Vélez Ramírez family for their help during the field experiments.

To all those people that encouraged me to continue and helped me in numerous special ways.

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1 INTRODUCTION

Anthracnose caused by the fungal pathogen *Colletotrichum sublineolum* is one of the most important diseases of sorghum [*Sorghum bicolor* (L.) Moench]. The disease is typically found in tropical and semi-tropical regions and has been reported to limit sorghum production in the United States, India, South America and Africa. Yield losses can exceed 50% and under severe epidemics complete plant defoliation can occur resulting in plant death. The disease can also contribute to losses in grain quality due to incomplete grain fill as shown by a decrease in seed weight and seed density.

Disease symptoms can be observed on all aboveground parts of the plant. The disease has been referred to as red leaf blight, stalk rot, panicle blight and seedling blight depending on the site of infection. Foliar infection is more frequently observed and results in the greatest reduction in yield.

Crop rotation, clean cultivation and fungicides can control anthracnose. However, the low value of the sorghum crop makes these practices uneconomical and impractical especially for developing countries where sorghum is an important crop. In addition, potential risks to the environment and human health can occur from fungicide use. The use of resistant cultivars is considered the most economical approach for successful management of the disease.

Anthracnose is highly variable with the occurrence of many physiological races. Changes in the virulence pattern of the pathogen populations have occurred resulting in a loss of plant host resistance. Sorghum hybrids grown in the United States have a limited genetic base including sources of resistance to anthracnose. The reliance on a single source of anthracnose resistance

can result in disease epidemics due to a breakdown in host plant resistance. Therefore, additional sources of resistance are needed for the development of cultivars with durable resistance.

Plant germplasm collections have been established to preserve genetic variation for crop improvement. These collections have been important sources for the development of disease resistant cultivars. The sorghum germplasm collection from Mali, West Africa may contain valuable sources of anthracnose resistance. The effective evaluation of this collection for anthracnose disease response can result in the identification of resistant germplasm for the development of resistant cultivars.

This study evaluated the sorghum germplasm collection from the Kayes region of Mali, West Africa, for the variation in reaction to foliar anthracnose. Sources of stable resistance were identified. This evaluation also provides information on the association of the anthracnose resistance with rainfall patterns in the region of origin. Association between anthracnose resistance and sorghum phenotypic characteristics, such as plant color and racial classification, was evaluated.

2 LITERATURE REVIEW

Plant germplasm provides a valuable source of genetic diversity for plant breeders to develop new cultivars. While germplasm acquisition and maintenance are of major importance, more attention is being given to adequate evaluation of germplasm resources and dissemination of information to plant researchers. If germplasm collections are to be effectively utilized, information on individual accessions must be documented so that plant breeders can identify potentially useful germplasm (Poehlman and Sleper, 1995b).

Sorghum originated in Africa over 5,000 years ago. The major center of diversity for sorghum is located in northeast Africa, associated with the countries of Ethiopia and Sudan (Poehlman and Sleper, 1995a, 1995b; Stemler et al., 1977). From the northeast region, migration and trade routes (Mann et al., 1983) carried sorghum throughout Africa, to India and China, and along the way many distinct races evolved (Poehlman and Sleper, 1995a). Harlan and de Wet (1972) classified cultivated sorghum into five major races: bicolor, guinea, caudatum, kafir and durra, with 10 intermediate races, resulting from combinations of major races. The races are generally easily identifiable by spikelet morphology alone. Race guinea is considered to be the oldest of the specialized races because of its distribution and diversity (Stemler et al., 1977). This is the dominant race of the western Africa (de Wet and Harlan, 1971) and it is grown in areas receiving up to 5,000 mm of annual rainfall (Mann et al., 1983). As a result, a secondary center of diversity has developed for race guinea in West Africa. In contrast, durra is the major race in Ethiopia and its distribution is closely associated with Islamic people in Africa (de Wet,

1978; Stemler et al., 1977). It is commonly grown in areas of low rainfall were the compact panicle shape typical of the race is less affected by grain mold.

The phenotypic variability of sorghum has led to a broad range of uses. It is grown for the production of grain, fodder, silage, pasture, syrup and brooms (Poehlman and Sleper, 1995a). It has also been used in wallboard by the housing industry and approximately 10% of the grain sorghum produced in the US is converted to ethanol for used as a biofuel (Paster, 2002). Approximately 1% of the United States grain sorghum crop is used for human consumption. The United States is the leading exporter of grain sorghum with approximately 50% of the crop exported. Sorghum is highly tolerant to heat and drought, and as a result it has become a major crop in the semi-arid regions of the United States where precipitation is insufficient for maize production (Paster, 2002; Poehlman and Sleper, 1995a). Sorghum production, however, is vulnerable to a wide array of plant diseases and insect pests.

Anthracnose, a fungal pathogen, is considered one of the most important diseases of sorghum. *Colletotrichum sublineolum* (Ascomycetes) is the causal agent of sorghum anthracnose and is widely distributed throughout the sorghum growing areas of the world (Wharton and Julian, 1996). Although *C. sublineolum* is morphologically very similar to *C. graminicola*, the characterization of isolates from maize and sorghum using molecular genetic analysis and mating tests have indicated that isolates from maize represent a distinct species from those attacking sorghum (Horvarth and Vargas, 2004; Sherriff et al., 1995; Wharton et al., 2001). Sorghum anthracnose was first reported in 1902 in Togo, West Africa (Thakur and Mathur, 2000) and in the United States in 1912 from Texas (Harris et al., 1964). The pathogen is favored by hot, humid conditions typical of tropical and subtropical regions of the world (Ali et al., 1987; Ngugi

et al., 2002; Pande et al., 1994; Thakur and Mathur, 2000). Anthracnose occurs in many African nations and has been reported as a major constraint to sorghum production in West Africa, in countries such as Mali and Burkina Faso (Néya and Le Normand, 1998; Ngugi et al., 2002).

Anthracnose can infect all aerial parts of the plant (Harris et al., 1964; Hess et al., 2002; Thakur and Mathur, 2000), but only leaf symptoms were recognized until 1943 when serious outbreaks of stalk rot were reported in Illinois (Koehler, 1943). Typical symptoms of foliar infection are small, circular, elliptical, or elongated spots (Thakur and Mathur, 2000). These lesions are generally 3-5 mm in length, but may be up to 20 mm. The lesions develop gray to straw-colored centers with wide margins that are tan, orange, or red to blackish purple, depending on the disease response and the host plant color. Under conditions of high humidity or high levels of rainfall, the lesions increase in number and coalesce to cover most of the leaf area, and may show zonation. On the surface of the tan centers of the lesions, few to numerous, small, circular, concentric, erumpent black dots develop, which are fruiting bodies of the fungus known as acervuli and contribute to the spread of the disease (Ferreira and Warren, 1982; Thakur and Mathur, 2000).

Severe anthracnose infection can causes premature defoliation, thus reducing plant growth and affecting plant development (Thakur and Mathur, 2000; Thomas et al., 1996). Sorghum anthracnose has been referred to as red leaf blight, stalk rot, panicle blight or seedling blight, depending on the site of infection. Foliar infection occurs more frequently and has been reported to be more severe than infection of other plant tissues (Marley and Ajayi, 2002). Infection in other tissue may occur in the absence or presence of foliar infection. As reported by Coleman and Stokes (1954), stalk rot and leaf anthracnose reactions are controlled by two separate but

closely linked genes. Midrib infection may occur on cultivars that have little leaf damage, and this response may be independent of leaf infection (Thakur and Mathur, 2000). Symptoms of midrib infection are elliptical to elongated lesions with acervuli. If midrib and foliar infections occur together, leaf damage, defoliation, and reduction of yield may be greater. Infection often extends to leaf sheaths, where sunken elliptical lesions are formed (Thakur and Mathur, 2000).

Losses in grain yield resulting from severe infection were estimated to exceed 50% on susceptible cultivars (Thakur and Mathur, 2000). Harris et al. (1964) has reported a highly significant negative correlation between grain yield and anthracnose leaf and head ratings for commercial and experimental hybrids in Georgia. Thomas et al. (1996) suggested that severe foliar infection during grain formation and direct infection of florets contributed to reduction in yield and grain weight in susceptible cultivars. As reported by Ngugi et al. (2000), *C. sublineolum* epidemics prior to the milk stage resulted in higher disease levels at crop senescence, which significantly reduces grain yield. Data from Puerto Rico indicated yield losses were associated with the formation of fewer grains (Thomas et al., 1996). Ali et al. (1987) reported a positive linear relationship between anthracnose disease severity and grain weight loss. In West African countries, such as Mali, losses in yield between 41 to 67% have been reported on sorghum cultivars under natural infection (Thomas et al., 1996). Because of the annual rainfall distribution present in Mali, certain regions provide favorable climatic conditions for disease development resulting in an increased disease pressure (Hess et al., 2002).

In areas favorable for high disease pressure, practices such as the elimination of susceptible (reservoir) weeds, the avoidance of susceptible hybrids, early planting, plowing under infected crop debris, intercropping (Ngugi et al., 2001) and crop rotation can help control the disease by

reducing the primary inoculum and thus preventing severe infection early in plant development (Ngugi et al., 2002; Pastor-Corrales and Frederiksen, 1980). In contrast, minimum tillage practices increase the probability of anthracnose in production fields due to the survival of the pathogen on plant residue (Casela and Frederiksen, 1993). Effective control of anthracnose can be obtained by the use of fungicides; however, the pathogen might become highly resistant as reported for *C. graminicola* (Avila-Adame et al., 2003). Furthermore, this practice is uneconomical for the farmers in developing countries where sorghum is a major crop.

Genetic resistance, the ability of the host to prevent a pathogen from becoming established or completing its life cycle, is considered the ideal method of controlling diseases in cultivated plant species (Tenkouano et al., 1993). The use of resistant cultivars is the most economical control method for sorghum anthracnose (Marley, 2004; Pastor-Corrales and Frederiksen, 1980; Thakur and Mathur, 2000). Host plant resistance is an important component for the integrated pest management of leaf anthracnose, and can help reduce quantitative losses in sorghum grain yield (Hess et al., 2002). The availability of stable sources of resistance with high yield and good grain quality appears to be very important to maintain sustainable sorghum productivity, as well as reduce the risk of lower sorghum production because of severe anthracnose epidemics (Hess et al., 2002; Néya and Le Normand, 1998; Pande et al., 1994; Thakur and Mathur, 2000).

Most sources of anthracnose resistance are considered to possess multiple genes (Thakur and Mathur, 2000). But, limited information is available on the genetics of host plant resistance and few sources have been used in sorghum improvement programs. Also, sources of horizontal resistance have been reported, which influence disease development. This type of resistance is expected to be inherited as a multigenic trait and significantly influenced by environmental

conditions. It is expressed as a reduced infection frequency, a slower rate of development in the host, and a slower rate of spore production over a shorter period of time (Casela et al., 1993). Although this type of resistance has importance, the use of horizontal resistance in hybrid production may have limited use as resistance would need to be incorporated into multiple parental lines. Thus, additional sources of resistance are essential for hybrid development.

Plant breeders have used landraces as the source for specific characteristics in the development of the modern High Yielding Varieties (Frankel, 1974; Poehlman and Sleper, 1995b). Alien sorghums generally possess many genes, which could contribute to yield, insect and disease resistance, therefore improving the quality of U.S. hybrids (Stephens et al., 1967). But many improved varieties have a narrow genetic base and, as a consequence, are almost uniformly vulnerable to a host of environmental risks, such as diseases, pests, and extreme weather conditions (Thesome et al., 1999). A number of resistant sorghum lines are available, and several have been used to produce commercial hybrid cultivars in the United States and India, thus sorghum varieties grown in the United States represent only a small fraction of those known in the world (Thakur and Mathur, 2000). When large acreages are planted to single hybrids, natural selection for virulent races of the pathogen could be favored (Harris and Sowell, 1970).

Changes in the virulence pattern of pathogen populations have been reported from several parts of the world. The first report on existence of races for sorghum anthracnose appeared in 1967 from the United States (Thakur and Mathur, 2000), and later Harris and Sowell (1970) reported changes in the disease response of hybrid Ga 615, released in 1962 as a resistant hybrid and becoming susceptible in 1970. Subsequent reports came from Brazil, Nigeria, Burkina Faso,

and India (Thakur and Mathur, 2000). From 1967 to 1991, some 44 races or pathotypes have been reported, but because of the use of different sets of host differentials and the use of different rating scales, a global picture of the pathogenic races in the pathogen is not clear (Thakur, 2004). The appearance of different pathogenic races could be explained by the long-time association of the pathogen with sorghum (Ali and Warren, 1987). Pande et al. (1991) reported nine distinct physiological races from isolates collected at different locations in India. Also, different symptoms produced on sorghum genotypes and differences in cultural characteristics suggested physiological variation within populations (Pande et al., 1991). Souza-Paccola et al. (2003a) reported the parasexual cycle as an important source of variability in plant pathogenic fungi and was responsible for the high variability observed in *C. sublineolum*. A gene-for-gene interaction between sorghum genotypes and pathogenic races has not been demonstrated (Rosewich et al., 1998), although it has been considered that the pathogen evolved alongside the traditional sorghum landraces, suggesting a gene-for-gene interaction (Ngugi et al., 2002).

Little information is known about the genetics of resistance to anthracnose of sorghum. A single dominant gene for resistance was identified by LeBeau and Coleman (1950). More recently, a single recessive gene conferring resistance in SC326-6 has been reported for a Texas anthracnose isolate (Boora et al., 1998). This line is used frequently as a parent in sorghum breeding programs. However, Rosewich et al. (1998) reported a loss of resistance to Georgia anthracnose isolates. Anthracnose is now observed in this cultivar in the form of sporulating midrib lesions.

Additional sources of resistance are needed for breeding programs to develop hybrids with greater levels of resistance to anthracnose. Even though, Marley and Ajayi (2002) indicated that

many local landraces in West Africa lack satisfactory resistance, West African countries such as Mali may provide good sources of anthracnose resistant sorghum germplasm since disease pressure is high and favorable climatic conditions that occur could contribute to the evolution of host plant resistance (Hess et al., 2002; Néya and Le Normand, 1998; Thomas et al., 1996). Therefore, the Malian sorghum germplasm collection may be a source of genetic variation for anthracnose resistance and the evaluation of this germplasm could result in the identification of new sources of resistance (Hess et al., 2002; Néya and Le Normand, 1998; Poehlman and Sleper, 1995b).

3 MATERIALS AND METHODS

3.1 Sorghum germplasm collection from Mali, West Africa

The United States National Plant Germplasm System (NGPS) maintains 2,351 sorghum accessions from Mali, West Africa. Mali is divided into eight regions (Mopti, Gao, Sikasso, Koulikoro, Tomboctou, Ségou, Kidal and Kayes) and sorghum germplasm has been obtained from all regions except Kidal. Detailed passport information is available for a portion of the collection, thus allowing sorghum accessions to be identified for each region. The Kayes region, located in western Mali, is divided into 7 administrative districts; Kayes, Diema, Nioro, Yelimane, Bafoulabe, Kita and Kenieba (Figure 3.1), and 277 sorghum accessions were collected from this region in 1978 and donated to the US-NPGS (Table 3.1). Latitude and longitude data are available for 232 accessions and passport information was used to identify an additional 45 accessions from the Kayes region of Mali (Appendix I). Sorghum accessions from the administrative districts of Yelimane and Diema are bulked into the Nioro district as it appears in the passport information provided. Seed samples for the 277 accessions were obtained from the USDA-ARS Plant Genetic Resources Conservation Unit in Griffin, Georgia.

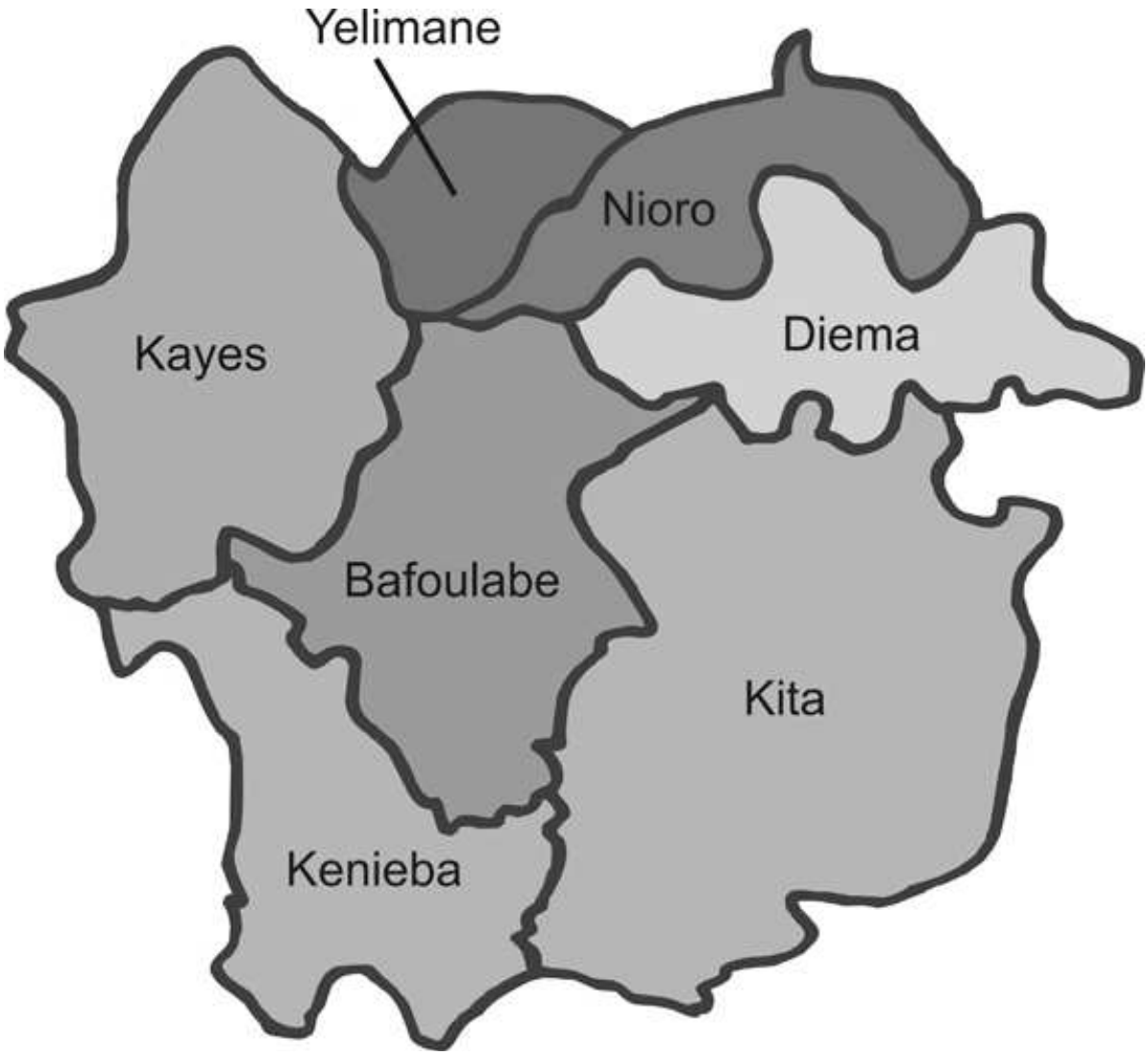

Figure 3.1 Administrative districts from the Kayes region of Mali, West Africa

Table 3.1 Summary of the sorghum accessions collected from the villages located in the administrative districts in the Kayes region of Mali, West Africa[1]

Administrative District	Bafoulabe	Kayes	Kenieba	Kita	Nioro[2]
# villages	9	17	12	16	24
# accessions	37	58	39	52	91

[1]Passport information data provided by the USDA, NGPS (GRIN, 2004).
[2]Yelimané and Diema districts are bulked into the Nioro district.

3.2 Research Location

The evaluation of the Kayes, Mali sorghum germplasm collection for anthracnose resistance was conducted at the USDA-ARS, Tropical Agriculture Research Station Experimental Farm in Isabela, Puerto Rico. The research farm is located in the northwest sub-humid region of Puerto Rico at a latitude of 18.28°N and longitude of 67.3°W. The research site is 128 m above sea level and the soil is classified as a Coto Clay (Typic Eutrustox). The average annual precipitation ranges from 1,000 to 1,500 mm, and its distribution is defined by a wet season from July to December and a dry season from January to June (Howorth, 1934).

3.3 Field Experiments

Two field evaluations were conducted to correspond to the wet and dry seasons. Experiments were established on October 15, 2003 for the wet season and on January 12, 2004 for the dry season. The planting dates were established to coincide with short day-lengths, essential for flowering initiation.

Total amounts of rainfall for the wet and dry growing seasons were 914.4 mm and 380.2 mm, respectively (SERCC, 2004). Average maximum and minimum temperatures were 27.9ºC and 22.0ºC for the wet growing season, and 27.4ºC and 19ºC for the dry growing season.

Experiments were planted in a partially balanced lattice design with three replications. This experimental design was selected due to the large number of experimental units and to compensate for field variation. Field plots consisted of single rows 1.8 m in length with 0.9 m row spacing. Approximately 50 seeds, as determined by seed weight, were planted in each row, which resulted in approximately 25 plants per row.

Fertilizer was applied at a rate of 560 kg ha^{-1} (15-5-10, NPK) at planting with a second application 30 days after planting, for the dry growing season. The second application of fertilizer was not conducted during the wet growing season due to wet conditions. Lorsban (Chlorpyrifos) 15G granular insecticide (Dow Agro-Sciences, Indianapolis IN) was applied at planting to reduce seed loss from fire ants. Irrigation was applied after planting for stand establishment and on a weekly basis as necessary. Rainfall was sufficient during the wet growing season and no irrigation was required for the evaluation. No irrigation was applied after inoculation; therefore infection response would be influence by climatic conditions during the growing season.

The experiment was surrounded by border rows of anthracnose susceptible genotypes. Susceptible germplasm lines ‘Dorado’, ‘Sureño’, BTx623, ATx623 and PI 609251 were used as border rows. The border rows were not inoculated, so infection in these rows would be the result of the natural spreading of the disease.

Control samples were selected based on data for the disease response from previous experiments and published results in order to represent a wide range of diversity for anthracnose disease response and genotypic variation (Table 3.2). Control samples were included in the study to assess the variation in disease response within and between experiments and were inoculated the same as the accessions included in the evaluation. Control genotypes PI 576390 and PI 609251 were included as inoculated and non-inoculated to assess disease development at the field.

Table 3.2 Control samples included in the field experiments and disease reaction previously reported

Accession[1]	Plant Name[2]	Disease Response	Reference
nc[3]	B35	Susceptible	Tenkouano, 1993
nc	BTx3197	Resistant	Erpelding, J. E. and L. K. Prom. 2004
NSL 8773	BTx378	Resistant	Erpelding, J.E. (unpublished data)
nc	BTx398	Susceptible	Erpelding, J. E. and L. K. Prom. 2004
NSL 95699	BTx622	Susceptible	Erpelding, J.E. (unpublished data)
PI 564163	BTx623	Susceptible	Boora, K. S., 1998; Sze-Chung, 1999
PI 552861	BTx631	Susceptible	Erpelding, J. E. and L. K. Prom. 2004
PI 561073	BTx635	Susceptible	Erpelding, J.E. (unpublished data)
PI 561072	BTxARG-1	Susceptible	Erpelding, J. E. and L. K. Prom. 2004
PI 609251	CIRAD 15	Susceptible	Erpelding, J. E. and L. K. Prom. 2004
PI 609582	KENINKE	Susceptible	Erpelding, J. E. and L. K. Prom. 2004
PI 609634	FARKA KOPSI	Susceptible	Erpelding, J. E. and L. K. Prom. 2004
PI 609636	TONDIGAME	Susceptible	Erpelding, J. E. and L. K. Prom. 2004
PI 609746	DJIMBIRI	Susceptible	Erpelding, J. E. and L. K. Prom. 2004
PI 612810	SG 6780	Susceptible	Erpelding, J. E. and L. K. Prom. 2004
PI 609151	EMETITIE	Susceptible	Erpelding, J. E. and L. K. Prom. 2004
nc	RTx2536	Susceptible	Fernandes and Schaffert, 1980
PI 536016	RTx2858	Susceptible	Erpelding, J.E. (unpublished data)
PI 561071	RTx436	Resistant	Erpelding, J. E. and L. K. Prom. 2004
nc	RTx7078	Susceptible	Erpelding, J.E. (unpublished data)
PI 576382	SC1056	Susceptible	Erpelding, J.E. (unpublished data)
PI 576390	SC192	Susceptible	Erpelding, J.E. (unpublished data)
nc	SC326-6	Resistant	Wharton, 1996; Rosewich, 1998
PI 533992	SC575	Susceptible	Erpelding, J. E. and L. K. Prom. 2004
PI 534163	SC599	Susceptible	Erpelding, J. E. and L. K. Prom. 2004
PI 534040	SC736	Susceptible	Erpelding, J.E. (unpublished data)
nc	SC748-6	Susceptible	Wharton,1996; Sze-Chung, 1999
PI 534043	SC804	Susceptible	Erpelding, J.E. (unpublished data)

[1]Plant introduction number (GRIN, 2004).
[2]Local name, collector identification or cultivar name.
[3]Not in collection.

3.4 Inoculum Preparation

Colletotrichum sublineolum isolates were cultured from infected leaf tissue collected prior to the establishment of the experiments from experimental plots at the research farm in Isabela. The anthracnose pathotypes present at the research site are unknown; therefore, infected leaf tissue was randomly collected from several susceptible sorghum genotypes to maximize diversity in the pathogen population being used to screen the accessions. From the infected leaf material, symptomatic leaf pieces were excised and surface sterilized in 0.5% sodium hypochlorite for 3 minutes and rinsed briefly in distilled water 3 times for 1 minute. Leaf pieces were placed on half strength Potato Dextrose Agar (1/2 PDA) media [10% (w/v) bacto agar plus 19.5% (w/v) PDA] and incubated at room temperature for 5 to 7 days in dark. A small portion from the developing fungus was transferred to fresh 1/2 PDA media and cultured at room temperature in the dark from approximately 5 days.

Seed colonization consisted of soaking 500 g seed in 1L tap water overnight. Seed was rinsed and placed in media bottles, followed by autoclaving at 121°C x 30 min at ~ 18 psi. Potential contaminations from grain mold pathogens were eliminated by a second autoclaving cycle after 12 hours. The seed was colonized using 5-day-old cultures. Outside edges of fungal cultures were excised and added to seed in the media bottles. Small pieces of each fungal culture were divided equally between bottles to maintain the variation in the pathogen population. The fungus was cultured on the seed for 5 to 7 days at room temperature in the dark for complete colonization.

3.5 Inoculation of Field Plots

Prior to anthracnose inoculation, seed from multiple bottles were mixed. Plants were inoculated (approximately 30 days after planting) at the 7-10 leaf stage. As reported by Ferreira (1982), a higher disease severity index is obtained at this leaf stage. Inoculation for the wet season was performed on November 15, 2003 and on February 21, 2004 for the dry season. Inoculation for the dry season was conducted at 41 days after planting, since plant growth was highly variable and for the majority of plants the 7-10 leaf stage was delayed. Anthracnose colonized sorghum grain was placed in the leaf whorl of each plant (approximately 10 seed per plant). Approximately 90% of plants in each row were inoculated in order to evaluate within-accessions variation.

3.6 Anthracnose Disease Assessment

In order to evaluate disease progression, disease assessments were conducted approximately 30, 40 and 60 days after the inoculation (60, 70, and 80 days after planting). For the wet growing season, disease assessments were conducted from December 12-16, December 30 to January 9, and from January 19 to February 13. For the dry growing season the disease assessments were conducted from March 23 to April 1 and April 12-24. Since a third evaluation could not be performed a final check was conducted on May 11 for those accessions showing variation in disease reaction. Anthracnose disease response was determined using a 1 to 5 rating scale (Figure 3.2). Also percentage of leaf area infected by anthracnose was determined for the final evaluation in the dry growing season. Accessions rated as 1 were considered highly resistant and

accessions rated as 2 were considered resistant; while those accessions rated as 3 were considered moderately susceptible, accessions rated as 4 were susceptible and accessions rated as 5 were highly susceptible.

Rust disease assessments were also performed during both growing seasons from field natural infection. Disease assessments were conducted at the final evaluation and for the final score the most prevalent disease phenotype was used. Rust disease response was determined based on leaf area, using a 1 to 5 evaluation scale. Rust disease rating scale; 1 = < 1% of leaf area infected; 2 = 1 to 10 % of leaf area infected; 3 = 11-25 % of leaf area infected; 4 = 26-50 % of leaf area infected; 5 = > 50% of leaf area infected.

Figure 3.2 Anthracnose disease rating scale

1 2 3 4 5

1 = no symptoms or chlorotic flecks on inoculated leaves; **2** = hypersensitive response (reddening or red spots) on inoculated leaves; **3** = chlorotic lesions on inoculated leaves with acervuli presence; **4** = necrotic lesions on inoculated leaves with numerous acervuli presence, lesion elongating and spreading to non-inoculated leaf tissue; **5** = flag leaf infected with most leaves dead due to infection and abundant acervuli present.

3.7 Statistical Analysis

Analysis of variance for the disease response was performed using the Infostat Professional (version 1.1) statistical software package. Sorghum accessions from Mali are considered landraces and, as a result, variation within accessions was expected. Therefore the most prevalent disease phenotype was used in order to conduct the statistical analysis. Statistical analyses of the data were conducted using the disease response from the final rating. At this stage, plants are approaching maturity and further disease progression is associated with colonization of senescent leaf tissue.

Comparisons between administrative districts and climatic zones were conducted. Phenotypic traits such as plant color, racial classification and rust disease response were evaluated in order to determine potential association with anthracnose disease response. Statistical analyses of these comparisons were conducted using non-parametric procedures, as sample numbers varied for the comparisons. A t-test for two means was conducted to compare the final disease response among the administrative districts, and among rainfall patterns.

4 RESULTS

4.1 Anthracnose Disease Reaction

Analysis of variance indicated significant differences ($p < 0.05$) for anthracnose disease response and the 277 sorghum accessions evaluated from the Kayes region of Mali.

A hypersensitive response was observed for all accessions within ten days after inoculation, therefore a disease rating of 1 was not observed at the field (Table 4.1).

Table 4.1 Number of Kayes, Mali sorghum accessions for each anthracnose disease rating based on disease response during the wet and dry growing seasons in 2003 and 2004, respectively

Disease Rating	Wet Season	Dry Season
1	**0**	**0**
2	**140**	**131**
3	**0**	**0**
4	**20**	**30**
5	**48**	**83**
Variable	**69**	**33**

During the wet season 140 accessions showed a consistent resistant response, but this response was not observed during the dry season for 20 of these accessions. Meanwhile 12 accessions were classified as susceptible and varied within replication. In contrast, during the dry season 131 accessions showed a consistent resistant response, but a consistent resistant response was not observed during the wet season for 11 of these accessions.

From the 277 accessions evaluated, a resistant response was observed for 137 accessions in both growing seasons. From these 137 accessions, a stable resistant response was observed for

120 accessions over growing seasons. Seventeen accessions did not confer a stable resistant response and showed variation in the anthracnose disease response for one replication. Eight of the 17 accessions showed variation between replications in the dry season and nine were variable in the wet season. Even though the disease response was not stable, these accessions were considered susceptible.

A disease rating of 3 was observed for some accessions during the first and second evaluations, but with disease progression these accessions were given susceptible ratings of 4 or 5. Thus, no accessions for this collection were rated as moderately susceptible.

From the 277 accessions, a susceptible response was obtained for 113 accessions over growing seasons. In general, more susceptibility was observed for the dry growing season with 41% of the accessions rated as susceptible. In contrast, 25% of the accessions were rated as susceptible during the wet season.

Variation within and between replications was observed for both growing seasons. Those accessions with varying disease response between growing seasons were finally classified as variable and considered susceptible. A total of 27 accessions were considered variable for both growing seasons combined. From these 27 variable accessions, 17 accessions showed a consistent susceptible disease response for one of the growing season and the disease response varied between replications in the other growing season. For 5 accessions, the disease reaction varied within and between growing seasons. Five accessions showed a consistent susceptible disease response within one growing season, but showed a consistent resistant response in the other growing season. Accessions PI 585733, PI 609994, PI 609021, and PI 609916 showed a consistent resistant response during the wet growing season and a consistent susceptible response

during the dry growing season. In contrast, accession PI 585709 showed a consistent susceptible response during the wet growing season and a consistent resistant response during the dry growing season.

Variation in disease response was also observed within an accession. As an example, resistant and susceptible plants were observed within a row for PI 609941with the majority of the plants rated as susceptible. This variation within accession PI 609941 was also observed for other foliar diseases including rust. The variation within an accession was not uniform within and between experiments. As an example, for PI 585716 variation within an accession was observed during the dry growing season where 50% of the plants were rated as 2 and 50% rated as 4 in one replication. High disease percentages were obtained during the dry growing season for accessions classified as resistant in the wet growing season, as for PI 609078 where variation in resistance was observed in the dry growing season with disease ratings of 2, 4, and 5, and infected leaf area ranging from 10-100%. A breakdown in resistance was observed for PI 609078 where midrib infection was observed for the first evaluation and the final rating was a 2/4 with anthracnose infected leaf area up to 100% for individual plants.

Breakdown for resistance was also observed for accessions PI 609041, PI 609039, PI 608953, PI 585690 and PI 610021 for the wet growing season. These accessions showed a resistant reaction for the first evaluation but susceptible lesions were observed on some plants within a row during the second evaluation. However, this variation in resistance was not enough to finally consider the accessions susceptible. Infection was observed on lower leaves, however these leaves senesced and therefore no further disease progression was observed.

4.2 Anthracnose Disease Reaction for Control Genotypes

A consistent susceptible response was observed for 21 control genotypes (Table 4.2). Percentages of infected leaf area ranged from 10% through 100%. For control accessions PI 609251, PI 609582, PI 609634, PI 612810 and PI 609151, 100% of infected leaf area was observed, however for the control genotypes BTx631, BTx-ARG-1 and RTx436, the anthracnose disease percentages ranged from 10% to 30%. Although these accessions had few lesions, for most of them the flag leaf was infected indicating the spread of the infection. SC736 was dead prior to maturity, therefore affecting the plant yield since no seed was produced. PI 609251 was dead and lodged after maturity indicating possible stalk rot symptoms; however, good seed production was obtained indicating that yield was not strongly affected. Seed yield losses were observed for the control genotype PI 609746 when compared to genotype PI 609251, since seed size was severely reduced. None of the accessions within the Kayes sorghum collection were as severely damaged as PI 576390 and PI 609251, although they were rated as 5 with high percentages of leaf area infection.

Consistent resistant response was obtained for 4 control genotypes, with hypersensitive response observed in each genotype. Panicle infection was observed for genotype SC748-6, though foliar infection was not present. Control samples PI 534043 and BTx3197 had varying disease response among replications and between growing seasons. Low levels of infection were observed for control genotype PI 534043 and a resistant reaction was observed for one replication. A delay in the susceptible disease response was observed for a few replications of BTx3197 during the wet and dry growing season but a susceptible disease response was obtained for the final evaluation.

Table 4.2 Anthracnose disease response for the control samples during the wet and dry season

Accession[1]	Plant Name[2]	Wet Season[3]	Dry Season
NSL 8773	BTx378 (REDLAN)	2	2
nc[4]	RTx2536	2	2
nc	SC326-6	2	2
nc	SC748-6	2	2
nc	B35	4	5
PI 536016	RTx2858	4	5
PI 552861	BTx631	5	4
nc	BTx3197	5	5
nc	RTx7078	5	5
NSL 95699	BTx622	5	5
PI 564163	BTx623	5	5
PI 561073	BTx635	5	5
PI 561072	BTxARG-1	5	5
PI 609251	CIRAD 15	5	5
PI 609582	KENINKE	5	5
PI 609634	FARA KOPSI	5	5
PI 609636	TONDIGAME	5	5
PI 609746	DJIMBIRI	5	5
PI 612810	SG 6780	5	5
PI 609151	EMETITIE	5	5
PI 561071	RTx436	5	5
PI 576387	SC1056	5	5
PI 576390	SC192	5	5
PI 534163	SC599	5	5
PI 534040	SC736	5	5
PI 534043	SC804	4\5\2	5
nc	BTx398	4	4\5\2
PI 533992	SC575-unin	2\5	2
PI 533992	SC575-inoc	4\2	2

[1]Plant introduction number, (GRIN, 2004).
[2]Local name, collector identification or cultivar name.
[3]Rows with a single value indicate no variation for disease response within an experiment. An accession with more than one disease response value indicates variation within an experiment (data presented for the three replications).
[4]Not in collection.

4.3 Anthracnose disease response of sorghum accessions within the administrative districts of the Kayes region of Mali, West Africa

Information corresponding to the administrative districts where the accessions were collected is available for each accession in the Kayes, Mali sorghum germplasm collection. As shown in Figure 3.1, administrative districts of Nioro and Kayes are located in the northern region, Bafoulabe is located in the central region and the districts of Kenieba and Kita are located in the southern region of Kayes. A higher number of resistant accessions were observed for the administrative districts in the southern region when compared to the districts in the northern regions. Table 4.3 summarizes the final disease rating of the accessions from the different administrative districts in the Kayes region. More than 70% of the accessions from the southern administrative districts showed resistant reactions whereas only 36% of the accessions from the northern administrative districts were resistant. Nearly an equal number of resistant and susceptible accessions were observed in the centrally located district of Bafoulabe. A comparison of mean disease rating showed significant differences between the northern districts and the southern districts (Table 4.3).

Table 4.3 Anthracnose disease response within the administrative districts of the Kayes region of Mali, West Africa

Administrative District	Total number of accessions	Resistant	Susceptible	Disease Means[1]
Bafoulabe	37	18	19	3.30 a
Kayes	58	19	39	3.79 a
Kenieba	39	29	10	2.62 b
Kita	52	37	15	2.77 b
Nioro	91	34	57	3.71 a

[1]Values within a column followed by the same letter are not significantly different at $p < 0.05$.

4.4 Anthracnose disease response within the Kayes rainfall pattern regions

Rainfall patterns for the Kayes region of Mali were divided into 4 regions based on total annual rainfall (Figure 3.1). Total annual rainfall ranges from 350 mm in the north to more than 1,100 mm in the south. The sorghum germplasm accessions were located in each rainfall region using the latitude and longitude, administrative districts and villages of origin. However, 13 accessions could not be located in any rainfall region due to insufficient passport information. Table 4.4 summarizes the total number of accessions for each rainfall region and the final disease response.

Table 4.4 Anthracnose disease response within the Kayes rainfall pattern regions[1]

Rainfall Region	Annual Rainfall[2] (mm)	Total number of accessions	Resistant	Susceptible	Disease Means[3]
1	350-599	40	12	28	3.90 a
2	600-799	114	40	74	3.73 a
3	800-1,100	91	59	32	2.93 b
4	> 1,100	19	16	3	2.32 c

[1]Thirteen of the 277 accessions were not included in the analysis.
[2]Annual rainfall pattern (Hess et al., 2002).
[3]Values within a column followed by the same letter are not significantly different at $p < 0.05$.

More anthracnose resistant accessions were found in the higher rainfall regions. More than 80% of the accessions from the southern regions with an annual rainfall of more than 1,100 mm were resistant. Meanwhile, only 30% of the accessions from regions with an annual rainfall ranging from 350 to 599 mm were resistant. As indicated by the differences in the disease response for the rainfall regions, more resistant accessions were observed as rainfall increased from north to south. This pattern is similar to that observed for the administrative districts. Comparison of disease means indicated significant differences for the accessions growing in the areas receiving more than 800 mm of rainfall (Table 4.4).

4.5 Anthracnose disease response association with sorghum phenotypic characteristics

4.5.1 Anthracnose disease response within sorghum racial classification

The sorghum germplasm collection for the Kayes region of Mali, West Africa is composed mainly of races guinea and durra. Races guinea and durra are morphologically

different, which may influence the anthracnose disease response for Kayes sorghum germplasm collection. A brief description of each race is included in the following section.

4.5.1.1 Race Guinea Background Information

Race guinea is characterized by long and loose panicles (Figure 4.1). The glumes in the spikelet are widely open when mature exposing the twisted grain, with a variation in grain size from large to small (Figure 4.2). These characteristics are adaptations for high rainfall region allowing a rapid dry down of the grain after rainfall.

Figure 4.1 Race guinea panicle

Figure 4.2 Race guinea spikelet morphology

4.5.1.2 Race Durra Background Information

Race durra is characterized by dense and compact panicles, ovate to oblong in shape (Figure 4.3); peduncle often recurve commonly known as “goose neck”; panicle branches are short, glumes tightly clasping the seed and covering approximately 50% of the grain. Glumes

possess a central transverse wrinkle and are lightly pigmented with grain size generally medium to large (Figure 4.4). Because of its compact shape panicle and predominantly white grain, race durra is commonly grown in areas of low rainfall and low grain mold risk.

Figure 4.3
Race durra panicle

Figure 4.4
Race durra spikelet morphology

4.5.2 Anthracnose disease response

As shown in the Table 4.5, there are significant differences for the disease response between the sorghum races durra and guinea. A significantly higher proportion of sorghum accessions from race guinea showed a resistant response to anthracnose, when compared to those accessions from race durra.

Table 4.5 Anthracnose disease response within sorghum racial classification

	Race				
	Durra	**Guinea**	**Caudautum**	**Durra-Caudautum**	**Guinea-Caudautum**
# accessions	69	197	6	4	1
Resistant	26	105	3	3	0
Susceptible	43	92	3	1	1
Disease Means[1]	3.77 a	3.21 b	-	-	-

[1]Values within a row followed by the same letter are not significantly different at $p < 0.05$.

The total annual rainfall in the Kayes region influenced the anthracnose disease response within the racial classification (Table 4.6). As the total amount of rainfall increased the number of resistant accessions increased for races, durra and guinea. For race durra in rainfall region 1 (350-599 mm of annual rainfall) only 30 % of the accessions were resistant. The number of resistant accessions increased to 100 % in rainfall region 3 (800-1100 mm annual rainfall). Similarly, 37% of the race guinea accessions from rainfall region 1 (350-599 mm of annual rainfall) were resistant whereas 71% of the accessions from rainfall region 3 (800-1100 mm annual rainfall) and 89% from rainfall region 4 (>1100 mm of annual rainfall) were resistant.

Similar to rainfall pattern, anthracnose disease response for the accessions was influenced by the administrative districts were the samples were collected (Table 4.7). A lower percentage of resistant accessions were observed for the northern districts for races durra and guinea, whereas a higher percentage of resistant accessions were observed for the southern administrative districts.

Table 4.6 Anthracnose disease response within racial classification for the rainfall patterns present in the Kayes region[1,2]

Rainfall Pattern[3]	Race Durra				Race Guinea			
	Resistant	Susceptible	Variable	Total	Resistant	Susceptible	Variable	Total
1	6	14	1	21	5	9	2	16
2	16	23	2	41	21	37	11	69
3	4	0	0	4	54	22	7	83
4	0	0	0	0	16	2	1	19

[1]Eleven accessions were not included as they represent other races.
[2]Thirteen accessions were not included due to insufficient passport information.
[3]Annual rainfall pattern for the Kayes region; 1 = 350-599 mm; 2 = 600-799 mm; 3 = 800-1,100 mm; 4 = >1,100 mm.

Table 4.7 Anthracnose disease response within sorghum racial classification for the administrative districts of the Kayes region

Administrative District	Race Durra				Race Guinea			
	Resistant	Susceptible	Variable	Total	Resistant	Susceptible	Variable	Total
Bafoulabe	3	0	0	3	13	15	3	31
Kayes	4	9	1	14	15	21	8	44
Kenieba	1	0	0	1	28	7	3	38
Kita	3	1	0	4	34	9	4	47
Nioro	15	30	2	47	15	18	4	37

4.5.3 Anthracnose Disease Response and Plant Color

The USDA sorghum germplasm collection from Mali has information on phenotypic characteristics for 40 different traits. Many phenotypic traits are associated with racial classification. Plant color is not associated with racial classification and as a result this trait may influence the anthracnose disease response for the accessions.

Accessions from the sorghum germplasm collection from the Kayes region of Mali represent 4 of the 9 plant colors used for sorghum phenotypic characterization (GRIN, 2004). The collection is mainly composed of accessions with plant colors purple-red and red-purple. Anthracnose disease response was found to be not significantly associated with sorghum plant color (Table 4.8).

Table 4.8 Anthracnose disease response within sorghum plant color

	Plant Color			
	Purple	**Purple-Red**	**Red-Purple**	**Black**[1]
# accessions	6	165	105	1
Resistant	4	87	46	0
Susceptible	2	78	59	1
Disease Means[2]	3.00 a	3.23 a	3.52 a	-

[1]Black plant color was not included since it is represented by only one accession.
[2]Values within a row followed by the same letter are not significantly different at $p < 0.05$.

4.5.4 Anthracnose Disease Response and Rust Disease Response

High levels of natural rust infection, caused by *Puccinia purpurea*, were observed during both growing seasons. Accessions from the sorghum germplasm collection from the Kayes region were susceptible to rust with 95% and 89% of the accessions rated as

susceptible during the wet and dry growing seasons respectively (Table 4.9). The response to rust disease was not associated with the anthracnose disease response. Only 14 accessions were observed to be resistant to rust and one of these accessions was also resistant to anthracnose. Generally, the accessions from the Kayes region were susceptible to other foliar diseases.

Table 4.9 Number of Kayes, Mali sorghum accessions for each rust disease rating based on disease response during the wet and dry growing seasons, 2003 and 2004, respectively

Disease Rating[1]	Wet Season	Dry Season
1	**2**	**6**
2	**12**	**24**
3	**51**	**36**
4	**110**	**80**
5	**102**	**131**

[1]Rust disease scale based on percentage of leaf area infected. Ratings of 1 and 2 are resistant, 3 moderately susceptible, 4 and 5 susceptible; 1 = > 1%; 2 = 1-10%; 3 = 11-25%; 4 = 26-50%; 5 = >50%.

5 DISCUSSION

Disease screening for sources of stable resistance is an essential component of plant breeding programs. The sorghum germplasm collection from the Kayes region of Mali provided a high number of resistant accessions. Approximately 50% of the collection provided stable resistance to leaf anthracnose. As reported by Erpelding and Prom (2004) for the Malian working collection, the Kayes sorghum germplasm collection could also be effectively used as a source of resistance. The sorghum collection from the Kayes region was composed of landraces and would be more representative of Malian germplasm collection from other regions in the country.

Variation in disease response was observed within and between growing seasons suggesting environmental conditions will influence disease development. The response obtained for the accessions evaluated is specific to the environmental conditions present during the 2003 and 2004 growing seasons. Therefore, evaluation of the same accessions under different environmental conditions may result in a different disease response. Weather records from the UPR - Isabela Agriculture Experimental Station (SERCC, 2004) showed that the growing seasons in the study differed in amount of rainfall (Appendix V, Appendix VI). Pande et al. (1994) recommended field screenings to be performed during the rainy seasons at locations where warm humid weather conditions prevail. These conditions are favorable for anthracnose disease development and provide heavy inoculum pressure during evaluations. Although the amount of rainfall differed between growing seasons, heavy inoculum pressure was present both years. Timing of the rainfall is as important as the total amount. Although the total amount of rainfall during the wet season was higher, the dry season rainfall was predominantly during the

mornings and was more uniform during the growing season (Appendix V, Appendix VI). This provided favorable environmental conditions since hot and humid conditions were present during the day. The interactions between weather conditions with the pathogen and the host can be highly variable. Even though, no variation in the resistant response over growing seasons was observed for 120 accessions, this would indicated stable sources of resistance not significantly affected by environmental conditions can be identified.

Variation within accessions was expected for phenotypic traits, since the collection is composed from landraces. Variation in disease response within accessions was also observed; therefore, the most prevalent response was used to evaluate the accessions. Disease reactions to anthracnose in the control genotypes were in agreement with published research except for genotypes SC 326-6. Previously, Boora (1998) reported a single recessive gene conferring resistance in this line and Rosewich (1998) reported a breakdown in resistance in Georgia. On this genotype the pathogen sporulates in midrib lesions but the leaf blade still maintained its hypersensitive reaction. Hypersensitive response was observed for this genotype and was consistent in all evaluations.

Variation in the pathogen can also influence the infection response. Control sample PI 534163 had a consistent susceptible reaction to the disease, even though it was reported to be resistant by Tenkouano (1993) and Fernandes and Schaffert (1980), for isolates from Georgia, Texas and Brazil. Results from this genotype suggest that a different anthracnose pathotype may be present in Puerto Rico. Guthrie (1992) reported a more homogeneous population of anthracnose in Puerto Rico than India, Africa and United States. This may reflect a geographically isolated gene pool of the pathogen. Furthermore, a higher genetic distance among

isolates was found, since Puerto Rican isolates share the fewest loci when compared to the other isolates. As reported by Erpelding and Prom (2004), and Guthrie (1992), this finding may reflect a different pathotype present in Puerto Rico. Although this data suggest a different pathotype present in Puerto Rico, the number of pathotypes in the population is unknown. Variation in the pathogen may be of more importance and could have resulted in the variation observed within and between growing seasons.

Significant differences in anthracnose disease response for the administrative districts of the Kayes region of Mali were found. Disease response varied between northern districts and southern districts. Results demonstrated a variation in disease response from north to south. Administrative districts located in the northern latitudes of the Kayes region had more susceptible accessions when compared to the southern latitudes.

Differences in total annual rainfall occur within the Kayes region of Mali. Total annual rainfall amount increases from north to south and ranges from 350 mm in the north to over 1100 mm in the south. Significant differences in anthracnose disease response were associated with the annual rainfall amounts received in each district in the Kayes region. More resistant accessions were observed in the wetter conditions in the south compared to the drier north. This would suggest that greater disease pressure under higher rainfall conditions can contribute to the selection of anthracnose resistance for the landraces grown in these regions. This information is highly valuable for the identification of regions of Africa that would favor the development of anthracnose resistance.

The sorghum accessions that compose the Kayes germplasm collection were collected from farmer´s fields throughout the Kayes region of Mali. Farmer´s confront disease problems that

reduce the overall seed yield of their sorghum plantings (Thomas et al., 1996). Differences in disease response suggest the presence of higher disease pressure in the south due to higher rainfall, when compared to north. Sorghum growers in the southern districts may be dealing with different disease problems than those present in the northern districts. Anthracnose development and spread is known to be favored by hot, humid and wet conditions. Therefore, anthracnose could be a more severe disease problem in the southern districts and farmers should be selecting for resistance over growing seasons. In contrast, disease pressure for anthracnose may be low in northern districts and therefore farmers may have limited opportunities to select for resistance in landraces being cultivated.

The sorghum collection is composed mainly of accessions from the races durra and guinea. Significant differences for disease response were found between these two major races. A significant higher proportion of sorghum accessions from race durra showed a susceptible response to anthracnose, when compared to those accessions from race guinea. Sorghum accessions from race durra, which are grown in the drier regions of Mali, tend to be more susceptible than sorghum accessions from the race guinea. Although these findings indicate that racial classification influence the anthracnose disease response, weather variables were the different races are grown may have a greater influence on the development of resistance in the germplasm accessions.

The races of sorghum have different morphological traits and are traditionally grown in contrasting environmental conditions. Although, race guinea is the major race cultivated in West Africa, there are some farmers cultivating sorghum race durra as well, and these are represented in the Kayes germplasm collection (Appendix I). As noted before in Table 4.3, there are

differences in the ratio of races guinea and durra based on rainfall patterns. There are fewer race durra accessions in regions of greater annual rainfall and no durra accessions were present in the region receiving more than 1,100 mm of annual rainfall. For race guinea, the number of accessions increased as the annual rainfall increases.

Results indicate that the differences in disease response observed between races durra and guinea are due to the environmental conditions where they are traditionally grown and not due to the influence of the racial classification. Environmental conditions in the southern districts of the Kayes region, where the annual rainfall ranges between 800 to more than 1,100 mm, are more favorable to the anthracnose development and spread than the northern districts, where the annual rainfall is less than 600 mm. Sorghums from race guinea have been cultivated in wetter regions because its open panicle shape allows better grain drying when wet conditions are present. These characteristics reduce the occurrence of grain mold, which can also affect grain quality. During the evaluation, the panicles of the race durra accession generally showed high levels of grain mold as compared to race guinea accessions.

From the passport information provided for the Kayes germplasm collection, we can assume that farmers in the northern districts of the Kayes region prefer the cultivation of race durra sorghums. Race durra sorghum is drought resistant or evading which may explain why farmers of northern districts cultivate this race.

Field experiments were not sprayed with fungicides in order to maintain natural infection. As a result, other diseases were present, for example zonate leaf spot, ergot, and rust. Estimated losses in sorghum due to rust are as high as losses due to anthracnose, 50% and 40-60%, respectively (Sharma, 1980). Ngugi (2002) reported a rust disease severity of 78 and 86% in

farmer´s fields in Western Kenya. Rust appears to be widespread irrespective of the rainfall and humidity regime in farmer´s fields (Ngugi et al., 2002). High disease pressure for rust was present in both the dry and wet growing seasons. Mutual interference could have affected the anthracnose development and therefore reduced the anthracnose disease ratings, as reported by Sharma (1980). However, plants were inoculated with anthracnose, which would favor the development of the disease. As an example, PI 609251 is highly susceptible to rust, but little rust infection was observed since the germplasm line was nearly 100% infected with anthracnose. In contrast, severe rust infection may weaken the plants and contribute to secondary infection by the anthracnose pathogen.

Sorghum germplasm collected from the Kayes region of Mali proved to be to be highly susceptible to rust with approximately 90% of the accessions susceptible to the disease. Although it is a serious problem for sorghum, rust resistance was not associated with the anthracnose disease response. Comparisons for the rust disease response within the administrative districts, rainfall regions and the racial classification of the sorghum collection were performed (Appendix II, III, IV). Significant differences were found between Kenieba and the districts of Nioro and Kita; as well as for the rainfall region 4 (> 1,100 mm) when compared to 1, 2 and 3. Although these differences were significant, a disease response pattern was not observed, as it was observed for the anthracnose disease response. Rust disease response is not associated with the climatic conditions in the Kayes region of Mali. This suggests that no selection is conducted for rust resistance and germplasm with resistance to multiple diseases can be identified for sorghum improvement.

6 CONCLUSIONS

1. Approximately 50% of the accessions evaluated showed resistance to anthracnose disease infection over growing seasons. This indicates that the sorghum germplasm collection from the Kayes region of Mali is a valuable source of resistance to anthracnose. Considerable variation was observed in the anthracnose disease response for the accessions suggesting genetic variation for host plant resistant. Horizontal resistant would also be a factor influencing resistance in the sorghum germplasm from the Kayes region.

2. Climatic conditions present in the Kayes region of Mali were associated with disease response, indicating that knowledge of climatic conditions in the region of origin would be useful for germplasm selection to identify new sources of anthracnose resistance.

3. An association between sorghum racial classification and the anthracnose disease response was found with race guinea having a greater portion of resistant accessions. However, the differences are a result of the areas where both races are traditionally grown. As a result, resistant accessions from each race can be identified for sorghum improvement. Accessions from race guinea tended to confer resistant and race classification could be used to identify other collection for evaluation.

4. Phenotypic traits such as plant color and rust disease response for the germplasm collection are not associated with the anthracnose disease response. These phenotypic traits were not associated with climatic conditions present in the region of origin. The lack of association would

indicate that accessions with resistance to multiple diseases can be identified for sorghum improvement.

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APPENDICES

Appendix I. Mali Germplasm Collection, Kayes Region – Accession Summary

Passport Information								Anthracnose	
Accession ID[1]	Longitude	Latitude	Region	Race	Plant Color[2]	Rainfall Pattern[3]	Rust Rating[4]	Disease Response[5]	Final Rating
PI 585690	09.31W	14.33N	NIORO	Guinea	4	2	2.3	resistant	2
PI 585728	11.08W	13.06N	KENIEBA	Guinea	5	3	2.2	resistant	2
PI 608953	09.11W	15.09N	NIORO	Durra	4	1	3.5	resistant	2
PI 608998	09.48W	15.06N	NIORO	Durra	4	1	3.1	resistant	2
PI 609036	11.42W	13.53N	KAYES	Guinea	4	3	3.7	resistant	2
PI 609039	11.14W	14.53N	KAYES	Guinea	4	2	2.5	resistant	2
PI 609041	11.06W	14.46N	KAYES	Guinea	4	2	3.2	resistant	2
PI 609922	11.41W	13.33N	KENIEBA	Guinea	4	3	3.5	resistant	2
PI 609941	10.45W	13.12N	KENIEBA	Guinea	5	3	3.5	resistant	2
PI 609955	10.40W	13.43N	BAFOULABE	Guinea	5	3	2.9	resistant	2
PI 609972	10.09W	14.12N	BAFOULABE	Guinea	4	2	2.7	resistant	2
PI 609983	09.30W	14.08N	KITA	Durra	4	2	2.8	resistant	2
PI 609999	nd[6]	nd	KITA	Guinea	4	3	3.3	resistant	2
PI 585716	11.42W	13.53N	KAYES	Guinea	4	3	3.0	resistant	2
PI 585734	10.22W	12.36N	KENIEBA	Guinea	4	4	3.8	resistant	2
PI 610021	nd	nd	KITA	Guinea	4	nd	4.7	resistant	2
PI 609078	nd	nd	NIORO	Guinea	1	nd	3.3	resistant	2
PI 525629	10.45W	14.39N	KAYES	Durra	4	2	3.7	resistant (c)	2
PI 525695	10.53W	12.16N	KENIEBA	Guinea	5	4	3.7	resistant (c)	2
PI 585683	09.58W	14.46N	NIORO	Guinea	4	2	3.7	resistant (c)	2
PI 585685	09.55W	14.31N	NIORO	Guinea	4	2	3.8	resistant (c)	2
PI 585687	09.55W	14.31N	NIORO	Durra	4	2	4.0	resistant (c)	2
PI 585689	09.31W	14.33N	NIORO	Guinea	5	2	4.2	resistant (c)	2
PI 585703	10.14W	15.25N	NIORO	Guinea	4	1	4.2	resistant (c)	2
PI 585704	10.14W	15.25N	NIORO	Durra	4	1	2.6	resistant (c)	2
PI 585710	11.34W	14.29N	KAYES	Guinea	5	2	4.3	resistant (c)	2
PI 585711	11.47W	14.35N	KAYES	Guinea	5	2	2.7	resistant (c)	2
PI 585720	11.35W	14.57N	KAYES	Guinea	4	2	3.3	resistant (c)	2
PI 585723	11.36W	15.32N	KAYES	Durra	5	1	3.3	resistant (c)	2
PI 585724	11.52W	13.54N	KAYES	Guinea	5	3	3.3	resistant (c)	2
PI 585726	11.52W	13.54N	KAYES	Guinea	4	3	3.3	resistant (c)	2
PI 585727	11.52W	13.54N	KAYES	Guinea	4	3	3.3	resistant (c)	2
PI 585730	11.17W	12.45N	KENIEBA	Guinea	4	4	3.6	resistant (c)	2
PI 585731	11.08W	12.40N	KENIEBA	Guinea	4	4	3.6	resistant (c)	2

Appendix I. Continued

Passport Information								Anthracnose	
Accession ID	Longitude	Latitude	Region	Race	Plant Color	Rainfall Pattern	Rust Rating	Disease Response	Final Rating
PI 585732	11.08W	12.40N	KENIEBA	Guinea	4	4	3.8	resistant (c)	2
PI 585735	10.22W	12.36N	KENIEBA	Guinea	5	4	3.8	resistant (c)	2
PI 585736	10.20W	12.49N	KENIEBA	Guinea	5	4	3.8	resistant (c)	2
PI 585737	10.26W	12.58N	KENIEBA	Guinea	4	4	4.0	resistant (c)	2
PI 585738	10.30W	13.13N	KENIEBA	Guinea	5	3	4.0	resistant (c)	2
PI 585740	nd	nd	NIORO	Durra	1	nd	4.2	resistant (c)	2
PI 608954	09.11W	15.09N	NIORO	Guinea	5	1	4.3	resistant (c)	2
PI 608964	08.48W	15.27N	NIORO	Guinea	5	1	4.3	resistant (c)	2
PI 608967	09.58W	14.46N	NIORO	Durra	4	2	4.3	resistant (c)	2
PI 608970	09.58W	14.46N	NIORO	Caudatum	1	2	4.3	resistant (c)	2
PI 608972	09.41W	14.55N	NIORO	Durra	4	2	4.3	resistant (c)	2
PI 608973	09.41W	14.55N	NIORO	Durra	5	2	4.3	resistant (c)	2
PI 608974	09.41W	14.55N	NIORO	Durra	4	2	3.3	resistant (c)	2
PI 608977	09.43W	14.45N	NIORO	Durra	4	2	3.4	resistant (c)	2
PI 608980	09.40W	14.30N	NIORO	Guinea	4	2	3.2	resistant (c)	2
PI 608982	09.31W	14.33N	NIORO	Durra	4	2	3.3	resistant (c)	2
PI 608985	09.31W	14.33N	NIORO	Guinea	4	2	3.8	resistant (c)	2
PI 608986	09.31W	14.33N	NIORO	Durra	4	2	3.8	resistant (c)	2
PI 608987	09.21W	15.03N	NIORO	Durra	4	1	3.9	resistant (c)	2
PI 608990	09.12W	14.42N	NIORO	Guinea	4	2	4.2	resistant (c)	2
PI 608992	09.12W	14.32N	NIORO	Guinea	4	2	4.2	resistant (c)	2
PI 608996	09.48W	15.06N	NIORO	Guinea	4	1	4.3	resistant (c)	2
PI 609001	09.48W	15.06N	NIORO	Durra	4	1	4.3	resistant (c)	2
PI 609003	10.06W	14.52N	NIORO	Durra-Caudatum	4	2	4.3	resistant (c)	2
PI 609005	10.06W	14.52N	NIORO	Caudatum	4	2	4.4	resistant (c)	2
PI 609008	10.33W	14.39N	NIORO	Durra	4	2	4.5	resistant (c)	2
PI 609009	10.45W	14.39N	KAYES	Durra	5	2	4.5	resistant (c)	2
PI 609013	09.51W	15.20N	NIORO	Guinea	5	1	4.5	resistant (c)	2
PI 609015	10.14W	15.25N	NIORO	Caudatum	4	1	4.5	resistant (c)	2
PI 609023	11.16W	14.05N	KAYES	Guinea	4	2	4.5	resistant (c)	2
PI 609025	11.34W	14.29N	KAYES	Durra	4	2	4.5	resistant (c)	2
PI 609026	11.34W	14.29N	KAYES	Guinea	4	2	4.5	resistant (c)	2
PI 609034	11.48W	14.20N	KAYES	Guinea	4	2	3.5	resistant (c)	2
PI 609044	11.25W	14.34N	KAYES	Guinea	4	2	4.5	resistant (c)	2
PI 609079	00.000	00.000	NIORO	Guinea	1	nd	3.3	resistant (c)	2
PI 609917	11.52W	13.54N	KAYES	Guinea	4	3	4.5	resistant (c)	2
PI 609918	11.52W	13.54N	KAYES	Guinea	4	3	4.5	resistant (c)	2
PI 609919	11.23W	13.27N	KENIEBA	Guinea	4	3	4.5	resistant (c)	2

Appendix I. Continued

Passport Information								Anthracnose	
Accession ID	Longitude	Latitude	Region	Race	Plant Color	Rainfall Pattern	Rust Rating	Disease Response	Final Rating
PI 609920	11.23W	13.27N	KENIEBA	Guinea	4	3	3.8	resistant (c)	2
PI 609921	11.23W	13.27N	KENIEBA	Guinea	4	3	4.1	resistant (c)	2
PI 609923	11.41W	13.33N	KENIEBA	Guinea	4	3	4.6	resistant (c)	2
PI 609926	11.41W	13.33N	KENIEBA	Guinea	5	3	3.2	resistant (c)	2
PI 609927	11.41W	13.33N	KENIEBA	Durra	4	3	3.2	resistant (c)	2
PI 609930	11.08W	13.06N	KENIEBA	Guinea	4	3	3.7	resistant (c)	2
PI 609932	11.17W	12.45N	KENIEBA	Guinea	5	4	3.7	resistant (c)	2
PI 609933	11.17W	12.45N	KENIEBA	Guinea	5	4	3.8	resistant (c)	2
PI 609934	11.08W	12.40N	KENIEBA	Guinea	4	4	3.8	resistant (c)	2
PI 609935	10.39W	12.35N	KENIEBA	Guinea	4	4	3.9	resistant (c)	2
PI 609936	10.20W	12.49N	KENIEBA	Guinea	5	4	4.0	resistant (c)	2
PI 609938	10.26W	12.58N	KENIEBA	Guinea	5	4	4.2	resistant (c)	2
PI 609939	10.30W	13.13N	KENIEBA	Guinea	5	3	4.2	resistant (c)	2
PI 609940	10.45W	13.12N	KENIEBA	Guinea	4	3	4.2	resistant (c)	2
PI 609942	10.45W	13.12N	KENIEBA	Guinea	5	3	4.2	resistant (c)	2
PI 609944	10.57W	13.21N	BAFOULABE	Guinea	4	3	4.2	resistant (c)	2
PI 609947	10.56W	13.46N	BAFOULABE	Guinea	5	3	4.3	resistant (c)	2
PI 609948	10.56W	13.46N	BAFOULABE	Guinea	4	3	4.3	resistant (c)	2
PI 609949	10.22W	13.35N	BAFOULABE	Guinea	5	3	3.8	resistant (c)	2
PI 609953	10.40W	13.43N	BAFOULABE	Guinea	5	3	4.3	resistant (c)	2
PI 609954	10.40W	13.43N	BAFOULABE	Guinea	5	3	4.4	resistant (c)	2
PI 609957	10.45W	13.57N	BAFOULABE	Guinea	5	3	4.4	resistant (c)	2
PI 609958	10.45W	13.57N	BAFOULABE	Guinea	5	3	4.4	resistant (c)	2
PI 609959	10.45W	13.57N	BAFOULABE	Durra-Caudatum	4	3	4.5	resistant (c)	2
PI 609960	10.45W	13.57N	BAFOULABE	Durra-Caudatum	4	3	4.5	resistant (c)	2
PI 609961	10.45W	13.57N	BAFOULABE	Guinea	4	3	4.7	resistant (c)	2
PI 609964	10.27W	14.15N	BAFOULABE	Guinea	4	2	4.7	resistant (c)	2
PI 609965	10.27W	14.15N	BAFOULABE	Durra	4	2	4.7	resistant (c)	2
PI 609966	10.27W	14.15N	BAFOULABE	Durra	4	2	4.7	resistant (c)	2
PI 609975	10.09W	14.12N	BAFOULABE	Guinea	4	2	4.7	resistant (c)	2
PI 609977	09.49W	14.08N	BAFOULABE	Durra	4	2	4.7	resistant (c)	2
PI 609982	09.30W	14.08N	KITA	Guinea	4	2	4.7	resistant (c)	2
PI 609987	09.35W	13.52N	KITA	Durra	4	3	4.7	resistant (c)	2
PI 609988	09.28W	13.22N	KITA	Guinea	5	3	4.7	resistant (c)	2
PI 609989	09.28W	13.22N	KITA	Guinea	5	3	4.7	resistant (c)	2
PI 609990	09.28W	13.22N	KITA	Guinea	5	3	4.7	resistant (c)	2
PI 609991	09.28W	13.22N	KITA	Guinea	4	3	4.7	resistant (c)	2
PI 609992	09.28W	13.22N	KITA	Guinea	4	3	4.7	resistant (c)	2

Appendix I. Continued

Passport Information								Anthracnose	
Accession ID	Longitude	Latitude	Region	Race	Plant Color	Rainfall Pattern	Rust Rating	Disease Response	Final Rating
PI 609993	nd	nd	KITA	Guinea	4	nd	3.1	resistant (c)	2
PI 609995	nd	nd	KITA	Guinea	4	3	3.8	resistant (c)	2
PI 609998	nd	nd	KITA	Guinea	5	3	4.1	resistant (c)	2
PI 610003	nd	nd	KITA	Guinea	5	3	4.1	resistant (c)	2
PI 610004	nd	nd	KITA	Guinea	4	3	4.2	resistant (c)	2
PI 610006	nd	nd	KITA	Guinea	5	3	4.6	resistant (c)	2
PI 610008	nd	nd	KITA	Durra	4	3	3.3	resistant (c)	2
PI 610009	nd	nd	KITA	Guinea	4	3	3.7	resistant (c)	2
PI 610010	nd	nd	KITA	Guinea	4	nd	3.7	resistant (c)	2
PI 610011	nd	nd	KITA	Guinea	5	3	4.1	resistant (c)	2
PI 610012	nd	nd	KITA	Guinea	4	3	4.2	resistant (c)	2
PI 610013	nd	nd	KITA	Guinea	4	3	4.3	resistant (c)	2
PI 610014	nd	nd	KITA	Guinea	4	3	4.3	resistant (c)	2
PI 610015	nd	nd	KITA	Guinea	5	3	4.4	resistant (c)	2
PI 610016	nd	nd	KITA	Guinea	5	3	4.4	resistant (c)	2
PI 610018	nd	nd	KITA	Guinea	5	3	4.5	resistant (c)	2
PI 610019	nd	nd	KITA	Guinea	5	3	4.6	resistant (c)	2
PI 610020	nd	nd	KITA	Guinea	5	3	4.7	resistant (c)	2
PI 610022	nd	nd	KITA	Guinea	5	nd	4.7	resistant (c)	2
PI 610023	nd	nd	KITA	Guinea	4	nd	4.7	resistant (c)	2
PI 610024	nd	nd	KITA	Guinea	5	nd	4.7	resistant (c)	2
PI 610025	nd	nd	KITA	Guinea	4	nd	4.7	resistant (c)	2
PI 610026	nd	nd	KITA	Guinea	4	4	4.7	resistant (c)	2
PI 610027	nd	nd	KITA	Guinea	4	4	4.7	resistant (c)	2
PI 610028	nd	nd	KITA	Guinea	5	3	4.7	resistant (c)	2
PI 610031	nd	nd	KITA	Guinea	5	3	4.7	resistant (c)	2
PI 610032	nd	nd	KITA	Guinea	4	3	3.4	resistant (c)	2
PI 525696	10.53W	12.16N	KENIEBA	Guinea	4	4	1.2	susceptible	4
PI 585686	09.55W	14.31N	NIORO	Guinea	5	2	1.5	susceptible	4
PI 585718	11.06W	14.46N	KAYES	Guinea	4	2	1.6	susceptible	4
PI 608951	08.58W	15.08N	NIORO	Guinea	4	1	2.3	susceptible	4
PI 608968	09.58W	14.46N	NIORO	Durra	4	2	2.8	susceptible	4
PI 608991	09.12W	14.32N	NIORO	Guinea	5	2	4.7	susceptible	4
PI 608997	09.48W	15.06N	NIORO	Guinea	5	1	4.8	susceptible	4
PI 609007	10.18W	14.42N	NIORO	Durra	5	2	4.8	susceptible	4
PI 609016	10.14W	15.25N	NIORO	Durra	4	1	4.8	susceptible	4
PI 609029	11.47W	14.35N	KAYES	Guinea	4	2	3.1	susceptible	4
PI 609030	11.47W	14.35N	KAYES	Durra	4	2	3.2	susceptible	4

Appendix I. Continued

Passport Information								Anthracnose	
Accession ID	Longitude	Latitude	Region	Race	Plant Color	Rainfall Pattern	Rust Rating	Disease Response	Final Rating
PI 609929	11.08W	13.06N	KENIEBA	Guinea	4	3	5.0	susceptible	4
PI 609937	10.26W	12.58N	KENIEBA	Guinea	4	4	5.0	susceptible	4
PI 609945	10.57W	13.21N	BAFOULABE	Guinea	4	3	5.0	susceptible	4
PI 609951	10.22W	13.35N	BAFOULABE	Guinea	4	3	2.7	susceptible	4
PI 609962	10.43W	14.13N	BAFOULABE	Guinea	5	2	2.7	susceptible	4
PI 609971	10.09W	14.12N	BAFOULABE	Guinea	4	2	5.0	susceptible	4
PI 609980	09.49W	14.08N	BAFOULABE	Guinea	4	2	5.0	susceptible	4
PI 609985	09.35W	13.52N	KITA	Guinea	5	3	5.0	susceptible	4
PI 585708	11.16W	14.05N	KAYES	Guinea	4	2	2.6	susceptible	4
PI 585681	08.48W	15.27N	NIORO	Durra	4	1	4.7	susceptible	5
PI 585694	09.48W	15.06N	NIORO	Guinea	5	1	4.8	susceptible	5
PI 585695	09.48W	15.06N	NIORO	Guinea	5	1	4.8	susceptible	5
PI 585696	10.06W	14.52N	NIORO	Durra	4	2	4.8	susceptible	5
PI 585698	10.18W	14.42N	NIORO	Durra	4	2	4.8	susceptible	5
PI 585702	09.51W	15.20N	NIORO	Durra	4	1	4.8	susceptible	5
PI 585722	11.35W	14.57N	KAYES	Guinea	4	2	5.0	susceptible	5
PI 585725	11.52W	13.54N	KAYES	Guinea	5	3	4.8	susceptible	5
PI 585741	00.000	00.000	NIORO	Durra	1	nd	4.8	susceptible	5
PI 608961	08.33W	14.52N	NIORO	Durra	5	2	4.8	susceptible	5
PI 608966	09.14W	15.16N	NIORO	Guinea	4	1	4.8	susceptible	5
PI 608975	09.41W	14.55N	NIORO	Guinea	5	2	3.9	susceptible	5
PI 608978	09.43W	14.45N	NIORO	Guinea	5	2	4.4	susceptible	5
PI 608989	09.12W	14.42N	NIORO	Durra	4	2	4.6	susceptible	5
PI 608995	09.12W	14.32N	NIORO	Guinea	5	2	4.7	susceptible	5
PI 609017	10.14W	15.25N	NIORO	Guinea	5	1	5.0	susceptible	5
PI 609018	10.34W	15.08N	NIORO	Guinea	5	1	4.8	susceptible	5
PI 609031	11.47W	14.35N	KAYES	Guinea	5	2	4.8	susceptible	5
PI 609045	11.25W	14.34N	KAYES	Durra	4	2	4.8	susceptible	5
PI 609046	11.35W	14.57N	KAYES	Durra	4	2	4.9	susceptible	5
PI 609047	11.35W	14.57N	KAYES	Guinea	5	2	5.0	susceptible	5
PI 609928	11.41W	13.33N	KENIEBA	Guinea	5	3	5.0	susceptible	5
PI 609950	10.22W	13.35N	BAFOULABE	Guinea	5	3	5.0	susceptible	5
PI 609967	10.27W	14.15N	BAFOULABE	Guinea	5	2	5.0	susceptible	5
PI 609970	10.09W	14.12N	BAFOULABE	Guinea	5	2	5.0	susceptible	5
PI 609984	09.35W	13.52N	KITA	Guinea	4	3	5.0	susceptible	5
PI 609996	nd	nd	KITA	Guinea	5	3	5.0	susceptible	5
PI 610001	nd	nd	KITA	Guinea	5	3	5.0	susceptible	5
PI 610005	nd	nd	KITA	Caudatum	4	3	5.0	susceptible	5

Appendix I. Continued

Passport Information								Anthracnose	
Accession ID	Longitude	Latitude	Region	Race	Plant Color	Rainfall Pattern	Rust Rating	Disease Response	Final Rating
PI 610007	nd	nd	KITA	Guinea	5	3	5.0	susceptible	5
PI 609915	11.52W	13.54N	KAYES	Guinea	5	3	3.3	susceptible	5
PI 585700	10.33W	14.39N	NIORO	Guinea	5	2	5.0	susceptible (c)	4
PI 585707	11.22W	14.27N	KAYES	Guinea	4	2	5.0	susceptible (c)	4
PI 608957	09.30W	15.18N	NIORO	Guinea-Caudatum	4	1	5.0	susceptible (c)	4
PI 609012	10.58W	14.33N	KAYES	Guinea	4	2	5.0	susceptible (c)	4
PI 609027	11.34W	14.29N	KAYES	Guinea	5	2	5.0	susceptible (c)	4
PI 609038	11.14W	14.53N	KAYES	Guinea	5	2	4.8	susceptible (c)	4
PI 609925	11.41W	13.33N	KENIEBA	Guinea	5	3	5.0	susceptible (c)	4
PI 585676	08.58W	15.08N	NIORO	Durra	5	1	4.7	susceptible (c)	5
PI 585682	09.14W	15.16N	NIORO	Durra	4	1	4.8	susceptible (c)	5
PI 585684	09.58W	14.46N	NIORO	Guinea	5	2	4.8	susceptible (c)	5
PI 585688	09.40W	14.30N	NIORO	Durra	4	2	4.8	susceptible (c)	5
PI 585691	09.21W	15.03N	NIORO	Guinea	5	1	5.0	susceptible (c)	5
PI 585692	09.21W	15.03N	NIORO	Durra	4	1	4.8	susceptible (c)	5
PI 585697	10.18W	14.42N	NIORO	Guinea	4	2	4.8	susceptible (c)	5
PI 585699	10.33W	14.39N	NIORO	Durra	4	2	4.8	susceptible (c)	5
PI 585701	10.33W	14.39N	NIORO	Durra	4	2	4.8	susceptible (c)	5
PI 585706	10.14W	15.25N	NIORO	Durra	4	1	5.0	susceptible (c)	5
PI 585713	12.04W	14.43N	KAYES	Durra	4	2	5.0	susceptible (c)	5
PI 585714	11.48W	14.20N	KAYES	Guinea	4	2	5.0	susceptible (c)	5
PI 585715	11.42W	14.06N	KAYES	Guinea	5	2	4.8	susceptible (c)	5
PI 585717	11.14W	14.53N	KAYES	Durra	4	2	4.8	susceptible (c)	5
PI 585719	11.06W	14.46N	KAYES	Guinea	5	2	4.8	susceptible (c)	5
PI 608952	09.11W	15.09N	NIORO	Durra	4	1	4.8	susceptible (c)	5
PI 608956	09.30W	15.18N	NIORO	Durra	4	1	5.0	susceptible (c)	5
PI 608962	08.33W	14.52N	NIORO	Durra-Caudatum	4	2	5.0	susceptible (c)	5
PI 608969	09.58W	14.46N	NIORO	Durra	4	2	4.8	susceptible (c)	5
PI 608971	09.58W	14.46N	NIORO	Durra	4	2	4.8	susceptible (c)	5
PI 608976	09.41W	14.55N	NIORO	Durra	4	2	4.3	susceptible (c)	5
PI 608981	09.40W	14.30N	NIORO	Durra	4	2	5.0	susceptible (c)	5
PI 608988	09.21W	15.03N	NIORO	Durra	4	1	4.5	susceptible (c)	5
PI 608993	09.12W	14.32N	NIORO	Durra	4	2	5.0	susceptible (c)	5
PI 608994	09.12W	14.32N	NIORO	Durra	4	2	5.0	susceptible (c)	5
PI 609000	09.48W	15.06N	NIORO	Durra	4	1	4.8	susceptible (c)	5
PI 609006	10.18W	14.42N	NIORO	Guinea	4	2	4.8	susceptible (c)	5
PI 609014	09.51W	15.20N	NIORO	Guinea	4	1	4.8	susceptible (c)	5
PI 609019	10.34W	15.08N	NIORO	Durra	4	1	4.8	susceptible (c)	5

Appendix I. Continued

Passport Information								Anthracnose	
Accession ID	Longitude	Latitude	Region	Race	Plant Color	Rainfall Pattern	Rust Rating	Disease Response	Final Rating
PI 609020	10.34W	15.08N	NIORO	Durra	4	1	4.8	susceptible (c)	5
PI 609024	11.34W	14.29N	KAYES	Guinea	4	2	5.0	susceptible (c)	5
PI 609028	11.34W	14.29N	KAYES	Durra	4	2	5.0	susceptible (c)	5
PI 609032	12.04W	14.43N	KAYES	Guinea	5	2	4.8	susceptible (c)	5
PI 609033	11.48W	14.20N	KAYES	Durra	4	2	4.8	susceptible (c)	5
PI 609035	11.42W	13.53N	KAYES	Guinea	4	3	4.8	susceptible (c)	5
PI 609037	11.42W	13.53N	KAYES	Guinea	5	3	4.8	susceptible (c)	5
PI 609043	11.25W	14.34N	KAYES	Guinea	5	2	4.8	susceptible (c)	5
PI 609048	11.35W	14.57N	KAYES	Durra	9	2	5.0	susceptible (c)	5
PI 609049	11.36W	15.32N	KAYES	Durra	4	1	5.0	susceptible (c)	5
PI 609080	nd	nd	NIORO	Durra	1	nd	5.0	susceptible (c)	5
PI 609914	11.52W	13.54N	KAYES	Guinea	5	3	5.0	susceptible (c)	5
PI 609924	11.41W	13.33N	KENIEBA	Guinea	5	3	5.0	susceptible (c)	5
PI 609943	10.45W	13.12N	KENIEBA	Guinea	5	3	5.0	susceptible (c)	5
PI 609956	10.45W	13.57N	BAFOULABE	Guinea	4	3	5.0	susceptible (c)	5
PI 609968	10.27W	14.15N	BAFOULABE	Guinea	5	2	5.0	susceptible (c)	5
PI 609969	10.27W	14.15N	BAFOULABE	Guinea	4	2	5.0	susceptible (c)	5
PI 609973	10.09W	14.12N	BAFOULABE	Guinea	5	2	5.0	susceptible (c)	5
PI 609974	10.09W	14.12N	BAFOULABE	Guinea	5	2	5.0	susceptible (c)	5
PI 609976	09.49W	14.08N	BAFOULABE	Guinea	5	2	5.0	susceptible (c)	5
PI 609979	09.49W	14.08N	BAFOULABE	Guinea	4	2	5.0	susceptible (c)	5
PI 609981	09.30W	14.08N	KITA	Guinea	5	2	5.0	susceptible (c)	5
PI 609986	09.35W	13.52N	KITA	Guinea	5	3	5.0	susceptible (c)	5
PI 610000	nd	nd	KITA	Guinea	5	3	5.0	susceptible (c)	5
PI 610002	nd	nd	KITA	Durra	5	3	5.0	susceptible (c)	5
PI 610017	nd	nd	KITA	Guinea	5	3	5.0	susceptible (c)	5
PI 585705	10.14W	15.25N	NIORO	Guinea	4	1	5.0	susceptible (v)	4
PI 585729	11.08W	13.06N	KENIEBA	Guinea	4	3	5.0	susceptible (v)	4
PI 585733	10.39W	12.35N	KENIEBA	Guinea	4	4	5.0	susceptible (v)	4
PI 608955	09.30W	15.18N	NIORO	Guinea	5	1	5.0	susceptible (v)	4
PI 608965	08.48W	15.27N	NIORO	Durra	5	1	5.0	susceptible (v)	4
PI 608983	09.31W	14.33N	NIORO	Durra	4	2	5.0	susceptible (v)	4
PI 609004	10.06W	14.52N	NIORO	Guinea	4	2	5.0	susceptible (v)	4
PI 609011	10.45W	14.39N	KAYES	Durra	4	2	5.0	susceptible (v)	4
PI 609022	11.16W	14.05N	KAYES	Guinea	4	2	5.0	susceptible (v)	4
PI 609040	11.14W	14.53N	KAYES	Guinea	4	2	5.0	susceptible (v)	4
PI 609042	11.06W	14.46N	KAYES	Guinea	5	2	5.0	susceptible (v)	4
PI 609952	10.22W	13.35N	BAFOULABE	Caudatum	4	3	2.8	susceptible (v)	4
PI 609963	10.43W	14.13N	BAFOULABE	Guinea	5	2	2.7	susceptible (v)	4

Appendix I. Continued

Passport Information								Anthracnose	
Accession ID	Longitude	Latitude	Region	Race	Plant Color	Rainfall Pattern	Rust Rating	Disease Response	Final Rating
PI 609978	09.49W	14.08N	BAFOULABE	Guinea	4	2	5.0	susceptible (v)	4
PI 609994	nd	nd	KITA	Guinea	4	nd	5.0	susceptible (v)	4
PI 609997	nd	nd	KITA	Guinea	5	3	5.0	susceptible (v)	4
PI 610029	nd	nd	KITA	Guinea	5	3	5.0	susceptible (v)	4
PI 609946	10.57W	13.21N	BAFOULABE	Guinea	4	3	3.8	susceptible (v)	4
PI 585709	11.34W	14.29N	KAYES	Guinea	5	2	5.0	susceptible (v)	4
PI 608999	09.48W	15.06N	NIORO	Caudatum	4	1	5.0	susceptible (v)	4
PI 610030	nd	nd	KITA	Guinea	4	3	5.0	susceptible (v)	4
PI 585721	11.35W	14.57N	KAYES	Guinea	4	2	5.0	susceptible (v)	5
PI 609002	10.06W	14.52N	NIORO	Guinea	4	2	5.0	susceptible (v)	5
PI 609010	10.45W	14.39N	KAYES	Guinea	4	2	5.0	susceptible (v)	5
PI 609021	11.16W	14.05N	KAYES	Guinea	5	2	5.0	susceptible (v)	5
PI 609916	11.52W	13.54N	KAYES	Guinea	5	3	5.0	susceptible (v)	5
PI 609931	11.08W	13.06N	KENIEBA	Guinea	5	3	5.0	susceptible (v)	5

[1]Plant introduction number for the Kayes sorghum accessions (GRIN, 2004).
[2]Plant color, 1 = purple; 4 = purple-red; 5 = red-purple; 9 = black.
[3]Annual rainfall pattern for the Kayes region; 1 = 350-599 mm; 2 = 600-799 mm; 3 = 800-1,100 mm; 4 = >1,100 mm.
[4]Rust disease scale based on percentage of leaf area infected. Ratings of 1 and 2 are resistant, 3 moderately susceptible, 4 and 5 susceptible; 1 = > 1%; 2 = 1-10%; 3 = 11-25%; 4 = 26-50%; 5 = >50%.
[5](c) = consistent disease response within and between growing seasons; (v) = variable disease response within and between growing seasons.
[6]nd = Insufficient passport information.

Appendix II. Rust disease response within the administrative districts of the Kayes region of Mali, West Africa

Administrative District	# Accessions	Resistant	Susceptible	Disease Means[1]
Bafoulabe	37	6	31	4.37 ab
Kayes	58	4	54	4.33 ab
Kenieba	39	2	37	4.03 b
Kita	52	1	51	4.50 a
Nioro	91	5	86	4.38 a

[1]Values within a column followed by the same letter are not significantly different at $p < 0.05$.

Appendix III. Rust disease response within the Kayes region rainfall patterns[1]

Rainfall Pattern	Annual Rainfall[2] (mm)	# Accessions	Susceptible	Resistant	Guinea / Durra	Disease Means[3]
1	350-599	40	38	2	16 / 21	4.51 a
2	600-799	114	103	11	69 / 41	4.38 a
3	800-1,100	91	87	4	83 / 4	4.32 a
4	> 1,100	19	18	1	19 / 0	3.90 b

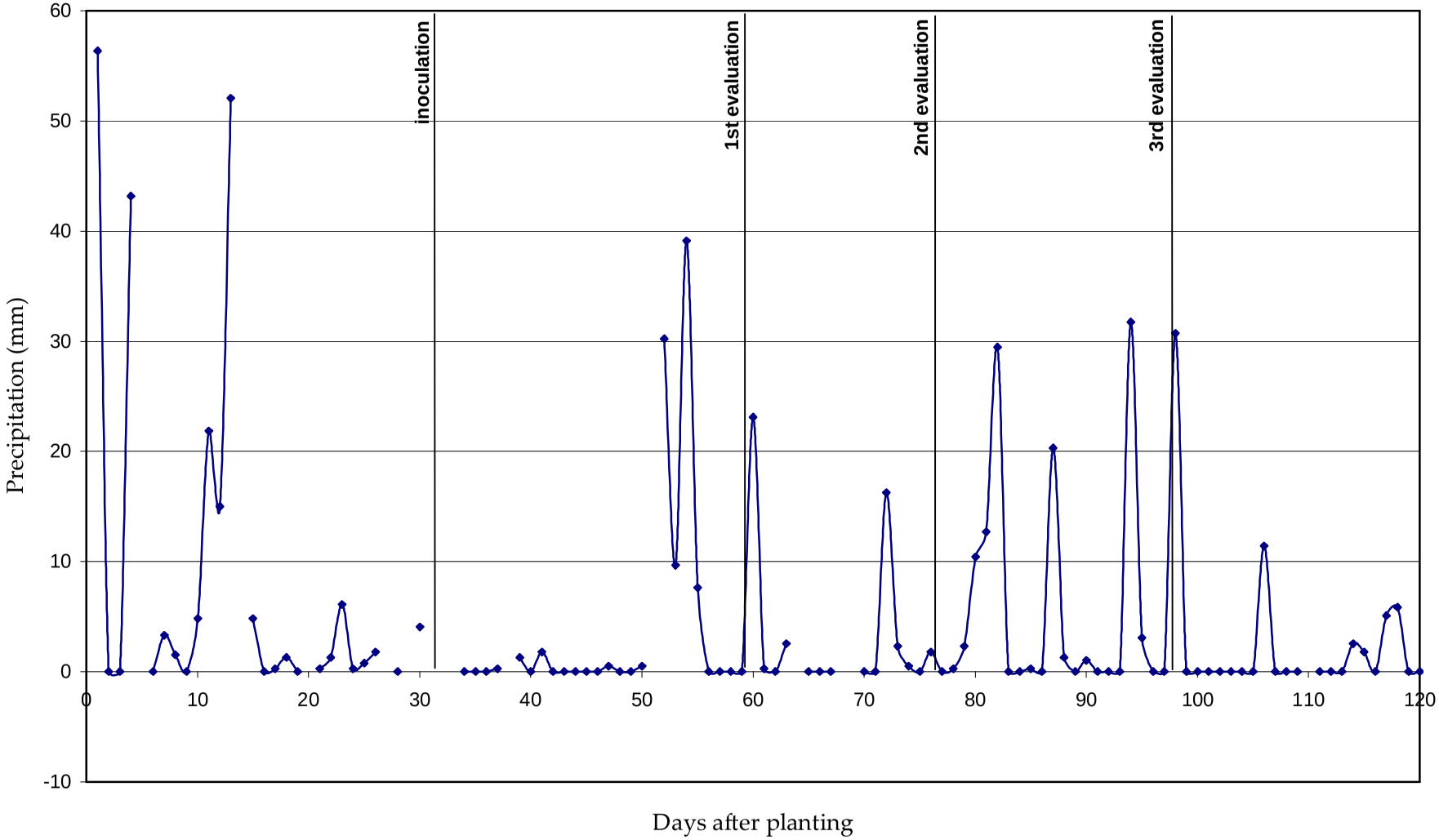
[1]Thirteen accessions were not included in the analysis due to insufficient passport information.
[2]Annual rainfall data (Hess et al., 2002).
[3]Values within a column followed by the same letter are not significantly different at $p < 0.05$.

Appendix IV. Rust disease response within sorghum racial classification

Race	Durra	Guinea	Caudautum	Durra-Caudautum	Guinea-Caudautum
# accessions	69	197	6	4	1
Resistant	3	14	1	0	0
Susceptible	66	183	5	4	1
Disease Means[1]	4.43 a	4.30 a	-	-	-

[1]Values within a row followed by the same letter are not significantly different at $p < 0.05$.

Appendix V. Isabela daily precipitation for the wet growing season



Appendix VI. Isabela daily precipitation for the dry growing season